Chapter 21

Amputations About the Shoulder: Prosthetic Management

John M. Miguelez, CP Michelle D. Miguelez, JD Randall D. Alley, CP

Introduction

The prosthetic rehabilitation of an individual with a humeral neck, glenohumeral, or interscapulothoracic level of absence has traditionally been a significant challenge to the rehabilitation team, often resulting in poor success rates. Each of these levels is anatomically unique, but the overall approach to the prosthetic management is similar (Figure 1). This chapter describes the three phases of prosthetic management that are critical to long-term prosthesis use and patient satisfaction: (1) the preprosthetic phase, during which the prosthetic rehabilitation plan is formulated; (2) the interim phase, during which the diagnostic prosthesis, which evolves into the definitive prosthesis, is created; and (3) the postprosthetic phase, during which the focus is on prosthetic refinement and training. The systematic method of care described in this chapter can maximize the patient's prosthetic rehabilitation potential.

Preprosthetic Phase

The preprosthetic phase includes the physical assessment of the patient, a thorough consideration of prosthetic design criteria, a discussion of prosthetic options and components, and, finally, the formulation of the prosthetic rehabilitation plan. The physical assessment of the individual with upper limb absence is one of the most crucial aspects of the rehabilitation process, because this is when information is gathered, both clinically and through open dialogue, that serves as the basis for subsequent rehabilitation. Failure to devote sufficient time and focus to the preprosthetic phase has directly contributed to the historically suboptimal prosthetic success rates for individuals with limb absence or amputation at the glenohumeral and associated levels.

Assessment

Initially, the practitioner should record not only the level(s) and side(s) of involvement but also whether or not a loss of dominance occurred. An overall health assessment should be made, and particular attention should be paid to cardiac and associated circulatory health because such proximal levels of limb loss require the user to expend considerable effort during operation of a body-powered or hybrid prosthesis. Ipsilateral considerations include the cause of absence, the date and extent of injury if applicable, tissue condition, range of motion and strength (for gross movement as well as the myoelectric signal), and any associated discomfort or sensitivity related to the region, whether from contact pressure, potential weight bearing, or motions required for operation of the prosthesis. All of these elements are vitally important when considering

not only the socket design but also the control strategy. The extent of contralateral limb loss, deficiency or other involvement, and the degree of function present should be noted. All the considerations that apply to the ipsilateral remnant are relevant to the contralateral limb, as harnessing design and control strategies must incorporate contralateral involvement. Lower limb deficiencies also play a significant role in balance, donning and doffing, and general upper limb component selection. For example, the prosthesis for an individual with an upper limb deficiency who uses a cane or a walker should have sufficient prehensile grip to withstand the forces applied to these balance aids.

Myotesting is important to determine the feasibility of using myoelectric control. The information myotesting provides is also important as a feedback tool for teaching and training and is a quantifiable assessment of patient progress. The interaction of the myoelectric signals during agonistic and antagonistic contractions in each relevant muscle or muscle group must be assessed, not simply the amplitude of a single channel in isolation. (Agonist and antagonist are loosely defined here as they relate to prosthetic function, which may or may not differ from physiologic function, depending on the muscle or muscle groups involved.) Finally, the practitioner must define the optimal



Figure 1 Typical clinical presentation of residual limb at the humeral neck (A), shoulder disarticulation (B), and interscapulothoracic levels (C).



Figure 2 Infraclavicular socket showing electrode placement.

placement of electrodes within socket confines, taking into consideration comfort from electrode contact pressure and the consistency of contact under varying conditions (Figure 2). This is discussed more fully later in this chapter.

The prosthetist should discuss the limitations of terminal devices and other components to help the patient develop a realistic set of expectations. The tendency to become "onehanded" and overuse the unimpaired limb should be discussed during the assessment. Important prosthetic design considerations include whether donning and doffing will be assisted or unassisted and whether any movements are to be avoided during this process. The availability of assistance from family, friends, or others should be considered. Any prior prosthetic experiences, such as the option used, the socket design, and the patient's perception of its effectiveness, comfort, and ease of use should be discussed and noted.

