Traumatic and Trauma-Related Amputations: Part II: Upper Extremity and Future Directions

LT Scott M. Tintel, LTC Martin F. Baechler, CDR George P. Nanos III, LCDR Jonathan A. Forsberg and MAJ Benjamin K. Potter


This information is current as of December 30, 2010

**Reprints and Permissions**

Click here to order reprints or request permission to use material from this article, or locate the article citation on jbjs.org and click on the [Reprints and Permissions] link.

**Publisher Information**

The Journal of Bone and Joint Surgery
20 Pickering Street, Needham, MA 02492-3157

[www.jbjs.org](http://www.jbjs.org)
Traumatic and Trauma-Related Amputations

Part II: Upper Extremity and Future Directions

By LT Scott M. Tintle, MD, LTC Martin F. Baechler, MD, CDR George P. Nanos III, MD, LCDR Jonathan A. Forsberg, MD, and MAJ Benjamin K. Potter, MD

Investigation performed at the Walter Reed Army Medical Center, Washington, DC

Current Concepts Review

Traumatic and Trauma-Related Amputations

Part II: Upper Extremity and Future Directions

By LT Scott M. Tintle, MD, LTC Martin F. Baechler, MD, CDR George P. Nanos III, MD, LCDR Jonathan A. Forsberg, MD, and MAJ Benjamin K. Potter, MD

Investigation performed at the Walter Reed Army Medical Center, Washington, DC

Amputation of an upper extremity is a catastrophic event primarily performed as the result of high-energy trauma in a young, otherwise healthy patient population. This is in stark contrast to the population requiring lower-extremity amputation, which predominantly comprises elderly patients with end-stage diabetes or peripheral vascular disease. While the surgical principles of upper and lower-extremity amputations have similarities, the morphologic and functional distinctions between the upper and lower extremities render the operative techniques and decision-making different in many key respects. Knowledge of these differences, and an awareness of the functional outcomes and prosthesis acceptance rates associated with each amputation level, are essential to ensure appropriate preoperative planning and to optimize patient outcomes.

Amputation Versus Limb Salvage and/or Replantation

Accurate predictors of the outcomes after severe trauma to the upper extremity have not been elucidated. While severity scores for the traumatized lower extremity have been developed, their application to the upper extremity has been equivocal and has not consistently proven efficacious. Indeed, limb salvage considerations differ considerably between the upper and lower extremities. One important consideration is the dramatic difference in the functional capabilities between a normal hand and a prosthesis, despite all modern advances in prosthetic design. The numerous degrees of freedom of the human arm and the dexterity and sensory feedback of the hand are only marginally replicated with current prosthetic technology. For this reason, a “bad hand” may be more functional than a “good amputation” in the upper extremity (Figs. 1-A, 1-B, and 1-C).

Disclosure: The authors did not receive any outside funding or grants in support of their research for or preparation of this work. Neither they nor a member of their immediate families received payments or other benefits or a commitment or agreement to provide such benefits from a commercial entity.

Disclaimer: The opinions and assertions contained herein are the private views of the authors and are not to be construed as official or as reflecting the views of the United States Army, United States Navy, or the Department of Defense.
The difference between a “bad foot” and a “good lower-extremity amputation” may not be nearly as important. For instance, more than 15% of the more than 750 lower-extremity trauma-related amputations managed at our institutions over the last decade were late amputations due to unsatisfactory or so-called failed limb salvage; however, to our knowledge, only two patients during this same time period voluntarily requested late transradial amputation following an initial upper-limb salvage.

Additionally, anatomic and functional differences make the upper extremity more amenable to limb salvage and/or replantation than the lower extremity. Since the upper extremity is not used for walking, there is less concern about limb-length equality. Shortening osteotomies may allow primary vascular and/or nerve repairs, as well as primary soft-tissue closure, making upper-extremity limb salvage less of a problem and perhaps more successful in certain circumstances. The upper extremity also has less muscle mass, decreasing the risk of a crush syndrome with limb salvage. In addition, increased collateral circulation in the upper extremity may allow the reperfusion time to be extended to eight to ten hours after a vascular injury.

