Chapter 23

UPPER EXTREMITY PROSTHETICS

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INTRODUCTION

Recent improvements in body armor, battlefield medicine, speed of evacuation, and surgical techniques have resulted in a high incidence of survival from blast wounds sustained during armed conflict (Figure 23-1). The mechanisms of injury include explosively formed projectiles, improvised explosive devices (IEDs), mobile IEDs, rocket-propelled grenades, suicide vehicle-borne IEDs, and gunshot wounds. Those individuals who survive are frequently polytraumatized and challenged with hearing or vision impairment, burns, traumatic brain injury (TBI), upper and lower extremity injuries, and/or amputations. Service members with well-irrigated, but open, wounds are rapidly transferred from the battlefield to a rehabilitation hospital, which requires an organized approach to prosthetic rehabilitation. To enable a young and motivated amputee population to return to highly active military and civilian lifestyles, the military healthcare system has implemented a comprehensive, multidisciplinary model of rehabilitative care.

The entire rehabilitation process is accelerated because of the superior premorbid physical status and goal-oriented mindset of the service member, both of which have been fostered in the military environment. Wounded service members approach rehabilitation with focused determination to reach the initial goal of returning to active duty or reintegrating into civilian life. They place high expectations on themselves and on the care they receive. Prosthetic rehabilitation for these individuals is also complemented by their previous training in the manipulation of external devices, including weaponry and computer systems, as well as the excellent hand-eye coordination developed through military training, recreational pursuits, and electronic gaming. Harnessing these characteristics, through the protocols discussed in this chapter and throughout this book, provides the military amputee with the best opportunity to achieve and maintain high levels of function, productivity, and quality of life. This chapter reviews amputation-level nomenclature, upper limb prosthetic classifications, and treatment protocols for the three distinct phases of prosthetic rehabilitation: (1) the Preprosthetic Phase, (2) the Interim Prosthetic Phase, and (3) the Advanced Prosthetic Phase.

Figure 23-1. The Improved Outer Tactical Vest (IOTV) accommodates Small Arms Protective Inserts (SAPIs), Enhanced Small Arms Protective Inserts (ESAPIs), and Enhanced Side Ballistic Inserts (ESBIs).
Photograph: Courtesy of BAE Systems, Farnborough, Hampshire, United Kingdom.

NOMENCLATURE AND CLASSIFICATIONS

Amputation Level Nomenclature

Historically, there has been varied nomenclature that describes amputations and amputation levels. In this chapter, level-specific language was adopted to describe amputations (Figure 23-2). Other terminology may be used throughout this book that is based on local variations in descriptive wording.

Prosthetic Options

There are five principal prosthetic options to consider for the upper limb amputee:

1. electrically powered prosthesis,
2. body-powered prosthesis,
3. hybrid prosthesis,

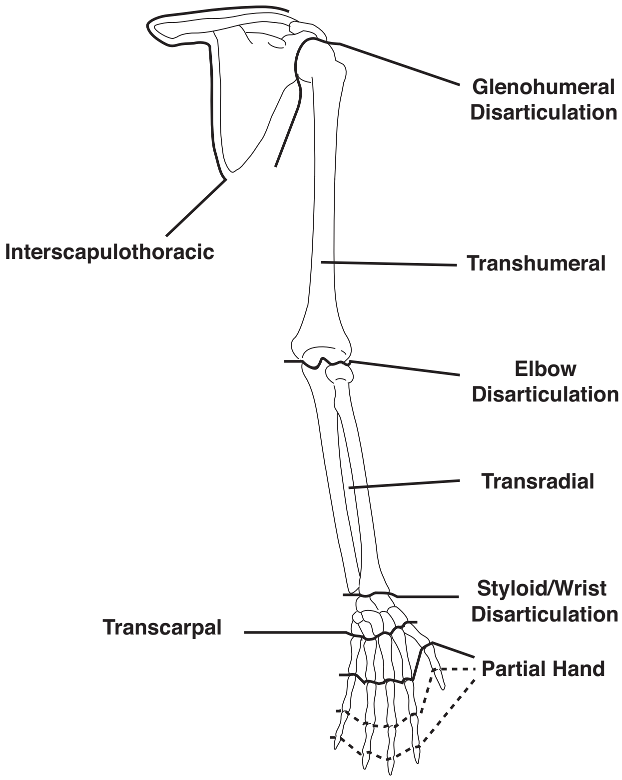

Figure 23-2. Upper limb amputation levels.
Illustration: Adapted with permission from Otto Bock HealthCare, Minneapolis, Minnesota.

4. passive/cosmetic restoration, and
5. task-specific prosthesis.

The types of prostheses recommended/selected are based on many factors, including level of amputation, condition of the residual limb, individual goals, and work requirements. Often, more than one option is required for an individual to accomplish all of his or her goals.

Electrically Powered Prosthesis

This category of prosthesis uses small electric motors in the terminal device [TD (hand or hook)], wrist, and elbow to provide movement. The motors are powered by a rechargeable battery system. There are several means of controlling this type of prosthesis, the most common of which is myoelectric control. (Figure 23-3). Myoelectric signals are derived from the contraction of voluntary control muscles in the residual limb and are recorded by surface electrodes implanted in the prosthetic socket. Electrodes must maintain contact with those particular muscles from which the control signals are derived. The recorded myoelectric signal is first amplified and then processed into a control signal governing the electric motors that operate the prosthesis. The magnitude of the processed signal is roughly proportional to the isometric force exerted by the muscle, and the microprocessor calculates actions based on the strength of the myoelectric signal.[1,2] Proportional control allows the patient to control the speed and force of the TD and wrist and elbow movements by varying the strength of the muscular contraction/signal input. For example, the larger the myoelectric signal, the greater the grip force or speed of opening and closing. This provides a more natural response with less effort than the traditional on/off action of a purely digital control system. The programmable microprocessor enables a recent amputee with relatively weak or unbalanced electromyographic (EMG) signals to control the prosthesis effectively. As the amputee's EMG signals improve, further programming occurs to optimize control. The biophysics of myoelectric control and many of the technical considerations regarding signal extraction have been explained in detail previously.[3–6]

For amputees lacking adequate dual EMG output or control, or for prosthetic systems that require additional inputs to control more degrees of freedom, other potential methods of control include the following:

- single-site electrode control schemes,
- servo control,
- linear potentiometers,
- linear transducers,
- force-sensing resistors,
- push-buttons, and
- harness switch control mechanisms.

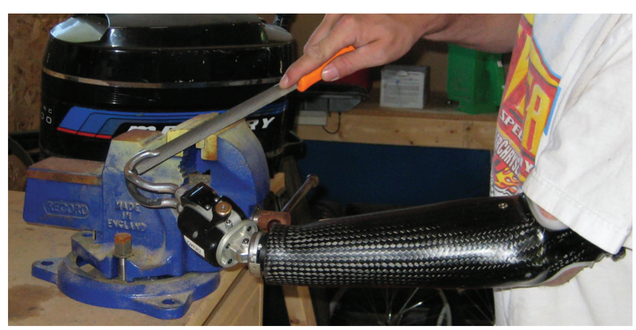

Figure 23-3. Transradial-level myoelectric prosthesis.
Photograph: Prosthesis provided by Advanced Arm Dynamics, Inc, Redondo Beach, California.

Several control schemes may be used on the same prosthesis to provide expanded function. The authors have presented technical considerations regarding these control options in other articles.[2,6] One of the unique characteristics of an electrically powered prosthesis is its ability to provide superior grasping force and wrist rotation capabilities without exerting excessive force on the fragile and acutely healing residual limb. Often, an electric prosthesis can be fit effectively within 24 hours of suture removal for rapid return to function. By contrast, the tissue traction and pressure applied to the distal end during actuation of a body-powered elbow or TD can significantly stress a suture line in the early stages of healing.

Inherent in the design of a myoelectric prosthesis is the elimination of external cabling needed for control of a body-powered prosthesis. Because electric motors are used to operate hand or hook function rather than a conventional cable and harness, grip force of the hand or hook is significantly increased, often in excess of 20 to 32 pounds per square inch. A cosmetic cover can also be applied to the prosthesis so that the prosthesis is not only highly functional, but also aesthetically superior. For amputations above the elbow, current prosthetic components allow simultaneous control of elbow flexion and extension while opening or closing the electric TD or while rotating the wrist. Historically, prosthetic options at and above the transhumeral level required the wearer to control one function at a time, also referred to as *sequential control*.

Unlike other prosthetic categories, the electrically powered prosthesis uses a battery system that requires regular maintenance (charging, discharging, eventual disposal, and replacement). Because of the battery system and the electrical motors, electrically powered prostheses tend to be heavier than other prosthetic options, although advanced suspension techniques can minimize this sensation. When properly fitted and fabricated, electrically powered prostheses do not require excessive maintenance. However, when repairs are required, they are often more complex than other options because of their sophistication. Additionally, an electrically powered prosthesis is susceptible to damage when exposed to moisture (Table 23-1).

Body-Powered Prosthesis

A body-powered prosthesis, sometimes referred to as a conventional or cable-driven prosthesis, is powered and controlled by gross body movements. These movements—usually of the shoulder, upper arm, or chest—are captured by a harness system and used to pull a cable that is connected to a TD (hook or hand). For some levels of amputation or deficiency, an elbow system can be added to provide additional motion. For a patient to control a body-powered prosthesis, the individual must be capable of producing at least one or more of the following gross body movements:

- glenohumeral flexion,
- scapular abduction or adduction,
- shoulder depression and elevation,
- chest expansion, and
- elbow flexion.

Additionally, a patient must possess sufficient residual limb length for leverage, sufficient musculature to allow movement and excursion, and sufficient range of motion for operation and positioning of the prosthesis. Thus, it is often difficult for the humeral neck, glenohumeral disarticulation, and interscapulothoracic amputation levels to control a body-powered prosthesis effectively (Figure 23-4).

Because of its simple design, the body-powered prosthesis is highly durable and can be used for

TABLE 23-1

ADVANTAGES/DISADVANTAGES OF ELECTRICALLY POWERED PROSTHESIS

Advantages	Disadvantages
Proportional grip force	Battery maintenance
Ease of electric TD/wrist operation	Overall weight consideration
Can be fit early in rehabilitation	Repairs may be more complex
Natural appearance	Susceptible to damage from moisture or excessive vibration
Can be applied to high amputation levels	
Simultaneous control of elbow and TD or wrist	
Larger functional work envelope than body-powered prosthesis	

TD: terminal device

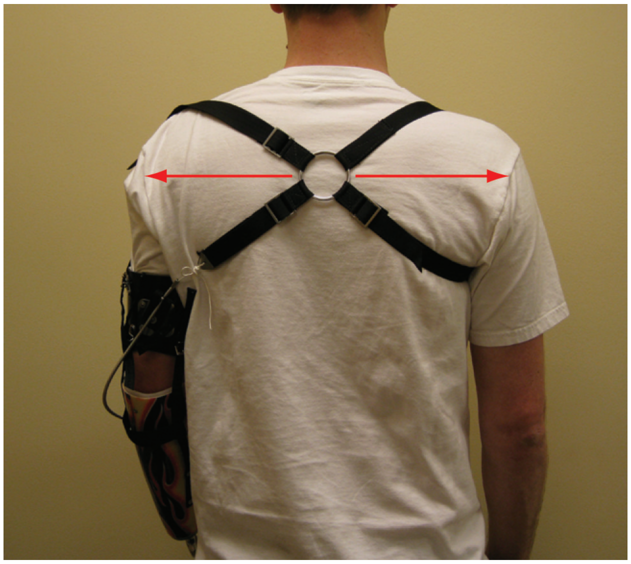

Figure 23-4. Figure-of-eight harness. *Arrows* indicate directional pull of biscapular abduction or glenohumeral flexion.
Photograph: Prosthesis provided by Advanced Arm Dynamics, Inc, Redondo Beach, California.

Figure 23-5. Definitive transradial-level, body-powered prosthesis.
Photograph: Prosthesis provided by Advanced Arm Dynamics, Inc, Redondo Beach, California.

tasks that involve water, dust, and other environments that could damage an electric prosthesis. Many patients who wear a body-powered prosthesis comment that they have a unique spatial awareness because of cable tension proprioception, which gives the wearer feedback on the position of the TD through the harness system. Maintenance costs for a body-powered prosthesis are also relatively low (Figure 23-5).

