

Progressive Upper Limb Prosthetics

Chris Lake, CPO, FAAOP*, Robert Dodson, CPO

*Advanced Arm Dynamics of Texas, 3501 North Macarthur Boulevard, Suite 650,
Irving, TX 75062, USA*

The field of upper limb prosthetics has become increasingly specialized [1]. At the same time, most practitioners see few individuals with upper limb deficiency—typically one upper limb client per year compared with about 30 clients experiencing lower limb deficiencies. Within this relatively small number of upper limb deficiencies, practitioners rarely encounter what could be considered “common” mobility issues associated with lower limb prosthetics. In consideration of Dillingham et al’s [2] findings, only 1908 of the approximately 18,496 annual upper limb deficiency cases involve styloid-level disarticulations to shoulder and interscapulothoracic levels. The other 16,588 individuals per year present with amputations distal to the wrist, which are much more difficult for a rehabilitation team to assess and treat.

This paradox of so few individuals needing such specialized care represents what prosthetists call the “upper extremity dilemma.” It is extremely difficult for a large number of practitioners (approximately 3000 American Board of Certification in Orthotics and Prosthetics [ABC] Certified Prosthetists [CPs] and Certified Prosthetist/Orthotists [CPOs] [ABC, personal communication, August 2005]) to increase their upper extremity knowledge with such a small patient base [3]. In contrast, practitioners have much more success honing their lower extremity skills in even a moderately busy practice given the nearly 113,702 lower limb deficiencies per year (56,912 Syme’s level and proximal).

Given the small number of patients and the highly technical aspects of upper limb prosthetics, upper limb treatment has earned its place as a specialty within the larger field of rehabilitation. Based on the Academy Upper Limb Society enrollment in summer 2005, approximately 66 individuals in the United States pursue upper limb prosthetics as a specialty. Some of these well-known specialists work for private companies that have upper limb specialty programs, whereas others have university-based and private practices.

* Corresponding author.

E-mail address: clake@armdynamics.com (C. Lake).

This article provides readers with basic knowledge of progressive upper limb prosthetics. This knowledge is based on clinical protocols and the real-life cases presented by members of the Academy Certificate Course in Upper-Limb Prosthetics. Much of this information is presented in general concept summaries of larger topics. For more in-depth information on these topics, the reader is directed to the Further Readings and References.

Understanding the unique differences of upper limb deficiency

Beyond the obvious differences between the two distinct levels of deficiency, it is crucial to understand the unique nature of upper limb impairment [4]. Typically, an individual has little or no warning of the impending loss. Most upper limb amputations result from a traumatic event. Most patients experience no preoperative stage in which they can attempt to prepare for life after an amputation. In many cases, an individual wakes up in the recovery room to find that he or she has lost part or all of one or both upper extremities. He or she must grapple with the physical pain of the injury and amputation, while facing the psychological blow of feeling less capable and independent in a world that often measures self-worth by what an individual can do.

In addition, it is difficult to disguise the loss of an upper limb. Most social interaction centers on a person's face and torso, and even casual onlookers may notice the missing limb. In contrast, lower limb amputees have an easier time adapting into society. Unless these individuals are wearing shorts, their level of deficiency can go undetected for quite some time, giving them the opportunity to share their feelings, particularly in the early days, in a more comfortable and supportive setting.

Many upper limb amputees have extremely high expectations for what a prosthesis can accomplish. Today's media and films often exaggerate the technical aspects of upper limb prosthetics. Patients may come in envisioning futuristic devices. Although an upper limb electrical prosthesis can be very sophisticated, most are less advanced than what patients expect. Some of this difference involves complex biomechanical principles being replaced in the upper limb versus mostly mechanical and weight bearing principles being replaced in the lower limb. Range of motion, dexterity, and strength all play a role in upper limb functionality. At this time, it may not be possible to equal all pre-amputation physical abilities of a patient with current technology. The rehabilitation team should encourage patients to ask questions about the pros and cons of different prosthetic options. Similarly, it is helpful to inform clients of the latest in prosthetic research and what could be on the horizon in the near future for their prosthetic care.

Many patients balk at the suggestion of seeking counseling, but it is crucial to encourage clients to recognize the many complex feelings that can surround an upper limb deficiency. The sense of touch is a fundamental tool that humans use to convey feeling and emotion to each other. The loss of even portions of the fingers can challenge clients and make them

feel isolated or lacking in a fundamental way. The human hand is a miraculous biologic achievement that allows its owner to engage in a multitude of activities, ranging from simply wearing a wedding ring to performing sophisticated job tasks. The greater the scope of the upper limb loss, the more deeply a patient may feel powerless and dependent. A carefully fitted prosthesis can return many important functions, but it also is essential that the individual's sense of loss be acknowledged and self-esteem be restored. In addition, psychological evaluation can provide insight on how patients learn. Knowing a client's unique personal learning style can help the clinician design the most successful training program.

Foundation

Progressive upper limb prosthetic care hinges on the initial patient assessment. The length of amputation, level of amputation, and prosthetic options all play a vital role in the ultimate patient outcome. The initial surgical and occupational therapy can be likened to the bedrock on which a stable house stands, whereas the initial assessment is similar to the piers that anchor and stabilize the house, elevating it to its maximum potential and functionality.