Graham et al. conducted a study in which the late functional outcomes of major unilateral upper-extremity replantation were compared with those of revision amputation and prosthetic fitting. The authors concluded that the patients who had been treated with replantation had better function as assessed with the Carroll Standardized Evaluation of Integrated Limb Function at an average of 7.3 years after the injury. The Carroll Standardized Evaluation of Integrated Limb Function is a battery of tests that assesses a subject’s ability to grasp, grip, and pinch variously sized and shaped objects and to perform tasks incorporating both accurate hand and object placement. The test also includes more complex motions such as the pouring of a water from a pitcher and concludes with the subject being asked to write. The test was originally developed for the quantification of upper-extremity limb impairment as a result of traumatic, arthritic, or neurologic conditions. The contention of the test developers was that it emphasized the integrated activity of the extremity and the functional capacity of the limb.

Graham et al. also concluded that if prehension of all digits was considered achievable, then replantation was superior to amputation. If prehensile function was not considered an achievable goal of primary treatment, then the number of satisfactory results obtained with replantation or amputation was similar. However, an increased proportion of excellent results in the replantation group persisted.

**Length Selection and Indications for Length Preservation Procedures**

After an upper-extremity amputation, the person utilizes the residual limb to interact with his or her environment even when a prosthesis is not worn. With increased extremity length and the preservation of each progressive joint, the person becomes exponentially more capable of positioning the terminal extremity in space and of feeling, grasping, and manipulating objects in the environment. For this reason, a longer residual limb leads to improved outcomes in most circumstances, and it is rare for a patient who has had an upper-extremity amputation to request limb shortening. While the specific injury may ultimately determine the level of amputation, it is crucial for the surgeon to know the requirements and capabilities of prostheses corresponding to each amputation level when the opportunity for length preservation is afforded.

When the residual tissue of a traumatically amputated limb is of inadequate quality or quantity to permit wound closure without shortening of the limb, extended means of wound management, such as use of a split-thickness skin graft, pedicled flap, or even free tissue transfer, should be strongly considered. However, the fitting of a prosthesis to a residual limb can be a challenge even in the best of circumstances, and particularly when the residual limb is irregular in shape as a result of flap coverage. Therefore, although preserving length of the residual limb is of prime importance, the surgeon must consider the ultimate size, shape, durability, and even appearance of the residual limb, as these factors will affect the ultimate satisfaction of the patient.

Baccarani et al. demonstrated successful length preservation in thirteen well-selected patients treated with free tissue transfer. These authors suggested the following major indications for free tissue transfer in the upper extremity to provide soft-tissue coverage of a residual limb: shoulder joint preservation, elbow joint preservation, and bone preservation. Furthermore, with respect to prosthetic use, the burden of direct pressure and shear force is less of a problem for a residual upper limb than it is for a residual lower limb. Therefore, although flap coverage is successfully used in both upper and lower-extremity amputations to preserve length, it should be employed more often for length preservation of the residual upper limb.

**Nerve and Muscle Management**

The proper management of muscles and nerves in upper-extremity amputations is very important. Traction neurectomy should be performed for each major upper-extremity nerve, including the cutaneous sensory nerves, in order to locate the inevitable neuromas away from the skin closure, myodesis, or myoplasty. However, neurectomy must be performed cautiously in order to avoid further denervation of residual muscle, which is undesirable for several reasons. First, denervated muscle will atrophy and possibly leave the residual limb poorly pad-
ded. Second, denervated muscle cannot contract and thus cannot provide a signal for control of a myoelectric prosthesis. Finally, the terminal nerve branches may be transferred non-anatomically to local residual limb muscles to create additional myoelectric control sites for more intuitive control of a motorized prosthesis. This concept, termed “targeted muscle reinnervation,” will be discussed in detail later in this review20-24.

Stabilizing the muscles and tendons of a residual limb is extremely important for successful prosthetic wear. The bone ends must be padded to avoid painful prominences. Myodesis, myoplasty, and myofascial techniques are all utilized in am-

**Figs. 1-A, 1-B, and 1-C** Clinical photographs demonstrating that a “bad hand” may be more functional than a “good amputation” when limb salvage remains practicable following severe upper-extremity trauma. **Fig. 1-A** The patient sustained loss of the ulnar three rays following an explosive blast injury to the hand, but maintained an intact thumb and a minimally injured index ray. **Fig. 1-B** A pedicled groin flap was utilized for robust soft-tissue coverage.
putation surgery to stabilize the residual muscle and maintain the distal bone end in a padded and covered position. Myodesis is achieved when a residual muscle and its fascia are sutured directly to bone through drill holes or are firmly attached to the periosteum. Myodesis provides the most structurally stable result. Myoplasty involves suturing a residual muscle agonist to its antagonist over the end of the bone to create physiologic tension. Finally, with a myofascial closure, residual muscle and its fascia are sutured together, creating the least stable musculotendinous reconstruction. Nearly physiologic tension should be set at the time of the myodesis or myoplasty to prevent retraction, simulate resting muscle length, and improve contractility characteristics, thus improving the quality of signal for control of a myoelectric prosthesis as well as improving control of the terminal residual limb.