The patient's level of cognitive ability may also limit the options appropriate for successful prosthetic use. Therefore, another goal of the evaluation is to understand the various control schemes and their cognitive demands on the user.

The vocational and avocational pursuits and personal desires of the individual must be discussed thoroughly during the patient assessment. Individuals with similar levels of limb absence may require completely different strategies to attain a successful result. In addition to the obvious physical issues of choosing suitable components, psychological and psychosocial elements must be considered carefully when designing the appropriate prosthesis.¹ The loss or absence of a limb at any level, whether from an acquired amputation or congenital deficiency, dramatically affects an individual's body image and self-esteem, and this psychological impact should be a primary focus of the evaluator.

Therapeutic intervention during the preprosthetic, interim, and postprosthetic phases is critical to the prosthetic rehabilitation of the individual with absence at the glenohumeral or associated level. The presence of an occupational therapist during the assessment is very helpful in the psychological, physical, and psychosocial preparation of the individual. Preprosthetic therapy should include strength training of the ipsilateral side, the contralateral upper limb, and the lower limbs; maintenance and enhancement of range of motion; desensitization techniques; edema control; and, if necessary, wound care.

Unfortunately, patient information on the various aspects of upper limb prosthetics is limited. Therefore, the practitioner should spend considerable time educating the patient about the basics of casting, fabrication, delivery, postprosthetic procedures, available technology, and potential functional gains and other attributes for each option.

Components

Regardless of the prosthetic option or control strategy selected, prostheses for these levels require components at the shoulder, elbow, and wrist as well as a terminal device. The three basic shoulder joint options are nonarticulated, friction, and locking. In some situations, such as for children or for the patient requiring an activityspecific prosthesis, a nonarticulated shoulder is preferred because this minimizes the added weight, bulk, and complexity of this portion of the artificial limb. A friction shoulder joint (Figure 3) allows the patient to position the arm in space, which is helpful for eating, self care, and other tasks. The friction shoulder joint is the simplest articulated joint, but it has the disadvantage that the contralateral limb must be used to assist with positioning. A locking shoulder joint allows the patient to position and then lock the humeral section in space, permitting bimanual activities. The locking mechanism can be activated by using a nudge control with the chin. Biscapular abduction, shoulder elevation, and humeral remnant motion including flexion, extension, and abduction can be captured through a harness system to activate a pull switch. The nudge lever and the pull switch are offered in either mechanical or electric locking versions. The latter requires significantly less excursion and force but is heavier and more complex.

Far more excursion and force are required to activate a body-powered elbow than an electric-powered one. At these high levels, the skeletal lever arm is sufficiently compromised that many patients find it difficult, if not impossible, to produce sufficient excursion to fully flex and lock a bodypowered elbow. Without the use of a multiposition elbow, the amputee cannot effectively position the terminal device in space to accomplish activities of daily living. In the past, an excursion amplifier was sometimes used to compensate for the reduced excursion available at these levels. The improved excursion required the user to generate increased force, however, which many found objectionable. In recent decades, electric-powered elbows have been more widely used for such highlevel fittings because they require far less effort to operate than does a bodypowered component, with or without an excursion amplifier.

The four basic wrist units are friction, locking, flexion, and quickdisconnect. A wrist unit allows the user to position the terminal device using the contralateral hand or compensatory gross body movements, expanding the user's functional envelope. The selection of a wrist unit is based on the functional requirements of the patient, not the level of amputation or deficiency.

Hooks generally have been considered more functional than bodypowered hands. The prehension pattern was considered superior for activities of daily living that involve precision. In addition, patients and rehabilitation professionals preferred hooks because of their more rugged design and usefulness for heavy-duty activities. The preference for hooks is especially pronounced with bodypowered prostheses because bodypowered hands provide less grip force and require significantly greater excursion and force to operate. Therefore, patients with these high levels of absence often find body-powered hands difficult to operate because of the inherently short lever arm of the residuum at these levels. Because electric-powered hands offer increased grip force yet require less gross body motion to operate, they have been used more widely during the past several decades for individuals with amputations and deficiencies at these levels.