Surgical and therapeutic implications

The best type of surgical technique for an upper limb-deficient individual is a myodesis approach, in which the surgeon sutures the residual muscles to the bone rather than to one another. This technique creates a much more stable platform for all forms of prosthetic management. Muscles can contract independently without soliciting undesired movement in nearby muscles. This particular surgical technique also creates clean, independent muscle delineation in the myoelectric user.

Early identification and treatment of adherent scar tissue are important because these painful adhesions deprive patients of the full potential of their prosthesis (Fig. 1). Adherences can be skin to bone, skin and muscle to bone, or any combination thereof. These adherences cause pain when contracting muscles or extending the residual limb through the appropriate motions needed to operate a body-powered prosthesis. Adherent scar tissue should be treated early and aggressively; this may require surgical management and aggressive occupational therapy. Lack of occupational therapy may lead to the unnoticed progression of such adhesions. Before prosthetic management begins, the following crucial occupational therapy procedures need to be done:

- Wound care
- Scar management
- Soft tissue mobilization
- Residual limb shaping
- Range of motion therapy and general muscle strengthening
- Edema control

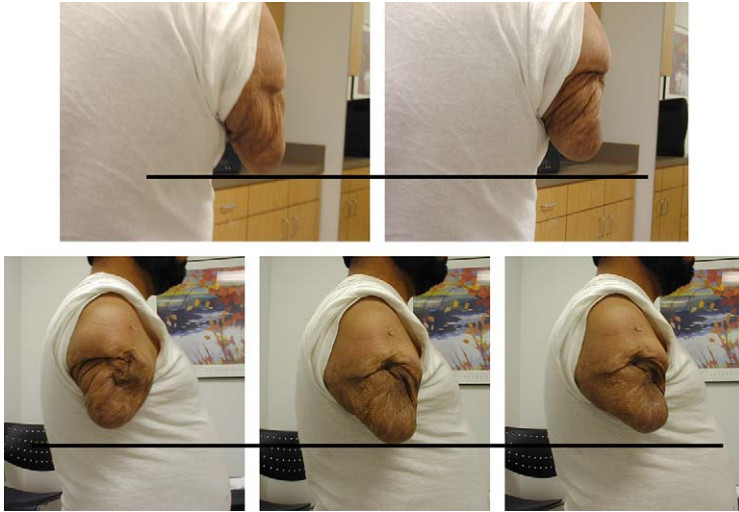


Fig. 1. Presentation of adherent scar tissue at the transhumeral level. Resting position (*top left*). On cocontraction of biceps and triceps (*top right*). Resting position (*bottom center*). Contraction of the triceps and biceps (*bottom left and right*).

Limb length plays an important role in what components can and cannot be fitted to the patient. Crucial decisions are made during surgery that can affect an amputee's prosthetic livelihood. In general, the longer the residual limb, the easier it is for patients to operate a body-powered or electrical prosthesis. The transradial level is usually the best scenario. With the preservation of the elbow, patients have an enhanced functional envelope, particularly when using an electrical prosthesis. For higher degrees of amputation, such as transhumeral and glenohumeral levels, an electrical prosthesis may prove to be a more functional option, secondary to the lack of excursion. Excursion requirements are based on harness anchor and reaction points that are determined by the length of the residual limb. High transhumeral and shoulder levels exhibit a 40% decrease in excursion ability compared with transradial levels [5]. Excessive limb length also can be problematic and limit the client's prosthetic choices. Another concern in this situation is that the prosthesis may look less "natural," which may make patients unhappy and less inclined to use the device.

Transcarpal styloid level considerations

The transcarpal styloid level allows for preservation of full supination, pronation, and wrist flexion and extension, provided that no traumatic event limits motion. Surgeons can make an anatomic decision about the styloids to enhance pronation and supination. Until more recently, prosthetists fitted these patients with passive prostheses. Now technologic advances with shortened electrical (transcarpal) hands combine functionality with a better

esthetic appearance and bilateral length symmetry. The transcarpal hand also can be adapted to a quick disconnect wrist that allows amputees to switch back and forth between electrical terminal devices designed for specific tasks or more lifelike appearance (Fig. 2).

Transradial level considerations

The transradial level is the most common level of amputation seen by the prosthetist. In general, these amputees benefit from having a longer residual limb that better distributes force across their limb during daily activities. For optimal prosthetic component selection, the postoperative residual limb length, including distal soft tissues, should be at least 10 cm proximal to the ulnar styloid. This length allows for the greatest ease in body-powered and electrical component selection [6]. Conventional components, such as a five-function wrist and electrical components incorporating powered rotators, all fit comfortably, and this clearance accommodates cabling, wiring, and any necessary socket clearance (Fig. 3).

Elbow disarticulation considerations

Although suspension is optimal, and humeral rotation can be captured, this level is the least desirable because of cosmetic issues and limitation of applicable prosthetic elbows. Unless the patient needs an elbow that allows external/internal rotation, it is best to fit this type of limb with outside locking hinges. These hinges add at least 1 more inch of mediolateral dimension in the finished prosthesis. This increased clearance can create problems with the patient's clothing. Also, amputees often dislike the general appearance. Aside from these drawbacks, keeping the elbow joint intact results in superior weight bearing and force distribution (Fig. 4) [6].