The most common complaint reported by wearers of this type of prosthesis is that the control harness is often uncomfortable, restrictive, and wears out clothes. Although new materials aid in reducing discomfort, the harness must fit tightly to capture the movement of the shoulders and to suspend the prosthesis. This can restrict proximal joint range of motion and the effective envelope of the prosthesis. The harness and cable system also limits the possible grip force of the hook or other TD. Other patients dislike the appearance of the hook and control cables, and request a prosthesis that is more "lifelike." Lastly, because of the inherent forces exerted on the residual limb during actuation of a body-powered prosthesis, careful consideration is required for those patients who have fragile, healing tissues about the residual limb. If a body-powered prosthesis is fit too early in the rehabilitation process, patients can experience breakdown around the suture line (Table 23-2).

TABLE 23-2

ADVANTAGES/DISADVANTAGES OF BODY-POWERED PROSTHESIS

Advantages	Disadvantages
Durable and can be used in tasks or environments that could damage an electric prosthesis (ie, conditions involving excessive water, dust, or vibrations created by some motorized vehicles and power tools)	Restrictive harness
	Decreased grip force compared with electric options
	Forces exerted on residual limb
	Difficult to control for high amputation levels
Secondary proprioceptive feedback	Limited function of typical body-powered hands
Lower maintenance costs than electric options	Appearance of hook and cables

Hybrid Prosthesis

A hybrid prosthesis incorporates body-powered and electrically powered components in a single prosthesis. The hybrid prosthesis often uses a body-powered elbow and a myoelectrically controlled TD (hook or hand). If desired by the wearer, an electric wrist rotator can also be included. Another type of hybrid prosthesis combines an electrically powered elbow with a body-powered hook or hand. Most commonly, hybrid prostheses are used for individuals with transhumeral and humeral neck amputations. Glenohumeral and interscapulothoracic level amputations may also be fit with hybrid prostheses. However, these cases require precise interface design because of the amount of gross body movement needed to operate this type of prosthesis and the EMG signal interference potentially created in the socket of the myoelectrically controlled hybrid during such movement. It is important for the electrodes to remain in a constant relationship with the best EMG signal that is discovered throughout the patient's range of motion (Figure 23-6).

Figure 23-6. Transhumeral-level hybrid prosthesis with cable-driven elbow and myoelectric TD.
TD: terminal device
Photograph: Prosthesis provided by Advanced Arm Dynamics, Inc, Redondo Beach, California.

There are several advantages to a hybrid prosthesis. Most important is the ability to simultaneously control elbow flexion or extension while opening or closing the electric TD or while rotating the wrist. Some prosthetic options require the wearer to control one function at a time (sequential control). The hybrid prosthesis also weighs less than a prosthesis with an electrically powered elbow while maintaining ease of operation and increased grip force of electric TDs (Table 23-3).

Passive/Cosmetic Restoration

Passive/cosmetic restoration is a popular prosthetic option. This involves replacing what was lost from amputation with a prosthesis that is similar in appearance to the nonaffected arm or hand and aids in stabilizing and carrying functions. A cosmetic prosthesis is sometimes called a passive prosthesis because it is a static device that does not provide active grasping capability. Cosmetic restoration is typically achieved using one of three materials: (1) flexible latex, (2) rigid PVC (polyvinyl chloride), or (3) silicone. These types of prostheses are often lighter weight than other prosthetic options and require less maintenance because they have fewer moving parts. Cosmetic restoration using silicone often goes unnoticed because it so closely resembles the nonaffected hand. Silicone does not stain like latex, and it provides the highest cosmetic restoration quality, with a longevity of 3 to 5 years, depending on usage patterns. These highly detailed silicone restorations are also commonly used to create a covering for the electric hands and body-powered hands in the previously discussed sections about those options (Figures 23-7 and 23-8; see also Table 23-4).

TABLE 23-3

ADVANTAGES/DISADVANTAGES OF HYBRID PROSTHESIS

Advantages	Disadvantages
Simultaneous control of elbow and TD or wrist	Requires a harness for elbow control
Lighter than fully electric elbow prosthesis	The force needed to fully flex the elbow may be difficult to generate for short transhumeral and higher amputation levels
Increased grip force compared with body-powered options	
Ease of electric TD/wrist operation	

TD: terminal device

Figure 23-7. Glenohumeral disarticulation amputee wearing a cosmetic silicone restoration.
Photograph: Prosthesis provided by Advanced Arm Dynamics, Inc, Redondo Beach, California.

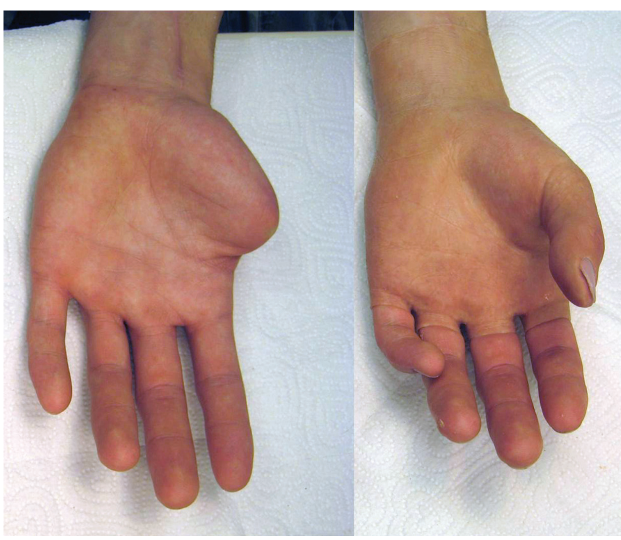

Figure 23-8. Silicone partial hand prosthesis.
Photographs: Prosthesis provided by Advanced Arm Dynamics, Inc, Redondo Beach, California.

TABLE 23-4

ADVANTAGES/DISADVANTAGES OF PASSIVE PROSTHESIS

Advantages	Disadvantages
Lightweight	Difficult to perform activities that require mechanical grasp
Minimal harnessing	Latex and PVC products stain easily
Low maintenance	
No control cables	
Cosmesis, positive body image	
Silicone products resist staining	

PVC: polyvinyl chloride

Task-Specific Prosthesis

Task-specific prostheses are designed particularly for an activity in which the use of a passive/cosmetic, body-powered, electrically powered, or hybrid prosthesis would place unacceptable limitations on function or durability. Often, this type of prosthesis is recreational in nature for activities such as fishing, swimming, golfing, hunting, bicycle riding, weight lifting, playing musical instruments, etc. Task-specific prostheses can also enhance work-related function involving the use of various tools. For more information regarding task-specific devices, see Chapter 24 on Upper Limb Prosthetics for Sports and Recreation (Table 23-5).

The current military prosthetic rehabilitation practice is to provide each service member an electric or

TABLE 23-5

ADVANTAGES/DISADVANTAGES OF TASK-SPECIFIC PROSTHESIS

Advantages	Disadvantage
Enhanced function in particular activity	Not appropriate for a broad range of functions
Minimal harnessing	
Limited or no control cables	
Durable, low maintenance	
Protects primary prosthesis from damage	

hybrid prosthesis, a body-powered prosthesis, and a passive silicone restoration prosthesis. As the service member progresses through prosthetic rehabilitation and his or her skills develop—allowing for exploration of sport activities and other specialized high-level skills—the team will address the need for a task-specific device. In most cases, the service member self-selects which prosthesis to use throughout the day for different tasks. Most service members routinely use all of their prosthetic options at some point while performing activities of daily living (ADLs). In the course of the rehabilitation process, a "primary" prosthesis will be identified, and this prosthetic option will often be duplicated to provide a backup device in the event that the primary prosthesis needs maintenance or repair.

Prosthetic Componentry

Upper extremity prostheses incorporate componentry from one or more of the following four categories, depending on the level of amputation:

1. TDs,
2. wrist units,
3. elbow systems, and
4. shoulder joints.

Terminal Devices

A large variety of TDs are available. TDs from all of the various manufacturers can be integrated into the rehabilitation plan to provide a variety of grip patterns, functional uses, and adaptations for specific tasks and appearances. Many service persons have identified useful TDs that can be interchangeable on a given prosthesis and some TDs that are best applied to a separate prosthesis for a unique application. Considerable ongoing research is being pursued to improve body-powered and electric TDs, as well as adaptive, task-specific TDs[2(p52),7–14] (Figure 23-9).

Two common categories of TDs include (1) the hook and (2) the hand. Hooks are useful for both fine prehension and rugged tasks. Hands provide a more anthropomorphic appearance, particularly with myoelectric TDs. Power to operate the body-powered TD is derived from body movements through a cable system, and electric TDs use electric motors from a battery-powered system. Body-powered TDs typically produce a voluntary opening, with rubber bands or springs providing the closing force. There are a number of body-powered TDs that provide voluntary closing functions. Service members with an amputation at the transradial level and longer are given the option to try both voluntary opening and voluntary closing styles, and to self-select one or both, depending on the activity. Most amputees with amputations proximal to the transradial level find voluntary closing to be quite difficult because of the amount of cable excursion required to operate both an elbow and a TD.[15–17] In the United States, all body-powered hooks and hands have the same ½-inch, 20-thread stud for attachment to wrist units. This allows ease of TD interchangeability.[15]

Most hook-style TDs are made from high-density plastics, aluminum, stainless steel, or titanium. Plastics are used as coatings or as housings for electric motors. Aluminum is appropriate for lightweight/light-duty applications. Titanium is strong and lightweight, and stainless steel is used where weight is less of a consideration than the overall strength of the TD material. One or all of these materials may be present in a single TD.

The prosthetic treatment protocols detailed in the section on the Interim Prosthetic Phase recommend a combination of TD technologies for both the externally powered and body-powered prostheses. This methodology accommodates the broadest range of prehension patterns and functional applications in daily living activities. Users of externally powered prostheses are able to interchange microprocessor-controlled electronic hand TDs and different microprocessor-controlled electric work hook-type configurations.

The microprocessor-controlled electric hand provides a natural appearance and can produce a grip

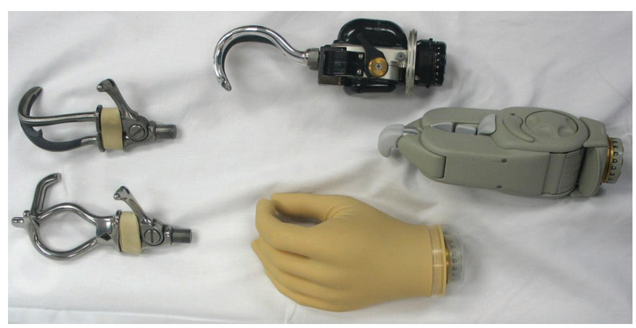

Figure 23-9. Examples of TDs: (*top center*) Motion Control ETD, (*right*) Otto Bock Greifer, (*bottom center*) Otto Bock SensorHand SPEED, (*bottom left*) Hosmer Dorrance 7LO work hook, and (*top left*) Hosmer 5XA hook.
ETD: Electric Terminal Device
TDs: terminal devices
Photograph: Product images used with permission from Motion Control, Inc, Salt Lake City, Utah; Otto Bock HealthCare, Minneapolis, Minnesota; and Hosmer Dorrance Corporation, Campbell, California.

Figure 23-10. The Otto Bock SensorHand SPEED responds twice as quickly as other electric hands and offers an automatic grasp feature.
Photograph: Courtesy of Otto Bock HealthCare, Minneapolis, Minnesota.

force of up to 24 pounds per square inch (Figure 23-10). The cylindrical grasp and palmar pinch patterns effectively handle cylindrical objects of various sizes, such as steering wheels, handlebars, control knobs, liquid containers, and many tools. Upgraded EMG processing capability enables one of these hands to respond to (myoelectric) muscle signals more than twice as quickly as standard electric hands. The sensory feedback technology and microprocessor allow the hand to react rapidly to changing situations. The automatic grasp feature of this hand monitors shear force and grip force, and automatically adjusts grip strength so that an object remains securely in the hand even when its center of gravity changes. Another microprocessor-controlled electric hand provides locking wrist flexion without the auto-grasp feature. The fingers of this hand can be opened instantly using the patented safety release feature. It is quite effective in all of the wrist positions.

One microprocessor-controlled hook-style TD combines powered pinch force with a tip-pinch grasping pattern to provide better purchase on small objects. The locking flexion wrist feature allows the wrist to be positioned at various angles of wrist flexion and extension, enhancing the functional envelope. Featuring water- and dust-resistant housings, the electric hook TD can be used in harsher environments without increasing the maintenance and servicing required. The lyre-shaped fingers allow the user to easily see what is being held for safe and accurate usage of tools and machinery. In an emergency, these hook fingers can be opened instantly by a patented safety release feature (Figure 23-11).