No data in the literature strongly suggest the superiority of myodesis over myoplasty; however, we recommend that myodesis and/or tenodesis be performed in all upper-extremity amputations (Fig. 2) because the mobile sling of muscle that is formed from a myoplasty can lead to painful bursa formation or result in exposure of prominent bone. Furthermore, myoplasty of antagonist muscles can lead to spread of signal, resulting in involuntary co-contraction and interference with myoelectric signal detection.

**Specific Amputation Levels**

**Wrist Disarticulation**

This level of amputation has several distinct advantages. If the distal radioulnar joint is unaffected, full forearm rotation is completely preserved and there is no risk of painful impingement of the distal parts of the radius and ulna. The large surface area of the distal part of the radius may allow increased weight-bearing through the terminal end. The long sensate residual limb increases the person’s functional reach. It is also a better platform for a prosthetic socket. This is important for stability of the prosthesis as well as for elbow motion; the shorter the
residual limb, the more likely the prosthetic socket will en-
coach on the elbow and impede motion.

The major disadvantage of this amputation level has been
the limited capabilities of the prosthetic devices. A survey of
United States surgeons conducted by Tooms in 1972, prior
to the introduction of modern wrist prostheses, indicated a
preference for distal transradial amputations over wrist disar-
ticulations. This was likely due to the inability to fit standard
prosthetic components and terminal devices distal to the wrist
while still maintaining a functionally and cosmetically acceptable
extremity length and bulk. With modern prosthetic components
and terminal devices, however, a patient with an amputation
through the radiocarpal joint can be satisfactorily fitted with a
functional prosthesis.

Prerequisite to attempting amputation through the radio-
carpal joint is an intact and healthy distal radioulnar joint3,26.
In
the performance of a wrist disarticulation, the thick palmar skin
of the hand should be utilized for distal coverage, if availablei.
The radial and ulnar styloid processes should be retained for
prosthesis suspension, but contouring the styloids is reasonable
to avoid osseous prominences and to facilitate robust soft-tissue
coverage. It is crucial to perform a tenodesis of the flexors and
tensors to maintain the tension in the muscle groups necessary
for successful use of a myoelectric prosthesis. In addition to the
ulnar and median nerves, careful attention must be paid to the
superficial branch of the radial nerve, the palmar cutaneous branch
of the median nerve, and the dorsal ulnar cutaneous nerve3. The
nerves should be transected proximal to the level of the closure and
transposed deep to the local musculature to protect them from
prosthetic pressure and prevent chronic pain. However, a cuta-
necous nerve should be preserved if it supplies skin that is retained
in the closure, even while the residual portion of the contributing
larger nerve is transposed.

Transradial Amputation
The transradial amputation is the most common upper-extremity
amputation27. The preservation of the shoulder and elbow as well
as the maintenance of some forearm pronation and supination
allows a terminal device to be easily positioned in space. When
practical, at least two-thirds of the forearm length should be
maintained. We advocate the removal of 6 to 8 cm of bone in
order to maximize the robustness of the soft-tissue envelope and
permit a wide variety of prosthetic options. In addition, we fre-
quently interpose local soft tissue between the distal aspects of the
radius and ulna to prevent painful convergence and instability.
The location of the amputation determines what soft tissue is
interposed. In the distal part of the forearm, the pronator quad-
dratus is utilized if intact; however, more proximally, one extensor
tendon and one flexor tendon are interposed and are secured
between the radius and ulna.

Benefits of a distal transradial amputation include in-
creased pronation and supination as well as a stable lever arm for
prosthesis wear and weight-bearing. In addition, the transradial
level is cosmetically appealing because of the ability to fit a body-
powered or myoelectric prosthesis with quick-disconnect com-
ponents while still maintaining equal limb lengths. The obvious
prosthetic and mechanical advantages of the transradial level
coupled with the superior prosthesis acceptance rates oblige a
surgeon to consider all reconstructive options, including free
tissue transfer, in order to perform an amputation at this
level27-32.