Fig. 2. Comparison of standard electric hand (*left*) and Otto Bock Transcarpal Hand (*right*). (Courtesy of Otto Bock, Minneapolis, MN.)



Fig. 3. Common prosthetic components at the transradial level include electrical and body-powered wrist rotators, terminal devices, and elbows. (Courtesy of Hosmer, Cambell, CA; Otto Bock, Minneapolis, MN; TRS, Boulder, CO; Texas Assistive Devices, Brazoria, TX; and Motion Control, Salt Lake City, UT.)

A surgical technique known as the Marquardt procedure can help patients maximize their mobility and overall physical appearance. This procedure has shown good results in adult cases. It involves an angular osteotomy, which recreates the bulbous end associated with the elbow disarticulation while shortening the residual limb [7,8]. Implantation of internal hardware to replicate the condyles is currently under investigation and may offer similar results [9].

Transhumeral level considerations

With the elbow joint absent, the length of the residual limb is a key factor in the fitting and ultimate success of a prosthesis. To allow enough clearance



Fig. 4. The elbow disarticulation level can cause prosthetic length issues based on available elbow componentry, especially if prosthetic humeral rotation is required as seen in the picture on the left. The prominence of the condyles provides anatomic suspension and interface stability.

for the different types of conventional and electrical elbows, the postoperative residual limb, including distal soft tissue, should be at least 14 cm proximal to the most distal aspect of the olecranon. Cabling for internal elbow rotation locks for the conventional user and battery placement/wiring connections for the electrical user necessitate this amount of clearance (Fig. 5).

Glenohumeral and higher level considerations

Patients who have had cancer or severe trauma represent most amputations at the glenohumeral and higher levels (eg, interscapulothoracic). These cases involve unique issues and challenges. Their devices incorporate the greatest degree of prosthetic componentry, and it is crucial that the rehabilitation team exercise the utmost care in assessment and fitting. In particular, the team must respond promptly to common complications, such as prosthesis weight and heat dissipation (Fig. 6) [6].

Prosthetic options

Ideally, prosthetic options should be discussed during the initial patient assessment. It is important not to develop any preconceived notions as to what type of prosthesis a person requires or desires. The clinician's assumptions might be incorrect or at odds with a patient's recovery goals. Clinical



Fig. 5. Electrical and body-powered elbows for the transhumeral level. (Courtesy of Liberating Technologies, Inc., Holliston, MA; Otto Bock, Minneapolis, MN; and Motion Control, Salt Lake City, UT.)



Fig. 6. By lowering the prosthetic shoulder joint, a better cosmesis is achieved.

experience shows that amputees eventually reject a prosthesis if it does not fulfill their basic personal requirements related to function, cosmetics, or psychological factors. Prosthetic options include the following:

- No prosthesis
- Passive prosthesis
- Body-powered prosthesis
- Electrically powered prosthesis
- Hybrid prosthesis
- Activity-specific prosthesis

No prosthesis

Many individuals decide not to wear a prosthesis for certain activities or choose not to wear one at all. Sometimes, a prosthesis does not significantly enhance the level of amputation, or the particular activity does not lend itself well to prosthetic enhancement. Other issues contributing to nonuse include poor initial prosthetic experience, discomfort from prosthetic design or weight, and lack of tactile sensation [10]. The acceptance and use of an upper limb prosthesis is enhanced dramatically when a patient is involved with an upper limb specialty program that incorporates expeditious prosthetic care

and occupational therapy [11]. These two aspects are paramount in any successful specialty program.

One particular concern when choosing this option is the problem of overuse syndrome. Clinicians are just now beginning to understand the effects of overuse syndrome in individuals who do not wear a prosthesis or wear a particular type of prosthesis that does not provide them an optimal level of function. Overuse occurs in prosthetic users and individuals who have had a stroke and have essentially become one-handed [12,13]. Often, overuse can be found in the form of repetitive strain-type injuries in which the person uses poor body posture or ergonomics to address certain tasks. Any patient declining a prosthesis should be referred to an experienced occupational therapist. The therapist can show the amputee how to be one-handed and teach proper posture and ergonomics when working around the full range of motion of the body, especially above the head.

Passive prosthesis

A passive prosthesis closely mimics the contours and esthetics of a contralateral limb, but has no active type of grasping. Patients appreciate this design because its lightweight construction requires minimal harnessing and little maintenance. The passive prosthesis may incorporate hands that remain rigid, have positionable fingers, or have a spring-loaded passive type of grasping mechanism. These prostheses can be very functional, even though they are passive in design. Research has shown that prostheses that might be considered to be worn for purely cosmetic reasons are in fact used functionally when performing everyday tasks (Fig. 7) [14].

Body-powered prosthesis

Body-powered prostheses represent a common type of prosthesis fitted within the United States (Fig. 8). These body-powered devices are durable and often weigh less than their electrical counterparts. Their mechanics depend on proprioceptive feedback through the harness system. Disadvantages of a body-powered prosthesis revolve around the restrictive nature



Fig. 7. Various passive prostheses. (Courtesy of ARTech Laboratory, Midlothian, TX.)