Another prehensor-type microprocessor-controlled TD offers a grip force of up to 32 pounds per square inch and is one of the widest opening electric TDs. This version is durably constructed with a protective coating and built-in friction-controlled wrist deviation. The grip surfaces are adjustable in all planes to allow multiple gripping and holding functions (Figure 23-12).

The electric hands and work hook-type TDs can be programmed to optimize prosthetic function. The programming systems provide the patient and the prosthetist with visual feedback of EMG signal strength and electronic adjustments on a computer screen. Once programming is complete, the patient-specific data settings are stored and can be uploaded to the specific TD after maintenance and repair. This prevents repetitious programming sessions and creates a comparative data cache for analysis of changes in muscle strength and muscle differentiation.

Figure 23-11. Motion Control ETD offers lyre-shaped fingers with water-resistant housings.
ETD: Electric Terminal Device
Photograph: Product image used with permission from Motion Control, Inc, Salt Lake City, Utah.

Figure 23-12. The Otto Bock Greifer provides up to 32 pounds of pinch force.
Photograph: Courtesy of Otto Bock HealthCare, Minneapolis, Minnesota.

Wrist Units

Wrist units connect the TD to the prosthesis. They are designed to position the TD for function and to provide the mechanism to interchange TDs. The appropriate selection of a wrist unit can greatly improve the functionality of a wearer by enhancing the range of TD positioning. There are essentially three capabilities of wrist units: (1) rotation (supination/pronation), (2) flexion and extension (or ulnar deviation/radial deviation), and (3) quick disconnection. Using these functions requires use of the contralateral limb or an object in the environment to manually rotate the unit unless an electric rotator is used. These three capabilities are sometimes combined into one unit. Rotation can be controlled by friction and optional locking positions. The quick disconnect ability allows wearers to easily interchange TDs based on the demands of their activities. Wrist units with flexion and extension allow the user to set the TD in some degree of flexion or extension. In many situations, a combination of these features improves a wearer's ability to perform ADLs, vocational activities, and avocational activities by accommodating demanding positions and achieving access to midline tasks. Historically, these combination units were predominantly used for bilateral amputees. However, unilateral amputees also benefit from the use of combination wrist units that enhance the ability to perform tasks with the prosthesis and the contralateral limb simultaneously (Figure 23-13).

These combinations can be found not only on body-powered prostheses, but also on electrically powered prostheses. An electrically powered wrist offers active rotation and should be used in all situations, provided that symmetry is preserved and length considerations are addressed. In the preprosthetic treatment phase, communication of surgical considerations should include the residual limb length needed to accommodate this componentry and maintain the appropriate overall length of the prosthesis. There are several methods to actuate an electric wrist rotator, but many amputees

Figure 23-13. Example of wrist units: (*top right*) Hosmer Dorrance quick disconnect wrist unit; (*bottom*) Otto Bock four-channel processor and electric wrist rotator; and (*top left*) Sierra Wrist Flexion Unit.
Photograph: Product images used with permission from Hosmer Dorrance Corporation, Campbell, California, and Otto Bock HealthCare, Minneapolis, Minnesota.

prefer a method referred to as "quick-slow" or "fast access." This scheme interprets the speed of a muscle contraction in a myoelectric system and immediately directs control to the wrist or the TD, depending on the speed of contraction. Another common control scheme used to switch between wrist and TD control is co-contraction. This method requires the patient to quickly co-contract the antagonist and agonist muscle groups to alternate between control of the wrist and TD. This creates a delay and is more cognitively taxing because it requires a patient to do the following:

- co-contract to select the wrist,
- position the wrist,
- co-contract to select the TD, and
- operate the TD.

As a result, co-contraction control switching can lead to frustration and the potential to lose track of which function is active at a given point in time. One variation in co-contraction uses a method to simplify the process by creating an automatic return to TD function after a preset time has elapsed, with no EMG input to the prosthesis. Amputees tend to prefer a high level of predictability when selecting a control scheme, and our experience has shown that quick-slow schemes are typically well-accepted.

Elbow Systems

Elbow systems allow the wearer to flex or extend the elbow to a desired position and lock it when necessary. Most body-powered and electrically powered elbow systems also provide passively controlled humeral rotation (Figure 23-14).

Body-powered elbow systems require up to 4½ inches of cable excursion to fully flex the elbow and operate the TD. This significant amount of excursion often precludes use by patients with reduced strength, limited range of motion, or shorter residual limbs. By incorporating flexion assist in their elbow systems, several manufacturers mitigate the amount of force needed to flex the elbow. Spring lift assists or forearm-balancing units will help to overcome some of the weight of the TD and assist in flexing the elbow. Whenever possible, elbow flexion assists should be used to reduce not only the effort required by the wearer, but also the shear forces applied to the residual limb so as to prevent irritation and tissue breakdown. Elbow flexion assists are particularly important in hybrid systems because of the additional weight of the electric wrist and TD. At the elbow disarticulation level, various manufacturers' outside locking hinges are used in combination with lift assist mechanisms and/or automatic forearm-balancing units (Figures 23-15 and 23-16).

Electrically powered elbows provide motorized positioning of the forearm, reducing or eliminating the need for glenohumeral range of motion or strength required to operate body-powered systems. Microprocessors in the electric elbow can use a variety of control inputs, including electrodes, force sensors, touch pads, and various types of linear potentiometers. The functional advantage of an electric elbow system comes at the cost of increased weight. Therefore, it is important to factor this into preprosthetic occupational therapy training and into the patient's expectations.

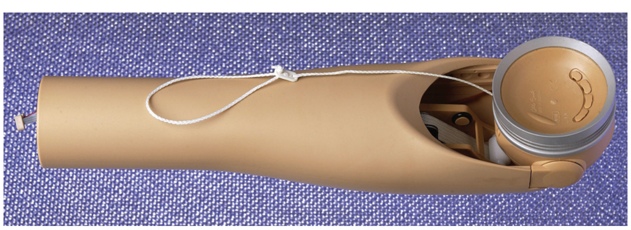

Figure 23-14. Otto Bock Ergo Arm.
Photograph: Courtesy of Otto Bock HealthCare, Minneapolis, Minnesota.

Figure 23-15. Otto Bock Dynamic Arm.
Photograph: Courtesy of Otto Bock HealthCare, Minneapolis, Minnesota.

Figure 23-16. The Motion Control Utah 3 Arm.
Photograph: Courtesy of Motion Control, Inc, Salt Lake City, Utah.

Figure 23-17. LTI Locking Shoulder Joint.
LTI: Liberating Technologies, Inc
Photograph: Product image used with permission from Liberating Technologies, Inc, Holliston, Massachusetts.

Shoulder Joints

Currently, the only commercially available shoulder joints must be passively positioned for flexion, extension, abduction, and adduction. The motions of abduction and adduction are friction based, whereas flexion and extension can be either friction based or locking (Figure 23-17).

PREPROSTHETIC PHASE

Rehabilitation Team

Successful upper extremity prosthetic rehabilitation must fully address the unique constellation of clinical and functional requirements presented by the patient and is, therefore, dependent on the coordinated efforts of a multifaceted care team. This team must include, but is not limited to, the following:

- patient;
- family, friends, and significant other;
- surgeon;
- physician/physiatrist—physical medicine and rehabilitation;
- psychologist/psychiatrist;
- occupational therapist;
- physical therapist;
- case manager;
- prosthetist; and
- nursing staff.

The treatment plan must be tailored to the specific needs and goals of the injured service person. Each of the team members will contribute critical information and experience to develop a cohesive, individualized treatment plan. During the Preprosthetic Phase, the Interim Prosthetic Phase, and the Advanced Prosthetic Phase, the prosthetist will consult with various members of the patient's rehabilitation team. The surgical team will use the prosthetist's input to identify an ideal amputation level and wound closure, and the occupational therapist will work closely with the prosthetist as the limb is prepared for prosthetic management, and the prosthetic devices are created and fit. During and following the Advanced Prosthetic Phase of initial rehabilitation, the prosthetist and other team members will work together to maintain consistent contact with the service member and address any subsequent prosthetic or medical issues.

Surgical Considerations for Optimal Prosthetic Rehabilitation

Although there are many issues for the military surgeon to consider in treating blast injuries, it is important to communicate the requirements of current prosthetic technology as they relate to residual limb length, shape, and musculature reattachment. The surgical considerations that will be described allow for optimal prosthetic rehabilitation for each level of amputation. As prosthetic technology evolves and different components are developed, surgical guidelines might require modification. Concomitant injuries might also take priority and affect the subsequent plan. The historical approach to "save as much as possible" can sometimes present difficult issues for the service person, particularly considering that residual limb length revisions may be necessary after closure so that a more functional solution for prosthetic rehabilitation can be achieved. If carefully planned in advance, surgery to close the amputation site can include any necessary length modifications and minimize the number of surgical procedures. In addition to the following general guidelines for residual limb length, muscle attachment, skeletal shaping, and soft-tissue closure, also see Chapter 8 (General Surgical Principles for the Combat Casualty With Limb Loss).

Guidelines for Residual Limb Length

The length of the residual limb can limit the prosthetic componentry options and therefore might affect functional potential. In determining the ideal length for amputation, it is essential that the surgeon and the patient understand how the individual's prosthetic options might be affected by the length of the residual limb. It should also be carefully explained that a residual limb that is too long might present complications when using a prosthesis in tight spaces or as it relates to cosmetic symmetry with the other arm/hand.

The following guidelines have proven helpful to support upper extremity prosthetic rehabilitation. For the transradial and transhumeral levels, formulas to determine optimal residual limb length have been suggested. These calculations were developed based on the sizes of an average individual and currently available mechanical and powered elbow, wrist, and TD units. In addition, patients will not use a prosthesis 100% of the time, and they might benefit from variations on these recommendations. Formulas to determine limb length for each amputation level should be developed after careful consideration of available componentry as it relates to leverage of the residual limb, both with and without a prosthesis.

Transcarpal and Transmetacarpal Levels. If at least two digits remain that are sensate and innervated (movable by patient), retain as much length as possible and minimize graft and scar tissue surface areas. If digits are insensate, lack an active range of motion, or are heavily grafted/scarred, revise the length to carpal level or styloid disarticulation, depending on the amount of graft and scar tissue present distal to the center of wrist articulation.

Styloid Level. Disarticulate at the wrist, keeping the radius, ulna, and interosseus membrane intact. A transradial-level amputation should be considered if supination and pronation are severely limited or absent secondary to injury of the forearm musculature and interosseus membrane.

Transradial Level. To determine optimal length that will accommodate current prosthetic componentry, the following steps are recommended (Figure 23-18):

1. Measure the contralateral/noninvolved limb from the lateral epicondyle to the thumb tip (with the elbow flexed at 90 degrees). This is X.
2. Subtract $8\frac{3}{4}$ inches or 22.5 cm (average length of prosthetic TD and wrist unit) from X, which will be the optimal final residual limb length for the affected side (or Y). A slightly larger value may be substituted for Y without a material decrease in functional levers.
3. Measure from the lateral epicondyle on the involved side marking the desired residual limb length (Y) determined in step 2. This should be the finished residual limb length, including soft-tissue padding. The ulna will be $\frac{1}{4}$ to $\frac{1}{2}$ inches (0.8 cm–1.25 cm) shorter than Y, and the radius will be $\frac{1}{8}$ to $\frac{1}{4}$ inches (1.25 cm–2.5 cm) shorter than overall length of the ulna.

Elbow Disarticulation Level. Disarticulation should be performed at the elbow, thus keeping the shape of the epicondyles intact.

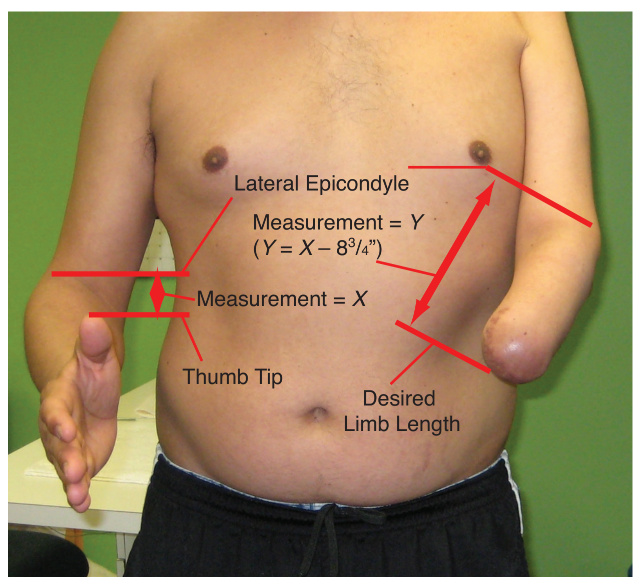

Figure 23-18. Procedure to determine preferred transradial residual limb length.