When the injury dictates that a transradial amputation
be performed in the proximal half of the forearm, no useful
pronation and supination is generally salvaged; however, only
5 cm of residual ulna is required for prosthetic fitting and re-
tention of elbow flexion3,33,34 (Fig. 3). With an even shorter ulna,
a prosthetic socket can be extended proximal to the condyles of the elbow to aid in prosthetic suspension. At this proximal
level, the biceps should be transferred to the ulna via tenodesis.
Postoperative rehabilitation should then focus on the preven-
tion of a flexion contracture at the elbow. Furthermore, if the

Fig. 3
Anteroposterior radiograph of a proximal, 7.5-cm transradial amputation
with resection of the residual radius and tenodesis of the biceps tendon
to the residual ulna. Even at this proximal level, prosthetic fitting was
feasible with reasonable prosthetic suspension and residual limb
control, and a myodesis was performed as reflected in the distal ulnar
drill hole (arrow).
patient also has disability related to the lower extremities and will rely more heavily on the upper extremities for mobility, preservation of even an extremely short ulna should be considered, as the proximal part of the ulna is a reasonably stable and a natural weight-bearing surface.

**Elbow Disarticulation/Distal Transhumeral Amputation**

The elbow disarticulation and transcondylar humeral amputations are similar in nature because of maintenance of the metaphyseal flare of the distal part of the humerus. The shape of the residual humerus allows improved suspension and better rotational control of a prosthesis when compared with those following a more proximal transhumeral amputation. The major disadvantage of an elbow disarticulation is cosmetic because, in most cases, the prosthetic elbow joint is located either distal to the normal, contralateral elbow joint or external to the plane of the humerus and prosthesis. The improved suspension and rotational control, however, likely outweigh the perceived poor cosmetic appearance of the limb. As such, an immediate or delayed humeral shortening osteotomy may be considered to elevate the elbow joint and improve cosmetic appearance, while preserving functionality, in selected cases.

If the condyles of the humerus are not preserved, the ideal level for amputation of the humerus is approximately 3 to 5 cm proximal to the elbow joint. This level will allow fitting of standard prosthetic components, while retaining adequate length to suspend and control a prosthesis. A Marquardt angulation osteotomy as described by Marquardt and Neff may also be considered for patients with a distal transhumeral amputation. This osteotomy creates an angulated distal residual humerus, which provides improved suspension and rotational control of the prosthesis, similar to that achieved with an elbow disarticulation.

**Proximal Transhumeral Amputation**

Every effort should be made to salvage at least 5 to 7 cm of residual humerus, as this will affect prosthesis suspension and acceptance (Fig. 2). Skin grafting or free tissue transfer should be considered in cases where humeral length may be maintained. Latissimus dorsi, parascapular, and other free tissue transfers have been successfully utilized to preserve amputation length and facilitate salvage of humeral length. The deltoid muscle should be preserved even in very proximal transhumeral amputations, to allow active control of the shoulder joint. It is also important to salvage the humeral head, whenever possible. Doing so will improve the cosmetic appearance following the amputation and may eventually help the patient use a myoelectric or body-powered prosthesis. Without retention or reconstruction of the insertions of the pectoralis major, latissimus dorsi, and deltoid, however, the result will be the same as that of a shoulder disarticulation with regard to prosthetic fitting. For this reason, if the humeral head is retained to improve the cosmetic appearance of the shoulder and to potentially aid in force transmission, glenohumeral arthrodesis can be considered, usually as a planned, staged procedure. This will prevent a painful or disfiguring abduction contracture or subluxation, which may occur as a result of the unopposed forces of the rotator cuff (Figs. 4-A and 4-B).

**Shoulder Disarticulation**

Shoulder disarticulations are fortunately rare. They are usually the result of serious injuries and are frequently accompanied by substantial thoracic and abdominal trauma. These amputations are usually performed as an emergency, life-saving measure. Efforts should be made to save the scapula and clavicle as this improves the contour of the shoulder and aids in prosthetic suspension. Nerve and muscle management is critical at this level. Residual muscle must not be inadvertently denervated as this will cause atrophy and may adversely affect prosthetic fitting. Furthermore, the terminal branches of the brachial plexus are necessary should the patient undergo targeted muscle reinnervation in the future. The usual flap closure consists of a deltid myofasciocutaneous flap, but, in the posttraumatic setting, the use of any available tissue or free tissue transfer may be required.