Prosthetic Options

It is imperative to discuss the prosthetic options available to facilitate the patient's participation in the rehabilitation process. Primary prosthetic options include independence without a prosthesis, use of a passive prosthesis, or use of an active prosthesis. Active prostheses can be further classified by the control method provided: body-powered, externally powered, or a hybrid system combining both body- and externally powered components. Some patients prefer an activity-specific prosthesis optimized for one task. These devices may incorporate active or passive terminal devices.

Independence Without a Prosthesis

The choice not to wear a prosthesis is an important option. Individuals who



Figure 3 Infraclavicular socket with passive ball-and-socket friction shoulder joint.

have experienced complete loss of the arm or who were born with such high-level absence may find the discomfort of high-level prostheses too great an obstacle to overcome. The loss of tactile sensation caused by wearing a socket can be another reason for rejection of a prosthesis. Many high-level amputees find that an active prosthesis offers only limited functional advantages.

Passive Prostheses

Many types of passive prostheses are designed for individuals with high levels of limb absence (Figure 4), including shoulder caps, which are often used as cosmetic restorations at the shoulder disarticulation and interscapulothoracic (ISO term: forequarter) levels. The most common reasons an individual with a highlevel loss opts for a passive prosthesis over an active one are reduced weight, improved cosmesis, and reduced energy and cognitive requirements. Initial, maintenance, and repair costs are typically lower than for other types of prostheses, although a high-definition silicone restoration may be more expensive than a simple mechanical prosthesis. The passive prosthesis offers little or no pinch force. Some passive prostheses have embedded wires in the hand component that allow prepositioning of the prosthetic digits by shaping the fingers manually.



Figure 4 Example of a passive prosthesis; harness for suspension is not pictured.

(Active) Body-Powered Prostheses

Operating body-powered prostheses at the humeral neck, glenohumeral, and interscapulothoracic levels presents a daunting challenge: generating enough force and excursion to activate the body-powered elbow, wrist, and hand components (Figure 5). Because of the absence of the skeletal lever arm and limited available excursion, the functional envelope is significantly reduced. Maximum elbow flexion is often difficult to achieve, as is any amount of abduction, because of the absence or limited length of the humerus.

The harness that is used at this level must provide maximum efficiency and hence is often fairly restrictive. Users may find it uncomfortable, especially in the contralateral axilla, which is often used as an anchor point. Compression of the nerve bundle in this region can result in nerve entrapment syndrome, in which anesthesia can occur if a sensory nerve is affected, and paralysis if a motor nerve is involved.²

Significant energy expenditure is also required to operate a bodypowered prosthesis at these proximal levels of limb absence. This can be a contraindication for individuals whose capacity has been diminished as a result of disease or medications, for those who have contralateral involvement, or for the elderly, who may simply not possess enough strength for adequate function.³ In addition, cosmetic appearance is limited, at best, and the gross body movements required for actuation call attention to the artificial limb.

and hand. The shoulder and wrist are

passive friction joints.

One of the most significant advantages of a cable and harness system is the inherent feedback. The commonly used hook terminal device allows for greater visibility when acquiring, manipulating, or grasping objects. Bodypowered prostheses are more durable than are electric-powered prostheses. Body-powered prostheses weigh less, and this weight is distributed more optimally than it is in most hybrid and electric-powered designs. Bodypowered elbows can be flexed more rapidly than electronic elbows, although at extremely high levels the lack of sufficient excursion may negate this potential advantage.

Harness and cable systems do not require battery charging, installation, or removal, or the dexterity and the cognitive ability required to perform these operations. Finally, the initial, maintenance, repair, and replacement

Figure 6 Example of a hybrid prosthesis with locking shoulder joint, body-powered elbow, and externally powered wrist and terminal device.

costs for body-powered prostheses are almost invariably less than for their electric-powered counterparts.

(Active) Hybrid Prostheses

A hybrid prosthesis has both bodypowered and electronic components. The most common configuration incorporates a body-powered elbow and electric-powered terminal device (Figure 6). Hybrid prostheses offer the advantages of both body-powered and electric-powered prostheses while minimizing their disadvantages. Hybrid prostheses are a viable option even for patients with amputations at the humeral neck and higher when adequate strength and excursion remain.