Fig. 8. Body-powered prosthesis.

of its design. The harness, which is required for functionality and suspension, limits the range of motion and functional envelope of the individual. (The *functional envelope* refers to the range of motion around a person's body in which he or she can operate the prosthesis without limiting or affecting the function of the contralateral limb.) When a patient uses a prosthesis outside the functional envelope, it becomes difficult to operate a terminal device without having to use gross body motion. These big-scale movements make it harder for amputees to use their intact side. As a result, they often rely on their intact side and do not use the prosthesis. Long-term use of a body-powered prosthesis can accelerate debilitating shoulder issues and anterior muscle imbalances and lead to nerve entrapment within the contralateral axilla [10,12,15].

Electrically powered prosthesis

The electrically powered prosthesis provides more grip force and enhanced functional envelope, while reducing or eliminating the overall harnessing necessary with a body-powered prosthesis. Many different designs are available. The term *myoelectric* commonly is associated with electrical prostheses even though other electrical control modalities exist. These include myoelectrodes, switches, slider-type input devices (servos, linear transducers, or potentiometers) and force-sensing resistors (or touch pads) [16].

1. *Myoelectrodes*. Myoelectrodes collect and filter surface electromyogram signals generated through muscle contractions and convert those signals into a form that can influence electrical motors (Fig. 9). Muscle sites are based primarily on the level of amputation and socket design and typically include the pectoralis, anterior deltoid, biceps, wrist flexors, posterior deltoid, infraspinatus, teres major, triceps, and wrist extensors. Any muscle that plays a reverse action or postural role should be evaluated carefully to avoid inadvertent and unwanted muscle contraction. A common example would be use of the trapezius for a myoelectric

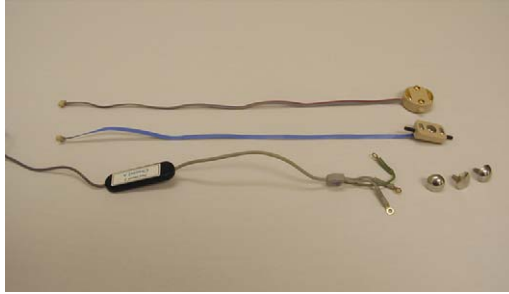


Fig. 9. Electrodes for the myoelectric prosthesis.

control site. Another area of concern is using a muscle for myoelectric control that is in close proximity to cardiac muscle, such as the pectoralis. A myoelectric site on this type of muscle could be affected by cardiac rhythm.

2. *Switch types.* A variety of motions are possible through different kinds of switching devices. Many switches are activated by pulling a cable or pressing a lever or button. Switches are designed to perform multiple functions and come in many presentations. Harness-type switches rely on excursion or some type of pull to actuate the switch. Depressing the switch with a chin, phocomelic finger, residual limb, or contralateral hand actuates another type of switch, often referred to as a push or “nudge” switch. A push switch may be placed distal to the axilla along the side of the torso or on the inner side of the person’s forearm on a transradial level amputee and activated by humeral abduction. More advanced switches are found in multiposition types of applications. A typical multiposition switch might offer three positions. The first one is a resting position where no function occurs. The second position pronates the wrist upward. The third position rotates the wrist downward. In addition, switches can be momentary (providing brief actuation while the switch is activated) or latching (maintaining function until the person activates the switch again) (Fig. 10).



Fig. 10. Switches for the electrical prosthesis. (Courtesy of Otto Bock, Minneapolis, MN.)

3. *Slider-type input devices.* Slider-type input devices convert excursion distance, speed, or force into proportional movement of a prosthetic limb. As a result, feedback enhances proprioception as illustrated in the direct force or excursion relationship to elbow, wrist, or terminal device function (Fig. 11A). Slider-type actuators come in two varieties (Fig. 11B). The linear type of potentiometer is a Servo input device that translates linear motion or excursion into proportional function. Examples of this input device are the Liberating Technologies Linear Potentiometer (LTI, Inc., Holliston, MA) and Otto Bock's Linear Transducer (Otto Bock, Minneapolis, MN). The second variety is the force-sensing type of Servo such as Motion Control's ServoPro (Motion Control, Salt Lake City, UT). The force-sensing control translates information gathered via a strain gauge and interprets it to activate proportionally a device that has been preprogrammed through a microprocessor or electronic system. Both types of Servos provide increased proprioception through the association of force or linear pull (excursion) to proportional function. Although force-sensing Servos require less excursion, the amputee faces a fairly steep learning curve to master finite control. In contrast, a linear potentiometer depends on the simpler principles of excursion and gross body movement and is easier for most patients to master.
4. *Force-sensing resistors.* Some electrical prostheses employ a force-sensing resistor (Fig. 12). These types of input devices consist of a force-sensing resistor matrix, which interprets pressure in a proportional manner. The amputee activates the force-sensing resistor by moving the shoulder complex, a phocomelic finger, residual humeral neck, or other residual anatomy. These types of input devices represent a low-profile solution providing an inexpensive proportional input device. Special care in force-sensing resistor application into the prosthetic interface is crucial