**Outcomes**

The loss of one or both upper extremities is a devastating event. Prehensile function and the sensation of touch are two functions that are respectively difficult and currently impossible to replace with modern prostheses. Prosthesis acceptance is a frequently discussed primary outcome measure in studies of upper-extremity amputation. However, the literature lacks high-quality evidence, and the majority of the available literature both is dated and offers only non-standardized comparisons of a wide variety of prostheses.

Rates of rejection of upper-extremity prostheses are frequently reported to be greater than 30%. In a number of studies ranging from nineteen to 135 patients, the reported rejection rates for upper-extremity prostheses were 21% to 38%, with all studies that included more than forty-five patients showing at least a 30% rejection rate. Additionally, if one were to consider only functional prosthetics and exclude cosmetic prostheses, the rejection rates would likely be substantially higher. High rejection rates have been loosely associated with poor training; delayed fitting; and, most notably, proximal amputations. In a 1995 survey, people who had undergone an upper-extremity amputation indicated that the top three reasons for their rejection of the prosthesis were limited usefulness, weight, and residual limb/socket discomfort. Factors associated with increased prosthetic acceptance have proven even more equivocal but have been suggested to include the loss of the dominant extremity, the absence of pain in the residual limb, and prosthetic fitting within thirty days after amputation.

Despite inconsistencies in the available literature, it is generally accepted that the rate of prosthesis use is directly associated with the level of the amputation. Prosthesis acceptance is increased with more distal levels of amputation. In addition to increased prosthetic use, higher functional scores are obtained by those with longer residual limbs. Transradial amputation is associated with the highest consistently reported prosthesis utilization rates, which range from 80% to 94% in a
number of reported series of ten to 127 patients (mean number of patients, eighty-five)\textsuperscript{27-32}. This is followed by transhumeral amputation, with a reported range of 43\% to 83\% in reported series of five to seventy-four patients (average number of patients, thirty-one)\textsuperscript{27,28,30,32}. As would be expected, shoulder disarticulation is associated with the lowest reported prosthesis acceptance rates\textsuperscript{27,28,47}. This trend is easily explained by the increased weight and complexity, decreased degree of prehensile control, and
difficulties of prosthetic suspension at the more proximal levels. The prosthesis acceptance rates illustrate the willingness of patients to function one-handed rather than use a burdensome, non-intuitive prosthesis. There are two unique situations that warrant mention: the literature indicates that people with a bilateral upper-extremity amputation will almost universally use at least one prosthesis and those with an ipsilateral brachial plexus palsy will routinely reject a prosthesis\textsuperscript{1,5-7,45}.\textsuperscript{46}

Another important outcome measure is the ability to return to productive employment. The available data indicate that most people who have undergone an amputation are able to return to work. However, one-half to two-thirds of these individuals change their occupations to accommodate for the loss of the limb\textsuperscript{27,29,46}.\textsuperscript{28,47-51} As would be predicted on the basis of prosthesis usage and functional outcomes, people with a transradial amputation have a higher rate of employment than those with a more proximal amputation\textsuperscript{37}.

Chronic pain is also an important outcome measure in people with an upper-extremity amputation. The prevalence of pain in the residual limb after upper-extremity amputation was reported to range from 7\% to 49\% in various series of eighteen to 104 patients (mean number of patients, sixty-two)\textsuperscript{12,41,47-51}. The prevalence of phantom-limb pain was reported to range from 30\% to 79\% in a number of series ranging from eighteen to 104 patients (mean number of patients, sixty-two). Most authors have reported that 50\% of patients in their series were affected by phantom-limb pain\textsuperscript{38,41,47-52}.\textsuperscript{24,53} Despite the relatively high frequency of pain in patients who have had an upper-extremity amputation, studies suggest that chronic pain does not impair functional prosthetic wear or the ability to return to employment in most cases\textsuperscript{27,47}.

Less frequently reported pain associations were highlighted in a study by Hanley and colleagues\textsuperscript{28}. They reported that 104 patients with an upper-extremity amputation had an increased rate of back pain (52\%), neck pain (43\%), and pain in the contralateral, sound upper extremity (33\%) as compared with the rates in the general U.S. population\textsuperscript{32,33}. Despite the infrequency of pain in the sound limb, this pain caused the most interference and days lost from work because of pain-related disability. This highlights the importance of educating patients with a new amputation about overuse-type injuries of the contralateral upper extremity\textsuperscript{34}.