Combining the two types of control has several potential advantages. The use of an electronic terminal device reduces the harnessing needed because body-powered motion is required only to flex the elbow. The functional envelope is enlarged in many instances, particularly when myoelectric control is feasible. Pinch



force is also much greater with an electronic device than is possible with voluntary-opening body-powered, terminal devices. Also, an electronic terminal device usually provides both voluntary opening and voluntary closing, a more natural reproduction of human hand movement. Operating the terminal device via myoelectric control is believed to improve muscle tone and reduce disuse atrophy. Advantages of the body-powered elbow are that it provides more rapid flexion/extension movements, gives the user important sensory feedback from the harness forces, and reduces the overall weight of the prosthesis. Also, the initial, maintenance, and repair costs of the system are less because an electronic elbow is not needed. Finally, a hybrid control system can encourage simultaneous operation of the elbow and terminal device.

(Active) Externally Powered Prostheses

Electric-powered components minimize the energy expenditure and discomfort associated with a control cable and harness (Figure 7). Both static and dynamic cosmesis are improved when a control cable is not required for either terminal device or elbow operation. Like hybrid systems, a myoelectric system offers increased pinch force, voluntary opening and closing, and, although a prosthetic shoulder joint permits only passive positioning, the potential for an even greater functional envelope.

A myoelectric elbow has the disadvantage of lacking the direct feedback offered by a harness and cable system, although indirect feedback is still available based on input effort, duration of supplied signal, elbow vibration, and sound. The weight of a fully electronic system is considerable, and care must be taken to ensure that the socket provides at least partial suspension to minimize the weight borne by sensitive areas. In addition, every externally powered prosthesis has battery installation, removal, and



Figure 7 Example of an externally powered prosthesis with locking shoulder joint plus myoelectric elbow, wrist, hand, and interchangeable electronic lock terminal device.

maintenance requirements, and operation of the primary and secondary electronic controls can impose a substantial cognitive demand on the user. Despite these disadvantages, many individuals with glenohumeral-level absences do well with completely electronic prostheses.

Activity-Specific Prostheses

Activity-specific devices include recreational prostheses and those designed to facilitate work tasks or activities of daily living. Activityspecific prostheses are very effective in accomplishing the specific tasks for which they are designed. Because these prostheses usually require only simple controls and minimal components, they are often less costly than more complex designs (Figure 8). The chief disadvantage of an activityspecific prosthesis is that it has limited utility. Interchangeable activityspecific prostheses can help to address this limitation.

Design Considerations

The foundation for successful prosthesis use is the socket. Unless the socket is comfortable and securely suspended, the prosthesis will not be



Figure 8 Activity-specific terminal device for playing billiards. (*Courtesy of Bob Radocy.*)

worn on a sustained basis. At the glenohumeral level, the key to achieving stability is an intimately fitted socket that provides rigidity in load-bearing areas and serves as a secure platform for anchoring components.⁴

Individuals with amputations and absences at the glenohumeral and associated levels have reported many problems with long-term prosthesis use. Frequently mentioned issues include the weight of the prosthesis, heat buildup within the socket, lack of stability, reduced control of the terminal device in certain planes and body positions, and difficulty in independent donning. The socket design must distribute the load primarily over areas with sufficient tissue padding while eliminating excessive pressure on skeletal protuberances. Heat buildup while wearing a prosthesis is directly related to the amount of skin covered by the socket and the resulting lack of heat dissipation. Therefore, reducing the surface area of the socket can greatly improve comfort and patient acceptance. Lack of stability and reduced control of the terminal device in certain planes and body positions are both results of a socket that changes position during movement. Without a stable socket, the efficiency of the harness system is greatly reduced. Consequently, the wearer must produce more gross body movement to operate the prosthesis, resulting in increased fatigue and frustration. With improved socket stability, a less complex harness system may be sufficient, which facilitates the donning process.



Figure 9 Early body-powered socket design demonstrating extensive coverage of the ipsilateral torso.