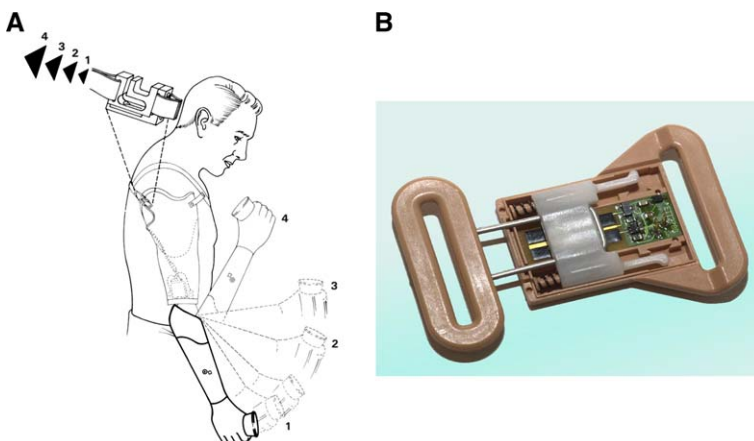


Fig. 11. (A) Relationship between force and elbow position. (Courtesy of Motion Control, Salt Lake City, UT.) (B) Otto Bock Linear Transducer. (Courtesy of Otto Bock, Minneapolis, MN.)



Fig. 12. Force-sensing resistors provide a low-profile, proportional input device.

to the success of the overall device. Improper installation results in premature failure and greater expense and can produce uncomfortable perspiration, moisture, and uneven shear force.

Myoelectric prostheses are a relatively new option, and with increased usage some exciting potential advantages are beginning to be seen. In particular, clinical experience is showing that myoelectric prostheses may prevent cortical reorganization and reduce the incidence of phantom pain [17]. In the authors' practice, patients who used a myoelectric prosthesis early in their rehabilitation reported less pain. Additional studies are needed to evaluate this phenomenon. It is important to discuss with the patient the different types of pain he or she may experience. The clinician also may need to explain that pain can take many forms, from the acute pain resulting from the surgical amputation itself to phantom pain and uncomfortable phantom sensations.

The chief drawback to an electrical prosthesis is its increased weight, which can cause muscle fatigue or friction about the residual limb. Moisture buildup also may pose a problem with electronic circuitry when proper fabrication techniques are not utilized. With the advent of water resistant terminal devices and electrodes, moisture is becoming less of an issue with the use of electronic prostheses.

There is a common misconception that body-powered prostheses are easier to maintain than electrical devices and require fewer repairs and overall maintenance. For the most part, clinical experience has debunked this myth. In reality, body-powered prostheses need maintenance just as frequently as electronic devices. Although it is true that it can cost more to repair an electronic prosthesis, downtime intervals tend to be similar or less than body-powered devices [18]. A proactive preventative maintenance program can greatly reduce overall patient frustrations with any prosthesis.

Hybrid prosthesis

The hybrid prosthesis combines the benefits of body-powered and electrical styles. This type of design allows simultaneous control of the elbow and terminal device and most commonly is simplified with the use of a body-powered elbow and electrical terminal device and wrist. In some cases, an amputee may choose a fully conventional system with an electronic wrist, but not



Fig. 13. Hybrid prosthesis.

usually as the first option. The previous discussion regarding body and externally powered prostheses is applicable to the hybrid-style prosthesis (Fig. 13).

Activity-specific prosthesis

The last prosthetic option is that of the activity-specific prosthesis. This type of prosthesis is designed for a specific activity where more typical prosthetic options are not sufficient. Patients in the authors' practice have used these custom devices successfully for activities such as gardening, weightlifting, and skydiving. The impact an activity-specific prosthesis can have on an amputee's overall quality of life cannot be overstated. These special prostheses allow patients to resume meaningful and exciting activities and help life "return to normal" in a tangible way. These devices also physically show to the amputee's family and friends that he or she is capable of doing many diverse activities (Fig. 14).

When discussing prosthetic options with patients, it is important to explore all the various options and work with patients to determine which approach best suits them and their needs. Often, more than one prosthesis is necessary to address all the patient's needs. With so many different types of prostheses now available, these devices should be viewed as valuable tools. Just as one would not want to limit his or her home toolbox to just a hammer or a screwdriver, an amputee should consider having several prosthetic "tools" to accomplish all the activities of daily living. Sometimes, one particular device can handle several kinds of activities. Other times, amputees are better served by using different types of terminal devices or an entirely different prosthesis.

Advances in upper limb technology

Current advances in upper limb technology can be divided into five categories:



Fig. 14. Activity-specific terminal devices. (Courtesy of TRS, Boulder, CO; and Texas Assistive Devices, Brazoria, TX.)

- Treatment protocol
- Prosthetic interface
- Materials
- Microprocessor technology
- Terminal devices

Treatment protocol

Within the upper limb specialty clinic, treatment protocols revolve around the expedited delivery process. This process involves fitting the patient within 2 to 3 days, then following the patient consistently through occupational therapy. This close interaction allows clinicians to evaluate better the interface, component choice and use, and therapeutic issues. Patient frustration is reduced because problems can be identified quickly and alleviated. It has long been thought and shown that early return to function is optimal. In the 1980s, Malone et al [19] showed that individuals fitted within 30 days had higher rehabilitation success, returned to work earlier, and reported less pain from their amputation. In 2005, Fletchall [11], evaluating “the value of specialized rehabilitation of trauma and amputation,” found similar trends indicating an approximate 96% success rate for patients who were seen immediately after their trauma versus a 56% success rate for those patients who were delayed from starting a specialized rehabilitation program. Additionally, 84% of those patients seen immediately by a specialized rehabilitation group remained in contact with their prosthetist/therapist as compared to only 41% of those patients who were delayed from

starting a specialized rehabilitation program. “This supports the theory that if an amputee receives therapy from a source that specializes, understands, fits him properly the first time, and trains him immediately, the amputee is going to retain the skill and knowledge for a longer period of time” [11].