Transhumeral Level. To determine optimal limb length using current prosthetic componentry, the following steps are recommended:

1. Measure the contralateral/noninvolved limb from the acromion process to the distal olecranon (with the elbow flexed at 90 degrees). This is *X*. Subtract 5½ inches or 14 cm (the average length of the prosthetic elbow unit) from *X*, which will be the optimal final residual limb length for the affected side (or *Y*). A slightly larger value may be substituted for *Y* without a material decrease in functional levers.
2. Measure from the acromion process on the involved side marking the optimal residual limb length (*Y*) determined in step 1. This should be the finished residual limb length, including soft-tissue padding. The humerus will be 1/2 to 3/4 inches (1.25 cm–2.0 cm) shorter than *Y* (Figure 23-19).

Humeral Neck, Glenohumeral, and Interscapulothoracic Levels. Follow the general surgical principles for residual limb length.

Guidelines for Muscle Attachment

Myoplasty. Attaching the transected muscles to themselves or others increases the incidence of co-contraction of antagonistic muscles, thereby greatly diminishing myoelectric control potential. Myoplasty limits prosthetic options.

Myodesis. Attaching the transected muscle directly to bone creates a solid anchor for each muscle to pull against during contraction. This creates a clear and distinct EMG signal, which is useful for differentiating electromyography from multiple muscles and optimum myoelectric control potential (Table 23-6).

Guidelines for Skeletal Treatment

General surgical principles apply to the treatment of bone. The cut end of bone should not present any unnecessary sharp edges, rough prominences, or splintering (Table 23-7).

Soft-Tissue Closure/Distal Suture Line

Note these four points:

1. Finished amputation should have ¼ to ½ inches (0.8 cm–1.25 cm) of soft-tissue padding over the skeletal distal end.
2. Nerves are transected sharply under tension to prevent future formation of neuromas without negatively impacting sensation and innervation of associated muscles.
3. Distal suture/staple line should run medial/lateral when the patient's residuum is in the standard anatomical position.
4. Conical shape is preferred, with a smooth contour of the distal end taking care to eliminate or minimize both invagination of tissue and "dog ear" formation (note: dog ear usually refers to excess tissue at the ends of the skin closure

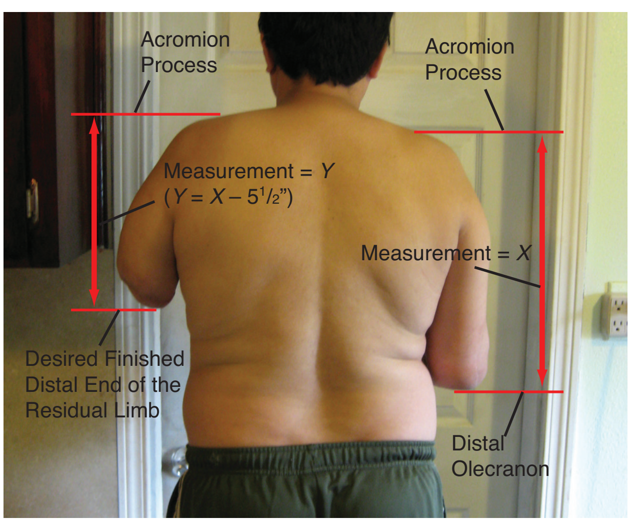

Figure 23-19. Procedure to determine preferred transhumeral residual limb length.

TABLE 23-6

GUIDELINES FOR MUSCLE ATTACHMENT

Level	Action
Transmetacarpal/transcarpal	Follow general surgical principles
Transradial Styloid disarticulation	Attach wrist flexors and extensors, and supinator and pronator muscle groups to radius and ulna
Transhumeral Elbow disarticulation	Attach biceps and triceps tendons to the humerus
Humeral neck, glenohumeral disarticulation, interscapulothoracic	Follow general surgical principles

TABLE 23-7

GUIDELINES FOR SKELETAL TREATMENT

Level	Action
Transmetacarpal/transcarpal	Follow general surgical principles
Transcarpal/transmetacarpal Styloid disarticulation	Do not bevel styloid prominence because this skeletal prominence will be used for suspension of the prosthesis
Transradial	Bevel and remove sharp edges from radius and ulna; radius should be ¼ to ½ inch (0.8 cm–1.25 cm) shorter than the ulna
Elbow disarticulation	Do not bevel epicondylar prominences because this skeletal prominence will be used for suspension of the prosthesis
Transhumeral	Bevel and remove sharp edges from the humerus
Humeral neck, genohumeral disarticulation, interscapulothoracic	Follow general surgical principles

that tend to be everted/protruding—somewhat triangular and pointed like a dog's ear).

Prosthetic Assessment and Rehabilitation Plan Formation

Once the residual limb length has been surgically established and the wound is initially closed, a comprehensive prosthetic assessment is performed. This occurs prior to suture or staple removal and is often initiated at the bedside in the intensive care unit or orthopaedic ward. The evaluation may span multiple visits to accommodate the physical, cognitive, and emotional status of the patient. Often, the initial visits are limited because the patient is heavily medicated or receiving medical attention for concomitant injuries. The prosthetic assessment includes the following:

- medical history,
- premorbid activities (vocational and avocational),
- psychosocial considerations,
- residual limb status,
- concomitant injuries, and
- patient functional requirements.

It is also important to consider the family/support system available to the patient and the potential discharge plan. The information gathered during the assessment is then used to develop a prosthetic recommendation that is used by the multidisciplinary team to create an individualized rehabilitation plan.

Patient Education

The prosthetic assessment also marks the beginning of the patient's education on prosthetic rehabilitation and the options available to him or her. Individuals who sustain blast wounds undergo myriad physical and psychological changes over the first weeks postinjury. Creating an open dialogue with service members and their families at this stage is essential to facilitate progression through the rehabilitation process. It is an opportunity to reconcile any preconceptions about prosthetic technology because exposure to popular films and media can create unrealistic prosthetic expectations. During this time, the service member and his or her family must process a significant amount of information regarding the injury, recovery, and implications for the future. Therefore, pertinent information should often be reiterated to ensure that it has been properly assimilated. Meetings with a trained peer visitor who has successfully completed prosthetic rehabilitation can also be beneficial in providing accurate information, as well as a user's perspective.

The anticipated timeline for prosthetic rehabilitation over the subsequent 12 to 18 weeks postinjury should be discussed during the assessment. Rehabilitation begins with residual limb management and preparation for prosthetic fitting, and continues beyond delivery of the definitive prostheses to the point wherein the patient is comfortable reintegrating into the community (see Interim Prosthetic Phase for level-specific protocols).

Figure 23-20. Healing residual limb.

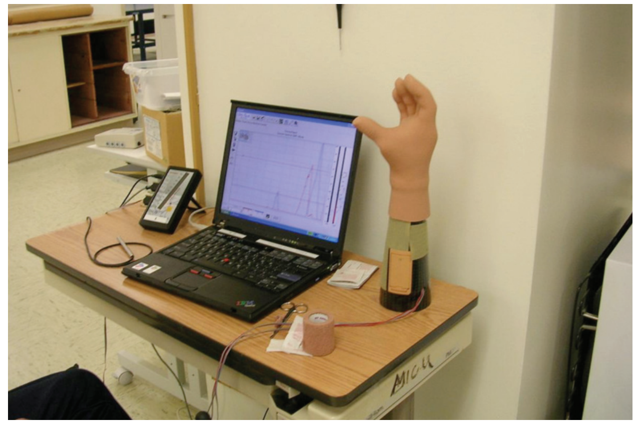

Figure 23-21. Otto Bock 757M11 MyoBoy for preprosthetic training with demonstration myoelectric hand and wrist. Photograph: Product image used with permission from Otto Bock HealthCare, Minneapolis, Minnesota.

Residual Limb Management

The first step in residual limb management is to address edema control. Blast injuries and multiple irrigations and debridements prior to wound closure can produce significant edema. Compressive dressings and garments are applied immediately following wound closure for the purpose of reducing swelling. Proper edema management using elastic bandages, presized tubular compressive fabrics, or silicone/urethane roll-on liners is necessary. Use of silicone liners has been particularly effective at edema reduction, but must not be implemented until drainage has ceased because of concerns regarding skin integrity and infection (Figure 23-20).

During the Preprosthetic Phase, the occupational therapist concentrates on desensitization, range of motion, myosite training, and limb loading in preparation for prosthetic fitting. This phase gives the prosthetics team valuable information on control schemes that are most likely to be immediately successful with the patient. This also allows the patient to develop a rapport with various members of the rehabilitation team who will be seen daily in the Interim Prosthetic Phase of rehabilitation. Finally, patients are encouraged to build confidence in their own abilities by controlling simulators and demonstration components, and working through challenging situations prior to early postoperative prosthesis (EPOP) fitting (Figure 23-21). Within 24 hours of suture and staple removal, residual limb impressions are taken to initiate the Interim Prosthetic Phase.

INTERIM PROSTHETIC PHASE

Military amputees, who are typically young and motivated, benefit from early prosthetic intervention because it offers greater independence, self-esteem, and long-term success.[18] As previously noted, the protocol established by the military healthcare system is to sequentially provide each service member with an electric or hybrid prosthesis, a body-powered prosthesis, a passive restoration prosthesis, and task-specific adaptations or prostheses. One of the goals during this stage of initial prosthetic device delivery is to minimize the time between suture removal and functional prosthetic use. Delivery of EPOP ideally occurs within 24 hours of suture removal. Often, the residual limb of these individuals presents multiple problems with healing, related to complicated suture lines, skin grafts, muscle flaps, or the presence of fragments or other foreign bodies. Therefore, a myoelectric EPOP device offers the safest approach to introducing a prosthesis to the individual in a way that minimizes excessive forces on the often fragile and healing distal residuum. The electric prosthesis is well-suited for this application because it does not require a restrictive harness and gross body movements for control that can exert unwanted forces on the healing residual limb or other healing areas that would be in contact with the harness. Myoelectric control of the EPOP also offers the advantages of immediate functionality, proportional grip strength, and TD positioning at initial delivery. Prior to EPOP fitting, it is important for the patient to have developed basic myoelectric control skills in occupational therapy during the Preprosthetic Phase.

The EPOP is fit during this initial healing period and is modified during rehabilitation until swelling is stabilized and wound closures are complete. The patient is fit with an EPOP using an expedited fitting protocol. A typical expedited fitting requires 1 to 3 days and allows the patient to begin occupational therapy with a functioning, but modifiable, device that can be used to address changes during initial rehabilitation and therapy for increased efficiency. EPOP procedures include adjustments for alignment, length, suspension, pressure distribution, functional performance, and programming of all electronics for system optimization and positioning of electrodes, batteries, access openings, and components.

The prosthetist must be prepared to accommodate the often dramatic volumetric changes in the residual limb for individuals who have sustained blast wounds. It is not uncommon during the first 4 to 8 weeks after EPOP delivery to perform multiple socket adjustments each week. A myoelectric prosthesis requires consistent skin-to-electrode contact to retain function. Therefore, it is imperative that adjustments for proper fit be performed in an expeditious manner. This is best accomplished using a thermoplastic flexible socket and rigid frame that can be modified several times during the Interim Prosthetic Phase.

EPOP methodology was developed to address military protocols for early fitting while minimizing the stresses on the healing residuum. Early in Operation Enduring Freedom and Operation Iraqi Freedom, it was found that the amount of residual limb edema was significant secondary to methods of irrigation and maintenance of open wounds prior to transferring patients to stateside medical care facilities. Many amputees had also sustained injuries to the chest wall, shoulder areas, and axillary regions that would preclude the use of a harness for control of a body-powered TD or elbow during the healing phase. Traditional immediate postoperative prosthesis (IPOP) has been bypassed because of the evolution of EPOP and because IPOP treatments cannot accommodate these rapid volume changes and preclude visual assessment of the healing limb, which is crucial immediately following closure. Closure of the amputated limb without the application of an IPOP allows the team to observe the healing wounds and begin preprosthetic therapy with shrinkers and myotraining as soon as the patient is cognitively and physically able. In preparation for the EPOP and Interim Prosthetic Phase, the surgeon is able to ensure that wound closure has matured to a point at which the mild pressures applied from a prosthetic socket that uses flexible thermoplastics against the skin can be tolerated. Fitting of the EPOP then provides the positive results of "instant gratification" and broad functional applications with minimal stress to the healing anatomy. The ability to make significant, frequent changes to volume, alignment, componentry, and programming during the EPOP Phase allows the rehabilitation team to keep pace with the highly motivated amputee.