**Future Directions**

**Prosthesis Design**

Contemporary myoelectric prostheses routinely utilize a terminal device with a tripod-type forceps grip that allows only one degree of freedom with high-magnitude grip strength\textsuperscript{1}. The ability to design an anthropomorphic upper extremity with multiple degrees of freedom has routinely been limited because of the increased numbers of motors and power sources required as well as the inability to provide comparable grip strength with a lightweight design\textsuperscript{1}. Recently, improved materials, more efficient ultrasonic motors, lighter batteries, and pneumatically or hydraulically controlled finger joints have made the design of an anthropomorphic hand with multiple degrees of freedom a reality\textsuperscript{53-45}.\textsuperscript{5,27,47,45-49} This has led to the design of prostheses capable of multiple grasping patterns with less necessary overall grip strength. At least two such prototypes are currently in production, and widespread clinical trials of these devices will likely begin in the near future\textsuperscript{1}.

Increasingly intelligent capabilities of future prostheses are also expected. On-board intelligent sensors will eventually provide sophisticated haptic feedback loops capable of real-time correction in order to automatically determine and adjust for touch, slip, position, and temperature. Improvements to the neural-prosthesis interface are also currently being investigated. Improved electromyographic (EMG) sensors as well as the possibility of implanted electrodes and even a sensory interface may someday be a reality. With these continued developments, it is conceivable that, in the future, an anthropomorphic prothetic hand capable of near-physiologic control without visual attention will markedly improve the quality of life of individuals with an upper-extremity amputation\textsuperscript{37}.

**Targeted Muscle Reinnervation**

Patients with an amputation at or above the elbow have two major difficulties with the control of prostheses. First, the muscle contractions necessary to signal the prosthetic device are not intuitive. Second, the remaining muscles provide too few distinct signals to control more than one prosthetic joint simultaneously, necessitating slow and cumbersome sequential, alternating control of each joint\textsuperscript{44}. Targeted muscle reinnervation was developed by Kuiken and Dumanian\textsuperscript{20-22} to improve the control of myoelectric prostheses. The premise of targeted muscle reinnervation is to regain the signaling ability of the nerves that formerly innervated the lost limb through a set of novel nerve transfers (Fig. 5). No function is lost with these nerve transfers, as the original recipient muscles are not present as a result of limb loss. Thus, the newly reinnervated muscle segments act like transducers of the transferred nerves’ original function, capable of producing electromyographic signals to control a myoelectric prosthesis\textsuperscript{37}.

In transhumeral amputations, four independently controlled nerve-muscle units are obtained by transferring the distal radial nerve to the motor branch of the lateral head of the triceps and the median nerve to the motor branch of the medial head of the biceps\textsuperscript{23}. These transfers provide the signals for intuitive prosthetic elbow opening and closing. With a distal transhumeral amputation with an adequate remaining, functioning brachialis, transfer of the ulnar nerve to the motor branch of the triceps and the lateral head of the biceps each keep their native innervation for intuitive prosthetic elbow flexion and extension. With a distal transhumeral amputation with an adequate remaining, functioning brachialis, transfer of the ulnar nerve to the motor branch of this muscle can provide a fifth control source. With shoulder disarticulation, the choice of nerve transfers is often dictated by the length of the remaining nerves and the anatomy of the remaining functioning muscles. Typically, the musculocutaneous nerve is transferred to the motor branches of the clavicular head of the pectoralis major; the median nerve is transferred to the motor branches of the sternal head of the pectoralis major; the terminal radial nerve is transferred to the thoracodorsal nerve; and the ulnar nerve is transferred to the motor branches of the
pectoralis minor muscle moved from underneath the pectoralis major, to the long thoracic nerve, or to a redundant motor branch of the pectoralis major. Targeted muscle reinnervation makes it possible for a patient who has undergone a transhumeral or shoulder disarticulation to simultaneously control the elbow and a terminal device with a myoelectric prosthesis. To date, the use of targeted muscle reinnervation has markedly improved the upper-extremity prosthetic function of a small number of patients. Patients who have undergone targeted muscle reinnervation have all become capable of intuitive and simultaneous opening and closing of the hand as well as extension and flexion of the elbow. Early laboratory evidence in animals and clinical results to date also suggest that targeted muscle reinnervation may help to alleviate symptomatic neuromas.