During the expedited fitting process, the authors track patients closely through therapy. The rehabilitation team has found it helpful to use outcome and evaluation tools to determine progress. In addition, peer mentoring and interaction with other amputees helps patients adjust to their upper limb deficiency.

Prosthetic interface

A major determining factor of whether a patient will use a prosthesis comfortably is the design of prosthetic interface. In recent years, new techniques in socket interface design have been published. One type of interface method that has gained acceptance in lower limb prosthetics now is beginning to be used more frequently in upper limb prosthetics—the roll-on suction suspension liner. This design helps provide a positive type of suspension, while eliminating suspension harnessing, which allows the incorporation of more functional control harnessing. Roll-on liners can be used with all type of prostheses, including myoelectric prostheses (Fig. 15).

Flexible socket construction is a type of interface that enhances comfort through its flexibility, while allowing a more functional range of motion.

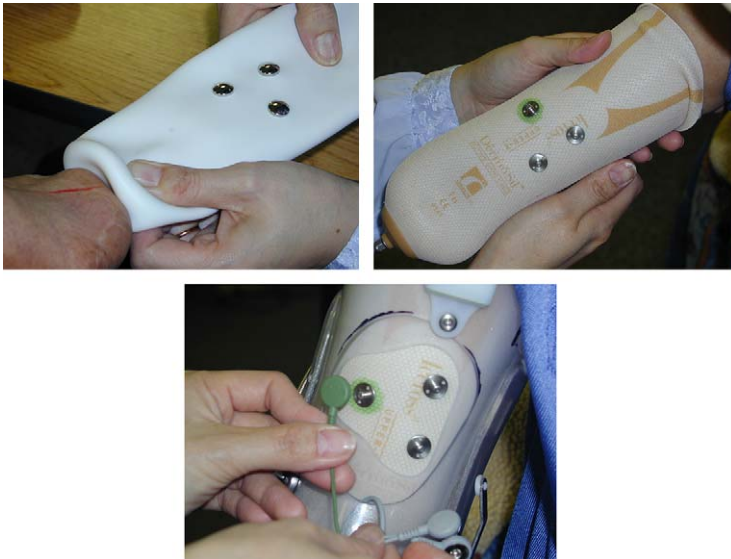


Fig. 15. Roll-on liner with electrodes embedded.

These flexible socket designs distribute force globally, resulting in better overall weight bearing. Flexible interfaces and roll-on suction suspension are incorporated in anatomic contoured sockets. The anatomic contoured socket considers the anatomy and bony structure of the residual limb. Earlier prosthetic devices merely contained the residual limb within the prosthesis. This containment approach necessitated the use of specific harnessing to stabilize the socket. Anatomic contoured sockets can be used in amputations at the styloid, transradial, elbow disarticulation, transhumeral, and shoulder level. Most upper limb-deficient individuals can benefit from these more progressive designs.

The unique anatomy of the styloid and elbow disarticulation amputation level lends itself to an impression technique in which the patient's residual limb is submerged in alginate impression material. The resulting mold presents an accurate contour of the patient's residual limb, ensuring a more comfortable prosthetic fit, and is easy to remove owing to the bulbous distal nature of the residual limb. A suction-type design is used to stabilize the residual limb at the contours of the styloids or epicondyles [20].

The transradial anatomic contoured socket contours to the muscles of the residual limb and maintains a suspension that incorporates the benefits of the mediolateral and anterior-posterior contours of the residual limb (Fig. 16). The distinguishing characteristic of this socket design involves intrinsic suspension from contouring of the radioulnar anatomy and musculature, which is a radically different approach than the older practice of extrinsic humeral epicondylar contouring. Intrinsic contouring is superior because it respects the geometric changes throughout the range of elbow motion. In some cases, the authors have modified transradial contoured sockets to a three-quarter type of design to improve air circulation. The contouring of the residual limb also provides for greater stabilization of the radius and ulna within the prosthesis when viewed radiologically (Fig. 17) [21]. Older designs did not address these geometric changes, and as a result amputees had discomfort about the epicondyles.



Fig. 16. Transradial anatomic contoured socket.

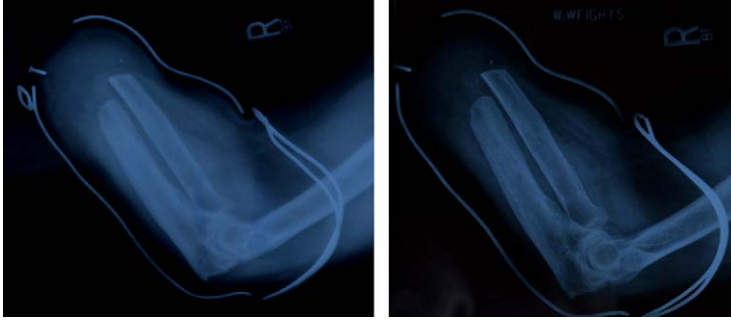


Fig. 17. Radiologic analysis of the TRAC interface without loading (*left*) and with loading (*right*).