To create an effective prosthesis, the prosthetist must be able to assess the many design criteria both individually and as they relate to one another. The harness system must be determined during the preprosthetic phase, as this will influence the socket design. The harness is especially critical in bilateral deficiencies or when significant areas of scarring or skin graft are present. With amputations at the humeral neck (see Case Study 2), the remnant humerus can often be used for primary or secondary control strategies, which may affect component selection and socket design. Finally, it is important to clarify the patient's cosmetic expectations for the prosthesis because these considerations may also affect component selection, socket design, control strategies, and long-term acceptance. The optimal socket is the one that balances these interrelated goals to meet the needs of the individual amputee.

Formulation of the Rehabilitation Plan

The preprosthetic phase culminates with the formulation of a detailed prosthetic rehabilitation plan. Comprehensive evaluations by the other



Figure 10 Body-powered socket design covering less of the torso surface area than did early designs.

members of the rehabilitation team, including the physician, the physical and occupational therapists, the psychologist, and the rehabilitation coordinator, should be concurrent with the prosthetic assessment. Interaction and communication among rehabilitation team members is critical to success at these levels. Once all members of the rehabilitation team have offered their recommendations, a final rehabilitation plan can be formulated. The recommendations must take into account the patient's physical capacity and willingness to commit to what is often a rigorous fitting and training schedule.⁵ A patient who has a sense of control and active participation in the formulation of the rehabilitation plan is more likely to put forth the effort necessary to execute the plan successfully.

The rehabilitation plan integrates the patient's prosthetic, therapeutic, psychological, and medical needs based on short- and long-term goals. Prosthetic options affect occupational therapy, physical therapy, and psychological counseling.⁶ One of the greatest challenges is orchestrating the interaction of the various services. When treatment team schedules are not coordinated in advance, lapses in care can delay the rehabilitation process and lead to patient frustration and discouragement. Progress evaluations should be scheduled regularly, during which the status and the evolving goals of the patient are discussed and the plan modified as necessary.

Interim Prosthetic Phase

After a thorough prosthetic and therapeutic rehabilitation plan has been formulated, the interim prosthetic phase starts. During this phase, the prosthesis is created and therapy transitions from general residual limb preparation to specific prosthetic training. Therapy could include electromyographic (EMG) site selection and specific muscle differentiation for a myoelectric prosthesis or further shoulder complex strengthening for body-powered components. This phase also includes the cast impression, creation of a diagnostic prosthesis, and the assessment of functional use of the diagnostic prosthesis, and it concludes with fabrication and delivery of a definitive prosthesis. The diagnostic prosthesis ensures that optimal socket fit and comfort and prosthesis control/function, alignment, and definitive fabrication specifications have been achieved.

The type of prosthesis control chosen influences socket design and should therefore occur before an impression of the patient's residual limb is taken. Regardless of which prosthetic option is selected, all glenohumeral and associated level prostheses require a stable and comfortable socket to support the prosthetic shoulder, elbow, wrist unit, and terminal device components.

Socket Design

Despite differences in anatomy, socket designs for humeral neck amputations, glenohumeral disarticulations, and interscapulothoracic-level amputations are similar and have gradually evolved to cover less of the torso. Early socket styles, which contained all of the shoulder girdle and covered much of the trunk, were bulky and hot and sometimes impinged on the clavicle or acromion^{7,8} (Figure 9). These early designs were replaced by sockets with more abbreviated trimlines that reduced weight and heat buildup⁹ (Figure 10). More extensive harnessing was often required to stabilize the prosthesis, however, despite the smaller surface area of the socket.

Simpson and Sauter are credited with the next evolution in socket design, the Perimeter Frame.¹⁰ Made of lightweight aluminum, this socket included large windows, or "cutouts," in the anterior, posterior, and acromioclavicular regions (Figure 11). By moving the acromioclavicular area or humeral neck inside the socket, the amputee could activate switches controlling electronic devices with good results. Myoelectrodes in the Perimeter Frame had limited success, however, because it was difficult to maintain skin-to-electrode contact.¹¹

In the 1980s, infraclavicular designs were developed.12 The infraclavicular design differs from its predecessors because it does not enclose the shoulder complex to support the weight of the prosthesis. Instead, it relies on compression of the deltopectoral muscle group anteriorly and the scapular region posteriorly.13 Intimate anatomic contouring of these load-bearing areas stabilizes the socket on the torso (Figure 12), enabling the wearer to effectively position the terminal device in space. Infraclavicular sockets are also less noticeable under clothing than are other designs. Because the acromioclavicular complex is not encased in this design, it is free to move independently of the socket. This movement can be used to activate secondary control inputs to control wrist rotation, shoulder or elbow locks, etc.^{14,15}