At the time of EPOP delivery, focus in the patient's therapy shifts to prosthetic training. When a prosthetic device is fit and delivered to a service member, thorough instruction on the system is given by the prosthetist. This instruction often takes place with the occupational therapist present so that various specifics can be noted for subsequent training sessions. Information is typically covered in a routine order, starting with donning and doffing. Common application techniques include the use of limited friction donning pull socks, evaporative moisture, or roll-on liners, as required by the design of the prosthesis. The following procedures are then taught from distal to proximal, dependent on amputation level:

- TD on-off and positioning;
- wrist controls;
- elbow on-off and lock-unlock;
- shoulder joint movements, lock-unlock;
- harness donning, doffing, and adjustment; and
- battery insertion, charging and care.

These functions are later practiced in occupational therapy. It is also necessary to review these functions periodically as the use of multiple prostheses and the interchangeability of TDs require slight variations in control. Consistent communication between prosthetist and occupational therapist is indispensable to ensure that any changes that impact the fit or programming of the prosthesis are immediately addressed. This relationship continues throughout the rehabilitation process to facilitate problem-solving as the patient is challenged to higher degrees.

There will come a time when the wounds have adequately healed and can sustain more aggressive pressures from the prosthetic socket interface. At this point, a transition is made from the EPOP approach to a preparatory version of the prosthesis. This preparatory phase still retains the adaptability of the EPOP for ongoing volume changes, but allows the socket to become tighter for improved suspension, electrode contact, and overall control of the prosthesis in space. By this time, the alignment, length, and basic structure should be well defined. The preparatory prosthesis provides the rehabilitation team with the opportunity to test the prosthesis and its components in real-world applications outside the clinic setting. Further modifications in volume, alignment, length, and structure can be made easily during this phase as the team prepares to progress to the definitive prosthesis (Figure 23-22).

Once the residual limb has reached volumetric stabilization, usually within 8 to 14 weeks after suture or staple removal, fabrication of the definitive prostheses begins. A goal for this stage is to ensure that at no point is the user left without a prosthesis. To accomplish this, it is often necessary to fabricate the definitive body-powered device prior to fabrication of the definitive myoelectric. Typically, both definitive devices are delivered within 7 to 10 days of each other.

Completion of the definitive silicone restoration/passive prosthesis and silicone restoration covering for the electric hand should coincide approximately with the fitting of the definitive electric and body-powered devices. This process typically takes 12 to 16 weeks from first impressions to definitive prosthesis. These remarkably life-like replications are custom painted on the inside of a clear silicone glove that is fabricated using a sculpted reversal of the amputee's sound limb. An impression of the sound side (if present) is taken in the Preprosthetic Phase. In bilateral upper extremity loss, the patient will often choose a family member as a model or even detailed photos of their own hands prior to the injury from which the artists can sculpt the restoration (Figure 23-23).

Evaluation for task-specific devices to support the service member's vocational and avocational interests occurs throughout the rehabilitation process. Not only are individuals returning to preinjury pursuits but also, through programs sponsored for wounded service members, they are developing new interests and challenges with their prosthetic devices. As described previously, this patient population is driven, competitive, and willing to test the limits of current prosthetic technology to reach their goals.

It is important to teach service members to perform basic maintenance on the various prostheses that they have received. Simple tasks (eg, cleaning, minor electrode adjustment, and cable and harness servicing) can be taught during the Interim Prosthetic Phase and reinforced in therapy as part of the treatment protocols. Service members are also taught to describe problems with their prostheses in a way that allows the prosthetist to diagnose and repair items that have broken or failed. In cases in which the service member has returned to active duty or is not near a service facility, the ability to describe a problem accurately will often help the rehabilitation team determine whether the service member should send a prosthesis to the center

Figure 23-22. Preparatory transhumeral-level electric prosthesis.
Photograph: Prosthesis provided by Advanced Arm Dynamics, Inc, Redondo Beach, California.

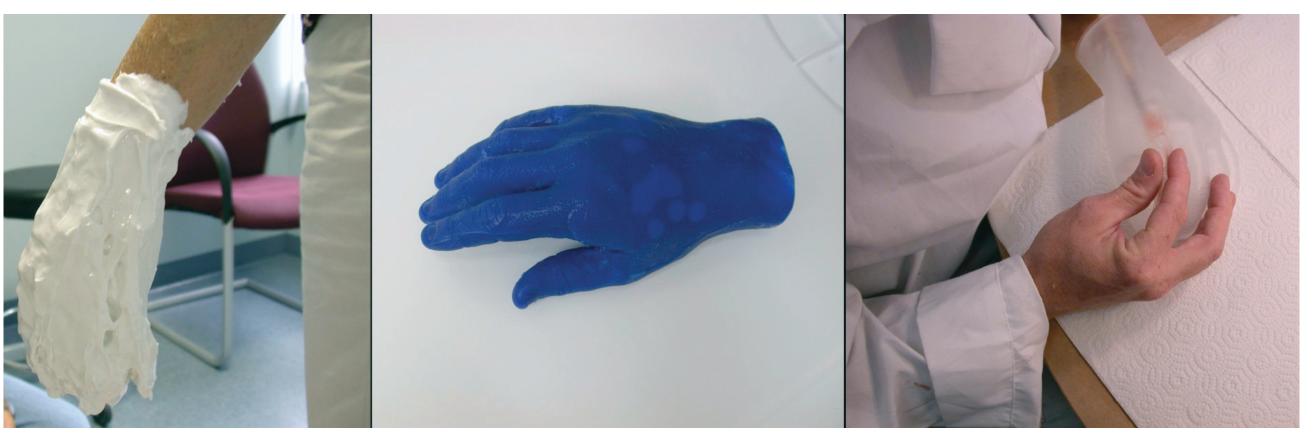

Figure 23-23. Steps in the silicone restoration process: (*left*) impression, (*center*) wax model, and (*right*) custom painting.

or directly to a component manufacturer for diagnosis and repair. This is especially important for the service member who requires a rapid turn-around of repairs because of essential job duties, whether military or civilian in nature.

The following section will address the specific and unique prosthetic requirements for each upper limb amputation level. Level-specific timelines, socket designs, components, and special considerations are discussed.

Level-Specific Recommendations

Finger, Thumb, and Partial Hand Amputations

Finger, thumb, and partial hand amputations comprise a portion of the military amputee population. Current prosthetic treatment approaches have been to create silicone restorations and to explore other mechanical and powered products. Typically, silicone restoration gives the service member some limited function for opposition against any remaining digits. The cosmetic nature of the restoration also gives the service member the appearance of wholeness in public, thus less attention is drawn to the injury. There have been some creative solutions to provide mechanical and powered function for finger and thumb prostheses. The current powered units are disadvantaged by the bulk of battery and controller shapes, as well as by the fragile nature of the components themselves. There are, however, some promising advances being made in this realm. A wide variety of task-specific adaptations for both the environment and a prosthesis have also been created to facilitate functioning for this population in ADLs, vocational activities, and avocational activities (Figures 23-24 to 23-26).

Figure 23-24. Custom-fabricated, task-specific hockey prosthesis.
Photograph: Prosthesis provided by Advanced Arm Dynamics, Inc, Redondo Beach, California.

Figure 23-25. Advanced Arm Dynamics powered fingers.
Photograph: Prosthesis provided by Advanced Arm Dynamics, Redondo Beach, Inc, California.

Styloid Disarticulation

The styloid disarticulation level has the benefit of an intact distal radial-ulnar joint, which preserves pronation and supination. Generally, the length of the residual limb will preclude the use of an electric wrist rotator or quick disconnect-style wrist unit to maintain length symmetry between the electric prosthesis and the noninjured limb. Because a quick disconnect wrist unit cannot be used, separate electric prostheses must

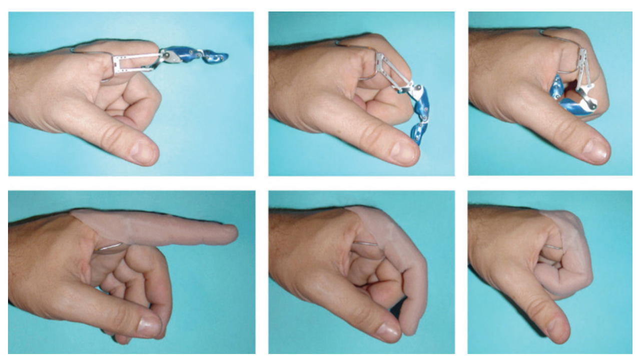

Figure 23-26. (*Top*) Body-powered X-Finger without silicone covering and (*bottom*) body-powered X-Finger with silicone covering (patent pending).
Photographs: Courtesy of Didrick Medical, Inc, Naples, Florida.

be fabricated for each TD. Without electric wrist rotation, it is imperative for the socket to allow anatomical rotation. This is best achieved through the use of a self-suspending suction socket that terminates distal to the olecranon and epicondyles. Suction is achieved through purchase over the styloids, with donning aided by the use of an evaporative moisture technique. In the case of a styloid-level, body-powered prosthesis—with the socket design's inherent suspension qualities—most often a figure-of-nine harness is used for control of the TD (Figure 23-27). There are occasions when heavy lifting will require an auxiliary figure-of-eight, with triceps cuff and flexible hinges to assist in load bearing. There are also cases in which a silicone suspension sleeve worn over the outside of the prosthesis has proven useful. Significant challenges exist if the styloid-level amputee lacks the ability to supinate and pronate or if the prominence of the styloids is insufficient to achieve suspension and rotational control. Therefore, it is important for the styloid disarticulation-level amputee to be carefully evaluated for appropriate suspension in the prosthetic design (Table 23-8).

Transradial Amputations

Transradial amputations are the most common level for upper extremity amputations proximal to the hand. Absence of the styloids creates the need for additional suspensory elements in the design of the prosthesis. This is most commonly achieved through self-suspending socket designs that use the bony anatomy of the elbow and proximal forearm contours to suspend the prosthesis. The surgical considerations covered earlier in this chapter define the optimal length of transradial level residual limb for use of componentry. Because of the shorter radius and ulna and damage to the interosseus membrane, anatomical pronation and supination are absent. To compensate for this deficiency, active or passive rotation must be provided for the amputee to preposition the TD.

Figure 23-27. Preparatory styloid-level myoelectric prosthesis.
Photograph: Prosthesis provided by Advanced Arm Dynamics, Inc, Redondo Beach, California.

For the electric prosthesis, an anatomically suspended dynamic muscle-contoured interface design—utilizing compression anterior to the epicondyles and superior to the olecranon and through the cubital fold—is often used. There are specific contours to allow hypertrophy of the remaining musculature in the residual limb. This socket design provides the best methodology to ensure superior suspension and skin to electrode contact throughout the range of motion.[19] To enhance comfort and range of motion, a window (referred to as a modification) can be removed from the socket about the olecranon. Residual limbs that are not suited for this type of prosthetic interface can, in some cases, be treated with silicone roll-on liners. Production and custom versions of these liners can be considered for short or irregularly shaped limbs.

Patients may prefer to use the same socket design for all of their prostheses. When the dynamic muscle-contoured socket is preferred, it is typically used with a figure-of-nine harness in the body-powered application. It is more common, however, to incorporate a silicone/urethane suction liner with a pin-lock system for the body-powered prosthesis. A figure-of-nine harness can also be used with this socket design, although there are occasions when heavy lifting will require an auxiliary figure-of-eight harness with triceps cuff and flexible hinges to assist in load bearing (Table 23-9).