The anatomic contoured socket at the transhumeral level is characterized by a reduction in the lateral trim line of the socket and an aggressive modification into the deltopectoral groove anteriorly and a flattened socket just inferior to the spine of scapula (Fig. 18). This type of residual limb contouring provides greater rotation control, enhances range of motion, and reduces the harnessing requirements [22].

At the glenohumeral or associated level of limb deficiency, the microframe shoulder design incorporates socket contours and trim lines that minimize the coverage of the residual limb. This design dissipates heat better and often reduces or eliminates the need to cover the shoulder with any type of rigid plastic. The microframe shoulder design uses anterior-to-posterior compression principles to help maintain suspension of the prosthesis (Fig. 19) [23]. The shoulder level of deficiency exhibits a high rate of rejection from



Fig. 18. Transhumeral anatomic contoured socket provides rotation control and enhanced range of motion.

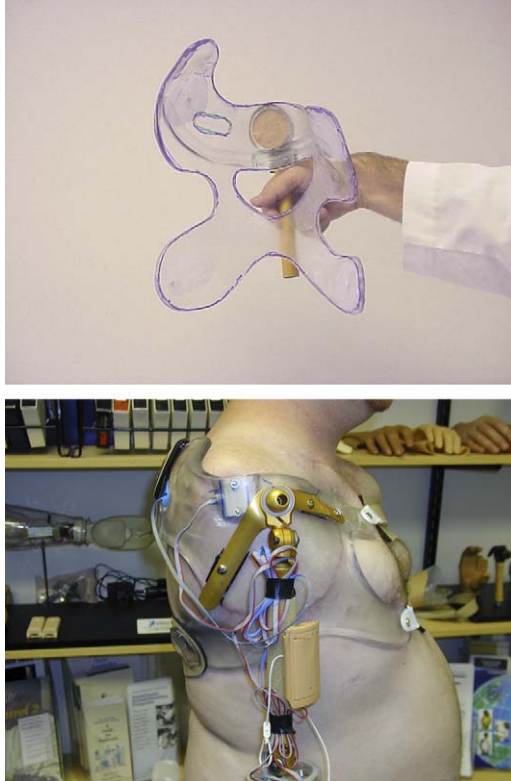


Fig. 19. Microframe provides enhanced suspension and heat dissipation for the glenohumeral and interscapulothoracic deficiency.

variables such as socket discomfort and heat buildup. The microframe design addresses these issues and provides a stable foundation for advanced systems necessary for this highly compromised patient population.

Materials

New prosthetic materials also are improving overall patient comfort. Of particular note is the friction-free donning sock. These socks have been used successfully in lower extremity prosthetics for some time. The socks can be ordered from a manufacturer or can be custom-made based on the patient's residual limb length and size. The socks allow individuals to push into their prosthesis with a minimal amount of friction and pull on the remainder of the socket by use of a lanyard with a contralateral hand or foot (Fig. 20).



Fig. 20. Use of a donning sock at the transradial level allows for reduced friction during donning and containment of the soft tissues.

Microprocessor technology

Currently, microprocessor technology influences terminal device control; wrist and elbow functions; and other options, such as shoulder joint locking and unlocking, remote on-and-off control, and sensory feedback. Microprocessors illustrate an augmentation to current types of control, not a type of stand-alone control. As a graphic equalizer enhances a complete sound system, the microprocessor delineates filters and enhances input characteristics to produce the desired output optimizing prosthetic function and increasing overall ease of use [24].

Microprocessors provide the ability to modify and enhance control options and input characteristics quickly and easily throughout all phases of upper extremity prosthetic care and product development. Although adjustable microprocessors allow for a faster return to function, they should not take the place of a well-structured rehabilitation plan that focuses on all aspects of upper extremity care from preprosthetic residual limb conditioning to long-term postprosthetic functional goals. Microprocessor use in upper limb prosthetics offers the following benefits [24]:

1. The ability to modify control options and fine-tune input characteristics quickly throughout all stages of prosthetic management without purchasing or exchanging components (eg, Servo/switch control from single site to dual site). This important aspect reduces third-party costs by providing multiple control options in one electronics package.

2. Faster prosthetic fitting and rehabilitation enabling a quicker return to function as encouraged by Malone's guidelines for optimal return to function. Amputees see significant benefits from an early fitting of Servo/switch control with a later transition to single site then to dual site as they move through the preparatory stages of their care.
3. More complex filtering of the electromyogram signal and ease in changing control thresholds and sensitivity of the prosthesis as the user's strength and ability evolves.
4. Real-time input signal analysis providing early detection of residual limb changes.
5. Ability to document and store patient information, allowing for long-term treatment goals to be monitored.
6. Use of complex algorithms to adjust inherently to various situations unknown to the patient, "reducing the mental effort" (Pat Prigge, CP, personal communication, 2000) necessary to function with an electric prosthesis.
7. Incorporation of predefined "behind-the-scenes" programs that monitor and respond to prosthetic functioning. Examples include automatic grasping of the SensorHand (Otto Bock, Minneapolis, MN), autocalibration in the ProControl System (Motion Control, Salt Lake City, UT), and usage monitoring in the Varigrip III processors (Otto Bock, Minneapolis, MN).