Diagnostic Assessment

The diagnostic socket with the harness affixed should be assessed both statically and dynamically while the patient is standing, sitting, and bending forward and to the side. It is important to evaluate the load-bearing surfaces and ensure that forces are evenly distributed so that excessive



Figure 11 Perimeter Frame-type socket. **A**, Anterior view. **B**, Posterior view.

pressure is not applied to any single area.

Diagnostic assessment also focuses on the identification and verification of sufficient EMG signal recognition for myoelectric control, sufficient capture of excursion for bodypowered control, or both for hybrid control. An experienced therapist is extremely valuable in assisting the patient and practitioner with locating and strengthening specific muscle groups. When myoelectric control is selected, the diagnostic socket should be carefully examined for consistent skin contact, especially during contraction of the desired control muscles.16 Some myoelectric systems require the patient to quickly cocontract antagonistic muscles to control functions such as unlocking the elbow or transferring control from the terminal device to an electric wrist rotator.¹⁷ Some patients have difficulty contracting both targeted control muscles simultaneously and will require either therapy training or a different control scheme. When bodypowered control is provided, the socket should be evaluated for maximum range of motion to determine optimal excursion. At the gleno-



Figure 12 The prosthetist applies downward force to the humeral segment, demonstrating the stability achieved with this infraclavicular socket design.

humeral and associated levels, range of motion and associated excursion are often insufficient for effective control of a fully body-powered prosthesis. This is even more problematic for children and for people of slight build or with narrow shoulders.

Once the controls have been confirmed, the components can be mounted and aligned. The location and angles of abduction/adduction and internal rotation of the shoulder joint should mirror the center of the contralateral shoulder. With humeral neck–level amputations, the mechanical shoulder joint location may not be anatomic, to avoid creating a prosthesis with obvious shoulder asymmetry. For patients with cosmetic concerns, one solution is to mount the shoulder joint inferior to the distal aspect of the humeral neck (Figure 13).

After all components have been attached and aligned, reliable control of the shoulder, elbow, wrist, and terminal device should be verified. Secondary control options, including a remote on/off, shoulder lock, elbow unlock, and wrist rotation, require analysis of gross body movement and selection of appropriate input options, often push- or pull-type



Figure 13 Diagnostic prosthesis with the shoulder joint located inferior to the humeral neck.

switches. Push switches can be activated with the chin, with elevation of the acromial complex, or with movement of the humeral neck. Pull switches are attached to the harness and are activated by excursion of the harness. Verifying control isolation (after each control option is added) ensures that inadvertent activation of a particular function does not occur.

Before creating the definitive prosthesis, the prosthetist must determine the socket material and thickness, frame color and composition, trimlines, and mounting locations for secondary control inputs. This is best accomplished while the patient is wearing the diagnostic prosthesis. The prosthesis is ready for final fabrication when all issues of comfort, control, function, cosmesis, and fabrication have been thoroughly addressed. By following this protocol, few unanticipated issues will arise during the delivery of the definitive prosthesis, and alterations should be minimal.

Postprosthetic Phase

Prosthetic delivery is the culmination of much hard work by the patient and the rehabilitation team and can be quite gratifying. Once the prosthesis is donned, the fit, function, and range



Figure 14 Child with high-level congenital deficiency. Note the contour of the affected side compared with the contralateral shoulder.

of motion should be assessed carefully to ensure that accurate duplication of the diagnostic prosthesis has been achieved. Controls and adjustments should be verified to optimize function. This could include snugging the harness of a body-powered component or fine-tuning the electronics for a myoelectric device.

The patient's perceptions are critical to the process. A prosthesis that may appear to fit and function well from the rehabilitation team's perspective will still not be successful if it does not meet the patient's requirements. For example, the harness may seem too tight or the patient may feel that too much effort is required or that cosmetic issues have not been adequately addressed. Responding to such concerns with specific changes and involving the patient in the decision-making process gives a sense of empowerment and increases the likelihood of a positive long-term outcome.