Elbow Disarticulations

Amputations at the elbow disarticulation level have a unique advantage for suspension and natural humeral rotation countered by the loss of any powered prosthetic elbow options. The remaining humeral epicondyles can be used to achieve anatomical/suction suspension. Suction is achieved through purchase over the epicondyles, with donning aided by the use of an evaporative moisture technique or a reduced friction pull sock. Suspension is achieved by a combination of a bony lock proximal to the condyles and suction, generally eliminating the need for an auxiliary suspension harness. In the case of an elbow disarticulation-level, body-powered prosthesis with the socket design's inherent suspension qualities, a figure-of-eight harness is most often used for control of the elbow, elbow

TABLE 23-8

PROSTHETIC RECOMMENDATIONS FOR THE STYLOID DISARTICULATION LEVEL

Phase	Styloid Level
1	**EPOP Electric*** Flexible thermoplastic inner socket, one-way mini-expulsion valve, rigid thermoplastic frame Anatomically contoured, self-suspending suction/evaporative moisture donning technique Myoelectric control, dual-site with two viable EMG outputs (other control options are used for patients who do not have two myo-sites) EPOP used until the residual limb can sustain greater pressures from the tighter fitting preparatory prosthesis Due to the lack of quick disconnect capability, terminal devices must be associated with separate sockets and frames, ie, microprocessor-controlled hand prosthesis, microprocessor-controlled powered prehensor prosthesis, microprocessor-controlled work hook prosthesis
2	**Preparatory Electric*** Similar fabrication as EPOP with more aggressive suspension design Multiple socket adjustments/replacements continue until residual limb volume has stabilized
3	**Body-Powered** Fit concurrent with definitive fabrication of electric prosthesis Flexible thermoplastic inner socket, one-way mini-expulsion valve, carbon fiber frame Anatomically contoured, self-suspending suction/evaporative moisture donning technique Titanium VO hook, VO hand, titanium VC hook, stainless-steel quick disconnect locking wrist, limited friction cable
4	**Definitive Electric*** Flexible thermoplastic inner socket, one-way mini-expulsion valve, carbon fiber frame Anatomically contoured, self-suspending suction/evaporative moisture donning technique
5	**Silicone Passive** Fit and deliver definitive custom silicone passive prosthesis with suction suspension
6	**Evaluate for Task-Specific Needs**

EMG: electromyographic
EPOP: early postoperative prosthesis
VC: voluntary closing
VO: voluntary opening
*Multiple socket/frames required because of a lack of quick disconnect capability: microprocessor-controlled hand prosthesis; microprocessor-controlled powered prehensor prosthesis; and microprocessor-controlled work hook prosthesis.

lock, and TD. A shoulder saddle and chest strap can be integrated to assist with load bearing and comfort as needed, and is commonly used for the hybrid prosthesis as well (Figure 23-28).

The lack of space for a traditional elbow unit is a challenge at this level of amputation. An elbow unit will typically provide humeral rotation through a turntable mechanism, but the outside locking hinges required for this level do not. Additionally, if the elbow disarticulation-level amputee lacks sufficient prominence of the humeral epicondyles, suspension and rotational control are difficult to achieve anatomically. An externally powered prosthesis at the elbow disarticulation level is, therefore, a hybrid approach because there is insufficient room for an electric prosthetic elbow. Utilization of locking hinges limits the number of elbow-locking positions and often adds significant medial-lateral width, which can be problematic with use of long-sleeved clothing. Specifically, patients have difficulty finding jackets and outerwear that fit over the prosthesis (Table 23-10).

Transhumeral Amputations

At this level of amputation, an elbow system is required. Although there are many elbow systems available, they can be broadly categorized as either mechanical or electrical (Figure 23-29).

A mechanical elbow system requires the amputee to use gross body motions of the shoulder, creating excursion through the harness system to flex the elbow. Electric elbow units provide powered flexion with myoelectric, linear potentiometer, linear transducer, force-sensing resistor, or switch control.

TABLE 23-9

PROSTHETIC RECOMMENDATIONS FOR THE TRANSRADIAL LEVEL

Phase	Transradial Level
1	**EPOP Electric** Flexible thermoplastic inner socket, rigid thermoplastic frame Anatomically contoured self-suspension with reduced friction donning sock technique, dynamic muscle-contoured interface with modification for transradial level Myoelectric control, dual-site, TD/electric wrist rotator switching (other control options are used for patients who do not have two myo-sites) Multiple interchangeable TDs through quick disconnect collar: microprocessor-controlled hand; microprocessor-controlled prehensor; microprocessor-controlled work hook with locking wrist flexion EPOP used until the residual limb can sustain greater pressures from the tighter fitting preparatory prosthesis
2	**Preparatory Electric** Similar fabrication as EPOP with more aggressive suspension design Multiple socket adjustments/replacements continue until residual limb volume has stabilized
3	**Body-Powered** Fit concurrent with definitive fabrication of electric prosthesis Flexible thermoplastic inner socket, carbon fiber frame Anatomically contoured self-suspension with reduced friction donning sock technique, dynamic muscle-contoured interface with modification for transradial level **OR** Silicone suction suspension using roll-on liner with pin-lock system Titanium hook, VO hand, titanium VC hook, stainless-steel quick disconnect locking wrist, limited friction cable (with wrist flexion unit for bilateral) Traditional flexible hinges/triceps cuff and figure-of-eight harness applied for load-bearing applications
4	**Definitive Electric** Flexible thermoplastic inner socket, carbon fiber frame Anatomically contoured self-suspension with reduced friction donning sock technique, dynamic muscle-contoured interface with modification for transradial level
5	**Silicone Passive** Fit and deliver definitive custom silicone passive prosthesis with suction suspension
6	**Evaluate for Task-Specific Needs**

EPOP: early postoperative prosthesis
TD: terminal device
VC: voluntary closing
VO: voluntary opening

Both electric and mechanical units provide passive humeral rotation. Socket design is critical and must allow as much range of motion of the glenohumeral joint as possible while eliminating any socket movement on the residuum. This can be achieved by using a dynamic, muscle-contoured socket that does not encapsulate the shoulder girdle.[20] Suspension of the electric prosthesis is achieved most often with suction suspension and an auxiliary dynamic shoulder saddle and chest strap. Suspension for the body-powered prosthesis can be accomplished in a variety of ways, including a silicone suction and pin-lock system, a figure-of-eight harness and Bowden cable system, or a system similar to that used with the electric design (Figure 23-30).

It is important to note that the force required to flex the mechanical elbow of a body-powered transhumeral-level prosthesis increases significantly, with only a small additional weight in the TD. Therefore, the amputee's residual limb must be carefully evaluated for readiness to accept the increased forces inherent in a body-powered design (Table 23-11).

Figure 23-28. Elbow disarticulation-level amputee with custom silicone restoration.
Photograph: Prosthesis provided by Advanced Arm Dynamics, Inc, Redondo Beach, California.

Humeral Neck, Glenohumeral Disarticulation, and Interscapulothoracic Amputations

Humeral neck, glenohumeral disarticulation, and interscapulothoracic amputations present the most difficult challenges for upper extremity prosthetic rehabilitation. At these amputation levels, there is little if any lever arm available to produce sufficient excursion for control of a body-powered prosthesis. Humeral neck amputations that do not leave sufficient humeral length to control a prosthesis must be fit in the same manner as a complete disarticulation of the glenohumeral joint. Scapular abduction and shoulder elevation can be captured to provide some of the control motions required, but this is often insufficient to provide the excursion required to flex the body-powered elbow joint or open the TD fully. Glenohumeral abduction, flexion, and extension are achieved using a prosthetic shoulder joint. Shoulder joints provide friction-resisted passive abduction/adduction and flexion/extension. Some shoulder joints permit multiple locking positions in the flexion-extension plane. This feature is particularly useful to enable patients to position the TD when operating the prosthesis over their heads.

Stability of the socket on a patient of this level is critical because slight movements between torso and socket are magnified into large motions at the TD. Myoelectrically controlled prostheses require consistent skin-to-electrode contact that is difficult, if not impossible, to achieve when the socket lacks stability. An infraclavicular interface design is the best methodology to provide enhanced stability while reducing surface area coverage, therefore resulting in a lighter weight prosthesis that reduces heat buildup. The infraclavicular design compresses anteriorally through the delto-pectoral region, posteriorally through the spine of the scapula, and inferiorly along the intercostal region.[21] The infraclavicular design is stabilized using a custom synthetic elastic harness.

The elbow joints used in these prostheses are the same as the units used in transhumeral prostheses and are controlled in similar ways. However, as noted previously, many patients have difficulty in achieving sufficient cable excursion to fully operate a body-powered prosthesis at this level. Adaptive devices designed to assist with this limitation include excursion amplifiers, elbow lift assists, and nudge control switches. Often, the prosthetist will resort to powered systems at this level for improved control and functional outcome (Table 23-12).

Bilateral Considerations

Bilateral amputees face a much more difficult rehabilitation process to become fully independent. The amputee does not have a sound limb to rely on or to provide fine prehension and sensory feedback. This creates an immediate need to learn how to operate prostheses to accomplish virtually all ADLs. Although the challenge is greater for bilateral amputees, they generally are also the most motivated because they rarely achieve full independence without mastering the use of prostheses.

The design of the prostheses is crucial because it must allow the patient to perform all ADLs as independently as possible. There is a tendency for the longer residual limb to become dominant in the bilateral amputee, and selecting the appropriate control scheme and prosthetic design for the now dominant side is critical for functionality. Design of the prostheses must allow the patient to bring the TDs to midline and operate them in that position. To achieve this positioning, the prosthetic

TABLE 23-10

PROSTHETIC RECOMMENDATIONS FOR THE ELBOW DISARTICULATION LEVEL

Phase	Elbow Disarticulation Level
1	**EPOP Hybrid** Flexible thermoplastic inner socket, one-way removable expulsion valve, rigid thermoplastic frame, outside locking hinges Anatomically contoured self-suspension (if epicondyles are present) with reduced friction donning sock technique or evaporative moisture technique Shoulder saddle/chest strap harness Myoelectric control, dual-site, TD/electric wrist rotator switching (other control options are used for patients who do not have two myo-sites) Multiple interchangeable TDs through quick disconnect collar: microprocessor-controlled hand; microprocessor-controlled prehensor; and microprocessor-controlled work hook with locking wrist flexion EPOP used until the residual limb can sustain greater pressures from the tighter fitting preparatory prosthesis
2	**Preparatory Hybrid** Similar fabrication as EPOP with more aggressive suspension design Multiple socket adjustments/replacements continue until residual limb volume has stabilized
3	**Body-Powered** Fit concurrent with definitive fabrication of electric prosthesis Flexible thermoplastic inner socket, one-way removable expulsion valve, carbon fiber frame, outside locking hinges Anatomically contoured self-suspension (if epicondyles are present) with reduced friction donning sock technique or evaporative moisture technique Shoulder saddle/chest strap harness Titanium VO hook, VO hand, stainless-steel quick disconnect locking wrist, limited friction cable, wrist flexion unit
4	**Definitive Hybrid** Flexible thermoplastic inner socket, one-way removable expulsion valve, carbon fiber frame, outside locking hinges Anatomically contoured self-suspension (if epicondyles are present) with reduced friction donning sock technique or evaporative moisture technique Shoulder saddle/chest strap harness
5	**Silicone Passive** Fit and deliver definitive custom silicone passive prosthesis with suction suspension
6	**Evaluate for Task-Specific Needs**

EPOP: early postoperative prosthesis
TD: terminal device
VO: voluntary opening

components may be angulated in relationship to the socket, creating preflexion for the TD. Flexion wrist units also improve midline accessibility by bringing the TD toward the head and mouth, which is essential for feeding and grooming activities. Many bilateral patients prefer a myoelectric prosthesis with an electric wrist rotator on at least one side for independent prepositioning of the TD. The body-powered prosthetic wrist unit will require manual positioning of the TD using the environment or another aspect of the body.

Bilateral amputees will also face challenges in donning and doffing their prostheses because they do not have a sound side to aid in the donning of the prosthesis. Rather, they must use their residual limbs to help position the prostheses to be donned. In the case of higher level amputations, it is often helpful to supply a donning stand or tree. The stand provides a place to store the prostheses while not being worn and to position one or both prostheses for donning. For prostheses that require a reduced friction donning

Figure 23-29. Transhumeral-level amputee wearing a definitive, body-powered prosthesis.
Photograph: Prosthesis provided by Advanced Arm Dynamics, Inc, Redondo Beach, California.

Figure 23-30. Transhumeral-level amputee wearing a hybrid prosthesis with myoelectric wrist and TD and body-powered elbow unit.
TD: terminal device
Photograph: Prosthesis provided by Advanced Arm Dynamics, Inc, Redondo Beach, California.

sock, the patient will often use his or her lower extremity to assist in pulling the limb into the socket.