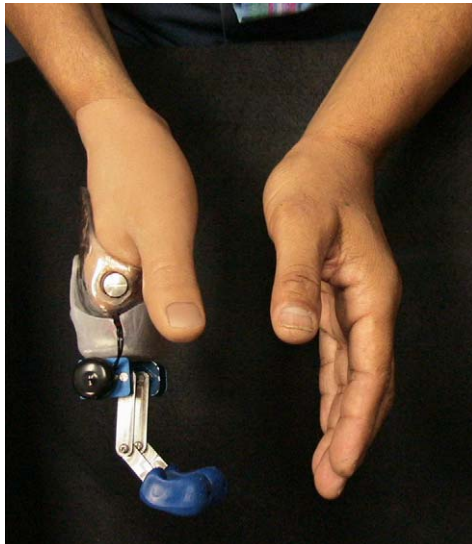


Fig. 21. Advanced Arm Dynamics Electric Partial Hand System. (Courtesy of Advanced Arm Dynamics, Dallas, TX.)

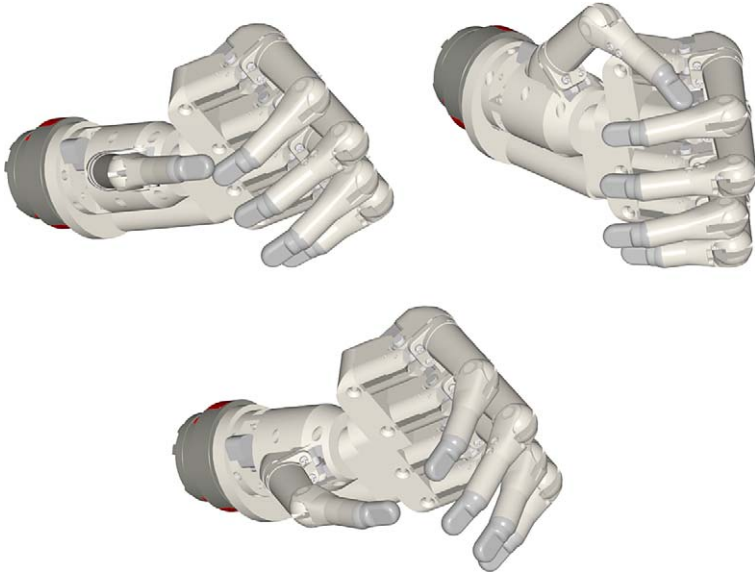


Fig. 22. The iLimb system hand allows various grasping patterns, dramatically widening the scope of the prosthetic terminal device. (Courtesy of Touch EMAS Limited, Edinburgh, UK.)

The aforementioned benefits lead to improved patient functionality and maximization of a patient's rehabilitation potential.

Terminal devices

Two breakthroughs in terminal device technology have had a significant impact on the future of electronic prostheses. The first is the introduction of water/dust resistant components. These new components function better in the real world and have fewer moisture-related problems.

The second major development is that of speed. The Otto Bock Sensor Speed Hand (Otto Bock, Minneapolis, MN) has affected the population with upper limb deficiency dramatically. For the first time, patients feel as if they are no longer waiting for the terminal device to activate. The movement is almost instantaneous with the production of a muscle signal, and that movement shows a higher degree of proportionality to the input signal provided by the patient. The lightning quick and fine-tuned response creates the sensation that the prosthetic limb is truly part of the patient's body.

One focus of renewed interest in the terminal device arena is that of the partial hand level deficiency. Clinically, many patients with an intact thumb and amputation of the remainder of the hand opt to use their sound side instead of a prosthesis, raising concerns that long-term overuse eventually would compromise the intact hand. When using a passive prosthesis at this level, patients consistently voice the wish that prepositioning was

unnecessary. The goal at this level is to provide a prosthesis that is completely functional instead of one that requires too much involvement of the sound side. The Advanced Arm Dynamics Electric Partial Hand (Advanced Arm Dynamics, Inc., Dallas, TX) addresses this need and is currently in extended beta site testing (Fig. 21).

Summary

The field of upper extremity prosthetics is a constantly changing arena as researchers and prosthetists strive to bridge the gap between prosthetic reality and upper limb physiology. With the further development of implantable neurologic sensing devices and targeted muscle innervation (discussed elsewhere in this issue), the challenge of limited input to control vast outputs promises to become a historical footnote in the future annals of upper limb prosthetics. Soon multidextrous terminal devices, such as that found in the iLimb system (Touch EMAS, Inc., Edinburgh, UK), will be a clinical reality (Fig. 22). Successful prosthetic care depends on good communication and cooperation among the surgeon, the amputee, the rehabilitation team, and the scientists harnessing the power of technology to solve real-life challenges. If the progress to date is any indication, amputees of the future will find their dreams limited only by their imagination.

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