Another important responsibility of the rehabilitation team is to help the patient develop realistic expectations. When the definitive prosthesis is delivered, the patient must confront the limitations of a prosthesis. Even the best-designed prosthesis cannot replace the function of a human arm. This can often be an emotional time, and access to a support network that includes a psychologist or counselor



Figure 15 Surgical removal of the proximal humerus results in a sensate arm with functioning musculature that hangs at the patient's side. Firing the biceps results in telescoping of the humeral soft tissues but not in elbow flexion.

is beneficial. This is especially true for the glenohumeral-level amputee because the loss at this level is so significant.

Occupational therapy becomes the focal point of the postprosthetic phase. The goal of postprosthetic therapy should be the integration of the prosthesis into the patient's lifestyle. The therapist begins with specific controls training: flexing and positioning the elbow, opening and closing the terminal device, and supinating and pronating the wrist. With guidance and practice, the patient will master these skills and then translate them into task-specific activities. During this process, it is important that the therapist and prosthetist maintain consistent communication to ensure seamless rehabilitation. Often the prosthesis requires minor adjustments as new tasks are undertaken or to address residual limb volume changes. Care and maintenance of the prosthesis, including cleaning the prosthesis and personal hygiene,



Figure 16 Clear test socket has a perimeter socket that is stabilized on the torso. The posterior humeral shell is articulated near the glenohumeral joint region, permitting the patient to passively abduct the arm for sitting at a desk or table.

should also be discussed. Finally, a specific plan for long-term follow-up care and component maintenance should be formulated.

Special Considerations Congenital Absence

Acquired amputations and congenital absences at the glenohumeral level have distinct clinical presentations that affect prosthetic management differently. With congenital absence (Figure 14), the clavicle and scapula are often misshapen and may be fused. They are usually foreshortened, and the lateral aspects are swept upward, creating a prominent and usually very mobile bony spur.¹⁸ The rest of the shoulder area is often fleshy and has the potential for weight support, but the lack of bony structures often results in problems with stability. The shoulder profile drops away quite sharply from the bony point of the glenoid area, and a prosthetic shoulder joint can be incorporated without cosmetic or technical difficulty.¹⁹



Figure 17 The finished "prosthosis" allows the patient to actively flex and extend the elbow for desktop activities. The lightweight padded shell restores shoulder symmetry under clothing.

Intercalary Amputations

Intercalary amputations, which are rarely encountered, are extremely challenging for the prosthetistorthotist to manage. One example is the Tikhoff-Linberg resection, where much of the humerus is removed but the balance of the upper limb remains sensate with intact musculature. It is tempting to consider these patients as having a loss similar to a brachial plexus injury, but prosthetic solutions that are successful for brachial plexus injuries often fail with this population. The overwhelming functional deficit is the complete loss of internal skeletal stability. As a consequence, when the patient fires the elbow flexors, the arm shortens but the forearm does not reach a horizontal position, as shown in Figure 15. Because the forces generated by the upper arm musculature are considerable, it is virtually impossible to create an external "prosthosis" that will prevent such telescoping from occurring.²⁰ In addition, it is impossible to carry even very light objects in the hand because the entire arm is connected to the torso only by soft tissues.



Figure 18 Although active flexion beyond 90° is impossible, the left hand can assist the unimpaired limb in light tasks, despite the absence of the humerus.

A locking elbow orthosis is not of much use because the skeletal loss makes the humeral section unstable. Biomechanically, it is necessary to create a prosthetic socket-like structure on the chest to stabilize the arm support, and many patients reject devices that extend from the torso to the wrist. In some instances, a posterior humeral trough connected to a torso platform can provide sufficient counterforce to permit the patient to voluntarily flex and extend the arm for desktop activities (Figures 16 through 18). Articulated devices, whether body-powered or electric-powered, are not always successful for this population because the intact forearm and hand weigh much more than would a hollow prosthetic forearm segment.