When fitting an electric prosthesis, there are some additional componentry options that require consideration. Bilateral patients often prefer internal battery systems because they do not have to remove and replace the battery—a task requiring a higher degree of dexterity. The internal battery system allows the amputee to simply plug the prosthesis into the charger without removing a battery. When removable batteries are used, it can be beneficial to add on/off or remote power switches to the prostheses. Power switches enable the patient to turn the prosthesis off without having to remove a battery. As previously described, electric wrist rotators offer enhanced function by allowing efficient prepositioning of the TD and should be included as often as possible. Wrist flexion units should also be considered whenever there is room (Figure 23-31).

Sometimes the right and left backup prostheses are harnessed independently for use of one or both prostheses as desired by the patient. This allows for maximum flexibility in combining different types of prostheses, including electric and body-powered devices, as well as use of only one prosthesis at a time. For the combat amputee who often has concomitant injuries, both residual limbs may not be ready for prosthetic intervention at the same time. By harnessing the prostheses independently, the patient may begin prosthetic rehabilitation at the earliest opportunity. Conversely, at higher amputation levels, including bilateral humeral neck or glenohumeral disarticulation levels, amputees may benefit from a socket and harness design that is integrated to facilitate donning, doffing, and suspension. This integration often creates a blending of prosthetic devices and harnessing that is donned and doffed much like a shirt or coat would be, often with the aid of a donning stand or dressing tree.

It is important to include input from members of the interdisciplinary team to design or recommend a variety of assistive devices and modifications to adapt the environment of the bilateral patient for maximum functional independence. It is not unusual to fabricate or provide a custom prosthesis for a specific ADL. An example would be a prosthesis designed specifically for bathing. Home, workplace, and vehicular adaptations are commonly used to promote function and independence in a variety of activities both with and without the use of the prostheses. Complete independence becomes more challenging at higher levels of amputations. Refer to Chapter 18 (Occupational

TABLE 23-11

PROSTHETIC RECOMMENDATIONS FOR THE TRANSHUMERAL LEVEL

Phase	Transhumeral Level
1	**EPOP Electric** Flexible thermoplastic inner socket, one-way removable expulsion valve, rigid thermoplastic frame Anatomically contoured interface with reduced friction donning sock technique Shoulder saddle/chest strap harness Microprocessor-controlled electric elbow unit; linear transducer control of elbow allows simultaneous control with myoelectric TDs or wrist rotator Myoelectric control, dual-site, TD/electric wrist rotator switching (other control options are used for patients who do not have two myo-sites) Multiple interchangeable TDs through quick disconnect collar: microprocessor-controlled hand; microprocessor-controlled prehensor; and microprocessor-controlled work hook with locking wrist flexion EPOP used until the residual limb can sustain greater pressures from the tighter fitting preparatory prosthesis
2	**Preparatory Electric** Similar fabrication as EPOP with more aggressive suspension design Multiple socket adjustments/replacements continue until residual limb volume has stabilized
3	**Body-Powered** Fit concurrent with definitive fabrication of electric prosthesis Flexible thermoplastic inner socket, one-way removable expulsion valve, carbon fiber frame Anatomically contoured interface with reduced friction donning sock technique Shoulder saddle/chest-strap harness Lift-assist enhanced elbow unit Titanium VO hook, VO hand, stainless-steel quick disconnect locking wrist, limited friction cable, wrist flexion unit
4	**Definitive Electric** Flexible thermoplastic inner socket, one-way removable expulsion valve, carbon fiber frame Anatomically contoured interface with reduced friction donning sock technique Shoulder saddle/chest strap harness
5	**Silicone Passive** Fit and deliver definitive custom silicone passive prosthesis with suction suspension or skin traction suspension
6	**Evaluate for Task-Specific Needs**

EPOP: early postoperative prosthesis
TD: terminal device
VO: voluntary opening

Therapy for the Polytrauma Casualty) for specific recommendations regarding therapeutic techniques and modifications for rehabilitation of the bilateral amputee.

Concomitant Considerations

Combat-wounded service members sustaining amputations often have concomitant injuries that can complicate rehabilitation. The following section describes some of the challenges encountered. See Chapter 1 (Developing a System of Care for the Combat Amputee) and Chapter 10 (Medical Issues) for more details.

Loss of Sight

The loss of sight in one or both eyes can significantly challenge a patient's ability to use a prosthesis. In the case of total blindness, the patient cannot use visual feedback that compensates for limited sensory feedback of prosthetic devices to develop prosthetic control skills. Typically, an amputee can observe an object being grasped and/or deformed by the TD and create an impression of the grip force being applied. At the transhumeral level or above, learning to operate an elbow system is also complicated by visual impairment

TABLE 23-12

PROSTHETIC RECOMMENDAITONS FOR THE HUMERAL NECK, GLENOHUMERAL DISARTICULATION, AND INTERSCAPULOTHORACIC LEVELS

Phase	Humeral Neck, Glenohumeral Disarticulation, Interscapulothoracic
1	**EPOP Electric** Flexible thermoplastic inner socket, rigid thermoplastic frame Infraclavicular interface Custom synthetic elastic harness Microprocessor-controlled electric elbow unit; linear transducer control of elbow allows simultaneous control with myoelectric TDs or wrist rotator Myoelectric control, dual-site, TD/electric wrist rotator switching (other control options are used for patients who do not have two myo-sites) Multiple interchangeable TDs through quick disconnect collar: microprocessor-controlled hand; microprocessor-controlled prehensor; and microprocessor-controlled work hook with locking wrist flexion EPOP used until the residual limb can sustain greater pressures from the tighter fitting preparatory prosthesis
2	**Preparatory Electric** Similar fabrication as EPOP with more aggressive suspension design Multiple socket adjustments/replacements continue until residual limb volume has stabilized
3	**Hybrid Prosthesis** Fit concurrent with definitive fabrication of electric prosthesis Flexible thermoplastic inner socket, carbon fiber frame Infraclavicular interface Custom synthetic elastic harness Lift assist-enhanced elbow unit Myoelectric control dual-site, TD/electric wrist rotator switching Multiple interchangeable TDs through quick disconnect collar: microprocessor-controlled hand; microprocessor-controlled prehensor; and microprocessor-controlled work hook with locking wrist flexion
4	**Definitive Electric** Flexible thermoplastic inner socket, carbon fiber frame Infraclavicular interface Custom synthetic elastic harness
5	**Silicone Passive** Fit and deliver definitive custom silicone passive prosthesis with suction suspension or skin traction suspension
6	**Evaluate for Task-Specific Needs**

EPOP: early postoperative prosthesis
TD: terminal device

because it is difficult to ascertain the position of the forearm without visual confirmation. Therefore, it may be necessary to provide additional training on creating feedback through environmental awareness techniques or the use of other body surfaces for proprioception.

Loss of Hearing

Many electrically powered prostheses provide auditory or vibratory feedback for mode changes and low battery warning. Amputees report that, with experience, they learn to use the sounds and/or vibrations produced by the motors of the elbow, wrist rotators, and TDs to provide positional feedback. Whereas both of these techniques take time to learn, they can develop into viable feedback. Auditory feedback may not work for the amputee with hearing loss; but, if vibratory feedback is strong enough to be noticed, it can assist. Generally the amputee with hearing loss, if vision is not affected, will rely on visual feedback for prosthesis position and function.

Figure 23-31. Bilateral upper limb amputee with right styloid-level body-powered prosthesis and left transradial-level myoelectric prosthesis.
Photograph: Prosthesis provided by Advanced Arm Dynamics, Inc, Redondo Beach, California.

Traumatic Brain Injury

It is not uncommon for a blast exposure to result in some level of TBI. Manifestations of TBI are diverse and individually unique based on the area of the brain that is affected. Some symptoms may include personality changes, loss of attention, changes in processing skills, changes in motor function, and frustration intolerance. Expeditious diagnosis of brain injury will allow more effective formulation of the individualized prosthetic and therapeutic rehabilitation plan. This may take the form of specific therapies for information processing, speech, motor control, and behavior modification. Sometimes a center specializing in TBI will be accessed prior to or during the other phases of rehabilitation. Depending on the outcome of more intensive treatments, some severe TBI amputees have successfully reintegrated into the prosthetic rehabilitation setting during or after TBI-specific treatment. It is useful to consider activating and training for one prosthetic component at a time to reduce frustration and encourage repetitive pattern formations. Introducing all of the possible functions of a given prosthesis in one visit may be overwhelming for a patient who has suffered TBI.

Lower Extremity Injury/Loss

Impaired lower extremity function or lower extremity amputation places further demands on the upper extremities for both stability and mobility needs. For amputees sustaining both upper and lower extremity amputations, gait training with a lower extremity prosthesis often requires the upper extremity prosthesis to be fit for safe balance with walking aids. Even those amputees who choose to wheelchair ambulate for a time will often benefit from the assistance of the upper extremity prosthesis to assist in propelling and controlling the manual or powered wheelchair. An upper extremity prosthesis is also useful for donning and doffing a lower extremity prosthesis (Figure 23-32).

Burns/Grafting

Thermal damage to the skin may require grafting and result in significant scar formation. Loss or change of the skin integrity creates range of motion and socket interface tolerance challenges. Silicone or urethane liners are often used to provide a protective barrier between the sensitive healing skin and the prosthetic

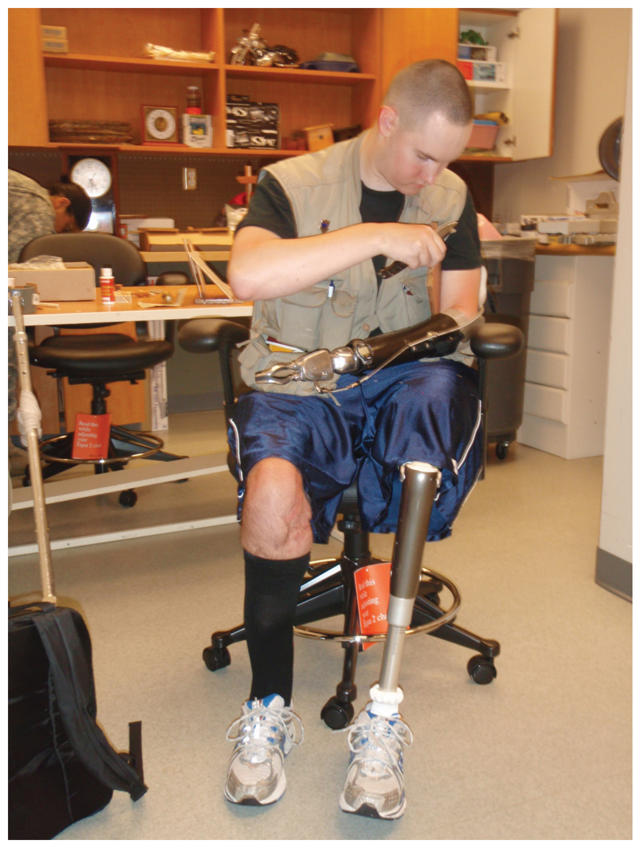

Figure 23-32. Patient with concomitant injuries (unilateral transfemoral-level and styloid-level amputations and shrapnel injuries to the right leg).
Photograph: Prosthesis provided by Advanced Arm Dynamics, Inc, Redondo Beach, California.

and external environment. Caution should be used with these liners if the wounds are open. These liners can trap bacteria and moisture, thus creating a breeding ground for infection that negatively impacts healing graft and scar tissue. Specific occupational therapy modalities for this amputee population may include ultrasound, massage, adherent scar treatments, and graft integrity management (Figure 23-33).

ADVANCED PROSTHETIC PHASE

Team members, including the patient, work together to formulate and execute a comprehensive rehabilitation plan beginning with the patient assessment and concluding with a long-term follow-up plan. Careful coordination and timing of the provision of services among team members result in seamless rehabilitation. Successful prosthetic intervention, combined with therapy protocols, contributes to the highest level of success for all amputation levels. When a rehabilitation plan is carefully executed as detailed in this chapter, it is imperative that functional gains and independence are not lost to follow-up.

Advanced prosthetic care is initiated after all definitive prostheses have been provided to the individual. Traditionally, this has been the end of initial prosthetic intervention; however, given our experience with service members rapidly returning to their previous lifestyles or attempting new vocational and avocational goals, advanced prosthetic protocols must be initiated sooner during the rehabilitation process. It is recommended that each service member be assigned a case manager or patient care coordinator who should contact the patient on a regular basis to ascertain his or her satisfaction with prosthetic function, fit, and overall condition. Specific issues that must be addressed include the following:

- volumetric changes resulting from residual limb maturation and/or weight fluctuation;
- repair or replacement of worn components;
- availability of new technology, as indicated for improved function;
- ongoing needs for therapeutic intervention; and
- new vocational and avocational requirements (Figure 23-34).

Figure 23-33. Patient with burn scar.

Advanced Prosthetic Phase Considerations

Residual Limb Stabilization

Because of the nature of the blast wound, and the progressive care model implemented by the military following wound closure, the amputee's residual limb is often extremely edematous. Throughout the Preprosthetic and Interim Prosthetic Phases, significant focus is therefore placed on reducing residual limb edema. Once residual limb edema stabilizes and the muscles cease to atrophy, the patient is ready to receive the definitive versions of the prostheses. After prolonged use of the definitive prostheses and full reintegration back into an active lifestyle with resolution of concomitant injuries, it is not uncommon for the muscles in the residual limb to hypertrophy. This is particularly notable in the myoelectric system, as prolonged use of EMG control results in muscle hypertrophy. The patient is also likely to gain weight as he or she returns to a normal diet, further changing residual limb size. Consistent communication with the service member following the delivery of the definitive prostheses is essential to ensure that volume changes secondary to hypertrophy or weight gain can be addressed in a timely manner. It is therefore

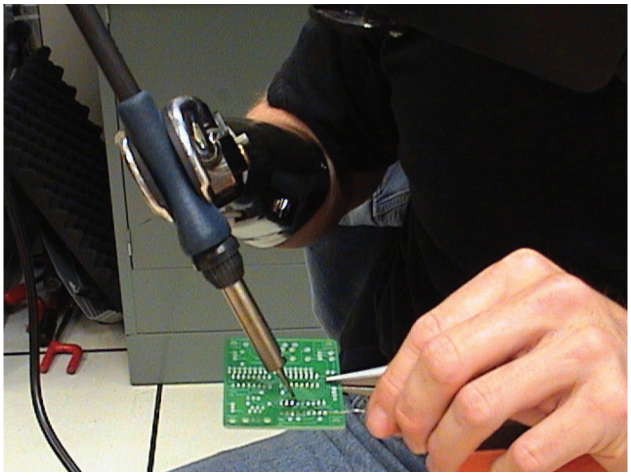

Figure 23-34. Advanced skills using a prosthesis.

important for the service member to have access to timely prosthetic care. The patient care coordinator should be able to arrange care in an expeditious manner so that prosthetic use is not interrupted. Significant lapses in care may lead to discontinuing prosthetic use because of comfort and control problems.

Self-Selection

The military model provides amputees with electric/hybrid, body-powered, and passive prostheses. Thorough training is absolutely essential to successful use of all three prostheses. Once competency has been reached, it is common for the service member to select which prosthesis will be used for certain activities. Often, the service member will alternate use of all three prostheses to meet the functional demands of daily life. Each amputee is unique, and it is not possible, nor is it prudent, to try to predict which single device will meet each amputee's current and evolving needs. Should an amputee self-select one type of prosthesis for a majority of activities, provision of a backup prosthesis should be considered to prevent discontinuation of prosthetic use when regular maintenance is required.

Challenges to Rehabilitation

Interruptions to the Rehabilitation Process

Prosthetic rehabilitation of the military amputee is often challenged by various interruptions. These interruptions may include convalescent leave, wound breakdown because of graft failure or infection, and the frequent need of additional surgeries to the residual limb or for other comorbid injuries. Additionally, problems such as the formation of heterotopic ossification (HO) or migrating retained fragments within the limb may impair prosthetic training. Concomitant injuries may take precedence over prosthetic interventions and delay rehabilitation until they are adequately resolved. Depending on the length of absence from prosthetic rehabilitation and the point at which the interruption occurs, the patient may require review and relearning of previously learned skills. Members of the rehabilitation team should make every effort to minimize delays and promote consistent communication to all members of the team, including patients and their families.

Residual Limb

The nature of blast wounds results in a residual limb that presents unique challenges. As discussed previously in this chapter, the resultant residual limb has significant edema that often contributes to pain issues. Proper edema management using ace wrap, elastic tubular sock, and silicone/urethane roll-on liners is necessary. Suture line breakdowns can be prevented with careful and regular monitoring. There may be times when prosthetic use must be temporarily suspended if the healing suture line is at risk. In addition, progression from an electric prosthesis to a body-powered prosthesis should be predicated on soft-tissue healing, especially surrounding the suture line.

In some cases, traditional socket designs may not provide effective suspension if the transradial limb is too short or irregularly shaped. At this level, custom silicone liners can often resolve challenging fitting issues. When used with specifically designed electrodes, custom liners can be helpful in providing a secure foundation on which to build the EPOP. If successful, this design can be carried forward into the preparatory and definitive phases. Custom silicone liners without electrodes can also be used for other types of prostheses. Very short transhumeral or humeral neck residual limbs are often best fit using infraclavicular interface techniques normally applied to glenohumeral disarticulation and higher amputation levels.[21]

Neuroma

Following nerve transection, neuromas typically occur as axons at the nerve ending attempt to regenerate. Symptomatic neuromas can often interfere with prosthetic use and function. They are usually identifiable by palpating or tapping the residual limb and replicating symptoms. If suspected, neuromas should be evaluated by a physician on the team, because treatment strategies should be used. Some common treatment approaches include oral medication and local steroid and anesthetic injections. Surgical resection may be necessary if there is no resolution of functionally limiting pain.[2(p61),22,23]

Heterotopic Ossification

HO seems to be more prevalent in amputees who have sustained a blast injury, and its presence may significantly impact the prosthetic rehabilitation process. HO is characterized by rapid and excessive bone growth throughout the residual limb. Bone growth is random and often so extensive that protrusions through the skin are not uncommon. Use of three-dimensional imaging technology and computed tomography scan can provide the rehabilitation team with an accurate three-dimensional model of HO formation and skeletal structure change. The three-dimensional model can be particularly useful in solving prosthetic socket-fitting issues resulting from the development of HO. Some amputees may require additional surgery to remove the bony growth should it affect range of motion or cause increased pain[24,25] (Figure 23-35).

Surfacing Shrapnel

Similar to the challenges associated with HO, blast wound injuries can also exhibit surfacing shrapnel. Dependent on the size and location of the fragments that are surfacing, socket modification may be needed, minor surgeries may be necessary, or prosthetic use may be temporarily suspended until the shrapnel is removed and the residual limb has healed.

Emotional Stressors (Psychosocial)

The less physical, but deeply important, aspect of amputation sustained in military action involves the psychosocial and emotional effects on the amputee. It is critical that each member of the team be aware of the status and treatment of the amputee from the psychological services team professionals. This will facilitate awareness of how service members best learn, what might unnecessarily frustrate them, and how the effects of their personal combat experience might compromise the aggressive rehabilitation plan.

FUTURE INNOVATIONS

Currently, there is a tremendous focus by independent research groups, DARPA (Defense Advanced Research Projects Agency), innovative prosthetic clinicians, and manufacturers to advance technology specific to the upper extremity amputee population. Areas of technological promise are aimed at increasing the degrees of freedom in componentry, as well as on the mechanisms for control, including:

- compliant hands,
- powered wrist units,
- powered shoulder and elbow joints,
- pattern recognition,
- targeted muscle reinnervation, and
- implantable electrodes.

Compliant hands allow for enhanced prehension patterns by powering independently articulating digits that can close around objects of various sizes and shapes. Powered wrist units that duplicate the complex movements of the human wrist (including rotation, flexion/extension, and radial/ulnar deviation) are currently being created and tested. Electrically powered elbow and shoulder joints that provide additional degrees of freedom will add functional capability for higher level amputees.

Although the evolution of these components is exciting and promising, the benefits of this technology will not be fully realized without advances in control schemes. Pattern recognition is an approach that uses the unique EMG signal patterns produced by specific muscle group contraction within the residual limb. Currently, between six and eight reproducible patterns can be captured and trained to control up to six degrees of freedom. Pattern recognition is limited by the number of surface electrodes that can remain in contact with the skin and the amount of processing power currently available within an electric prosthesis. One approach to address these challenges is targeted muscle reinnervation (Figure 23-36). This is a surgical technique that separates muscle tissue within the residual limb and reinnervates newly created sections of the muscle bellies with nerves previously used to control (innervate) the now amputated limb.[26] In another effort to address the limitations of surface electrodes, implantable electrodes are being developed that will use telemetry to transfer control information to the prosthesis. These exciting developments will undoubtedly benefit patients both now and in the future. It is the responsibility of rehabilitation team members to advance their knowledge, skills, and practices to apply these technologies effectively.

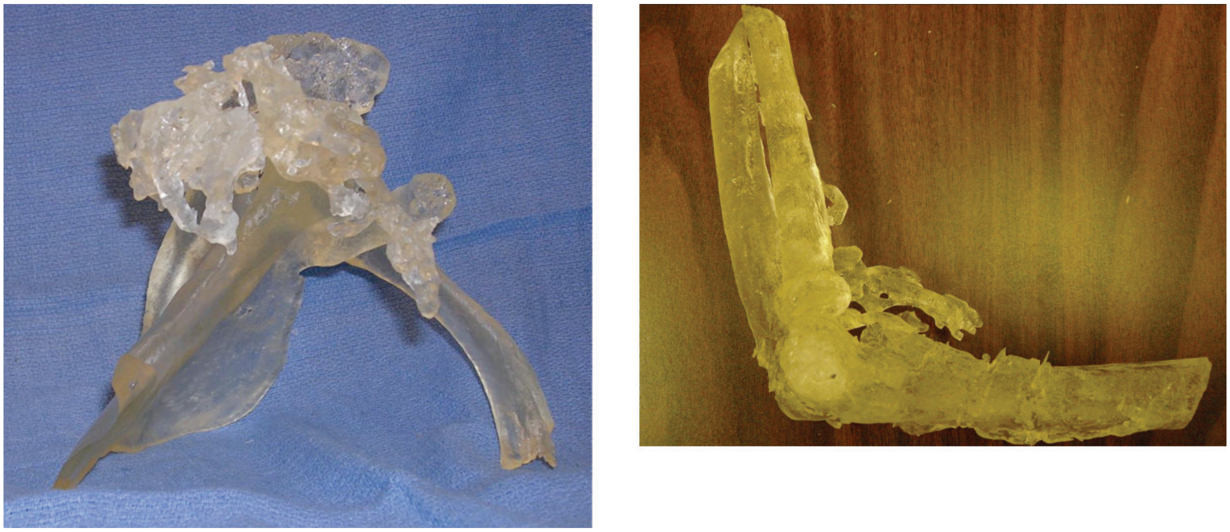

Figure 23-35. (*Left*) Model of heterotopic ossification in the area of the scapula and clavicle. (*Right*) Model of heterotopic ossification from a transradial-level amputation.

SUMMARY

The lifesaving benefits of body armor and battlefield medicine are unprecedented. In response to the increasing rate of survival with limb loss, upper extremity prosthetic treatment protocols have advanced to a new level of comprehensive care (Figure 23-37). The unique requirements and challenges presented by the military amputee population also influence the rehabilitation approach to prosthetic management (as outlined in this chapter). Preprosthetic Phase, Interim Prosthetic Phase, and Advanced Prosthetic Phase management using state-of-the-art prosthetic technology and techniques combined with aggressive therapy enable the amputee to reintegrate into a fulfilling life as successfully and rapidly as possible. Treatment protocols call for expedited care and the delivery of electric, body-powered, and passive prosthetic options with thorough training to maximize rehabilitation potential. A review of prosthetic categories with specific recommendations for socket design and component integration for each amputation level has been presented. It must also be understood that this young and motivated patient

Figure 23-36. Captain Katie Yankosek, MS, OTR/L, CHT, at Walter Reed Army Medical Center with Jesse Sullivan, a research volunteer who has undergone targeted muscle reinnervation and is wearing a prototype prosthesis.

Figure 23-37. Through progressive military prosthetic rehabilitation, some service members can return to active duty.

group is helping to drive the field of upper extremity prosthetics forward. Many military amputees are participating actively in cutting-edge research and development projects, exploring (independently) alternative prosthetic solutions, becoming involved in the political arena, and pursuing careers in related fields. Their contributions in these areas will continue to challenge and inspire not only the interdisciplinary rehabilitation teams involved in their care, but also the prosthetic industry as a whole.

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