Case Studies Case Study 1

A 22-year-old man incurred a brachial plexus injury secondary to a water skiing accident, resulting in a flail arm. Eight years after the injury, after multiple surgeries to attempt neural reconstruction, the patient elected to undergo a shoulder disarticulation. The residual limb/shoulder girdle had healthy skin without scar or graft tissue. However, the pectoralis muscle was significantly atrophied secondary to the brachial plexus injury and produced a 13-µV maximum EMG signal. The range of scapular motion was

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Figure 19 Definitive myoelectric prosthesis for an individual with shoulder-level brachial plexus injury.

extremely limited. The infraspinatus muscle produced an EMG signal in excess of 70 μ V. The patient reported overuse of his surviving hand and wrist and had a strong interest in maximum function with a good cosmetic appearance.

The patient was fitted with an infraclavicular socket using myoelectric control to operate an electric elbow, hand, and wrist rotator, plus switch control of an electric locking shoulder joint. The infraspinatus muscle site was used to proportionally control elbow flexion and terminal device closing, allowing precise positioning of the elbow and fingers. The weaker pectoralis muscle was used to provide single-speed control of terminal device opening. To decrease the weight of the prosthesis and reduce heat buildup, the socket trimlines were abbreviated and a window was cut inferior to the axilla. The resulting prosthesis allowed the patient to perform bimanual activities with a grip force in excess of 20 lb. The forearm and hand were covered with a custom silicone synthetic skin to closely resemble the contralateral limb and to address the patient's concerns regarding body image (Figure 19).



Figure 20 Individual with bilateral amputations, at the humeral neck and at the transradial level.

Case Study 2

A 39-year-old man presented 5 years postinjury with bilateral amputations (left side, transradial level; right side, humeral neck-level) secondary to an electrical burn (Figure 20). The right residual limb/shoulder girdle exhibited minimal scar and graft tissue and good range of motion and strength of the humeral neck. However, the left side (transradial level) had extensive scar and graft tissue in the areas of the scapula, pectoralis, deltoid, and axilla, which limited the ability to anchor the control/suspension harness for the humeral neck-level prosthesis through the axilla region. The patient had adequate EMG signals on both residual limbs, in excess of 80 µV. The team's focus was on obtaining patient independence, reducing prosthesis weight and heat buildup, increasing grip force, enlarging the functional envelope, and limiting shear forces on the scar and graft tissue.

On the right side (humeral necklevel), the patient was fitted with a hybrid prosthesis that used myoelectric control of electronic work hooks and wrist rotators, plus cable-operated control of an elbow with a forearm balancing unit (Figure 21). The cableoperated elbow significantly reduced the overall weight of the prosthesis.



Figure 21 Definitive hybrid prosthesis for an individual with bilateral amputations, at the humeral neck and transradial level. Note the position of the shoulder joint

The patient used ballistic body movements to flex the prosthetic elbow and humeral neck abduction/flexion to control the elbow locking mechanism, eliminating the need to route harness straps for elbow flexion across the fragile axilla region. The infraclavicular socket permitted independent locking of the cable-operated elbow because the humeral neck was not contained within the socket.

The left side (transradial level) was fitted with a self-suspending myoelectric prosthesis with an electronic work hook and wrist rotator control. Myoelectric control offered enhanced grip force and enlarged the functional envelope compared with the patient's previous body-powered prosthesis. By using a special donning aid incorporating a weighted, extra-long lanyard, the patient learned to don the transradial prosthesis independently by using his legs and feet to manipulate the lanyard. He then could use the transradial myoelectric prosthesis to don the prosthesis on the opposite side. The increased grip force, larger functional work envelope, and independent donning characteristics of these prostheses have allowed this patient to live independently in the community.

Summary

Recent improvements in components and control options have achieved successful prosthetic fitting of many amputees with glenohumeral and associated levels of loss. When bodypowered components were the only available option, prosthetic fitting was not as successful. A comprehensive and systematic approach, coordinated by an experienced rehabilitation team consisting of a physician, physical and occupational therapists, a psychologist, a rehabilitation coordinator, and a prosthetist can improve long-term success rates with these prostheses. The outcome is best when the patient has a sense of control and active participation throughout the rehabilitation process. Verifying optimal fit and function of the diagnostic prosthesis before fabrication of the definitive device has proved to be an effective method to avoid costly modifications that can result in loss of confidence for the patient.

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