Advanced Pattern Recognition

Early trials with a small number of patients who had undergone targeted muscle reinnervation have been conducted with use of advanced pattern-recognition algorithms to decode surface EMG data from reinnervated muscles. Data from EMG recordings have been collected from patients attempting sixteen different complex motions with the amputation stump following targeted muscle reinnervation. The complex EMG pattern-recognition software is capable of allowing the reinnervated muscles of a patient treated with targeted muscle reinnervation to intuitively control an advanced, multifunctional artificial upper extremity in real time. The development of targeted muscle reinnervation and these advanced pattern-recognition algorithms have provided the necessary technology to eventually produce a prosthesis that can perform complex movements and be customized to individual patients on the basis of their own natural voluntary EMG patterns.

Composite Tissue Allotransplantation/Hand Transplantation

To date, more than fifty hand, forearm, and arm transplants have been performed worldwide in thirty-eight patients and have shown that hand allograft survival can be achieved with highly encouraging functional outcomes. Proponents of composite tissue allotransplantation argue that hand/forearm transplantation provides function that is comparable with, or better than, that provided by replantation, enhances activities of daily living, allows the patient to perform activities not afforded by a prosthesis, and is associated with low morbidity and no recorded mortality to date. Critics of composite tissue allotransplantation highlight the lack of convincing long-term functional data, the unclear risk-benefit ratio, the possibility of life-shortening or fatal complications, and the need for chronic immunosuppressive medication for success.

A recent review of the cases of five patients who had a hand transplant performed in the United States illustrates both the optimism for the future of hand transplantation and the need for extreme caution in the performance of the procedure due to the potential for serious complications. Despite advancements in immune regimens, all five patients experienced at least one episode of acute rejection while being treated with conventional immunosuppressive regimens.
imunosuppression. Additionally, one transplanted hand was amputated at nine months because of what was diagnosed as a chronic rejection. One patient in this series required bilateral total hip replacement because of osteonecrosis, and one patient developed a lymphoproliferative disorder. Despite the inability to determine whether the lymphoproliferative disorder was related to the transplant, the authors emphasized that post-transplant biopsies and unbiased pathological confirmation of the earliest stages of acute rejection and subsequent timely intervention, treatment, and precise adjustments of immunosuppression on an individualized basis. When treated adequately and effectively, acute rejection does not seem to impair graft function or long-term survival.

Therefore, novel strategies to minimize immunosuppression or even to achieve the ultimate attainable clinical goal of transplantation to induce immune tolerance are particularly appealing in hand transplantation and composite tissue allotransplantation. This trend is further fueled by recent innovative advancements in solid-organ transplantation, where both cell-based therapies and non-cell-based protocols have resulted in reduction or elimination of long-term immunosuppression. With such advancements in the development of less morbid regimens for the prevention of tissue rejection, hand transplantation may become a widely accepted alternative for a patient with upper-extremity loss.

Overview

Upper-extremity amputation is a devastating event. Optimal surgical treatment and rehabilitation involve many considerations and decisions unique to the reestablishment of upper-extremity function. Knowledge of proper amputation techniques, preferred amputation levels, and the judicious use of tissue coverage methods can ostensibly optimize clinical outcomes. While the knowledge and technical skill of the surgeon are of obvious importance, patient rehabilitation is maximized by the participation of a multidisciplinary team of surgeons, nurses, therapists, prosthetists, mental health specialists, and social workers. Rapidly developing research that may lead to improved quality of life after an upper-extremity amputation continues to progress. This is illustrated by targeted muscle reinnervation, which was developed in response to the improvements in mechanical prostheses and biomechanical interfaces. Research on composite tissue allotransplantation, which became possible because of microsurgical advancements and the ability to suppress tissue rejection, has also continued to rapidly expand. Surgical treatment algorithms for upper-extremity amputation must therefore continue to evolve in step with technological and medical advancements.

The Journal of Bone & Joint Surgery - JBJS.org
Volume 92-A - Number 18 - December 15, 2010

Traumatic and Trauma-Related Amputations

Overview

Upper-extremity amputation is a devastating event. Optimal surgical treatment and rehabilitation involve many considerations and decisions unique to the reestablishment of upper-extremity function. Knowledge of proper amputation techniques, preferred amputation levels, and the judicious use of tissue coverage methods can ostensibly optimize clinical outcomes. While the knowledge and technical skill of the surgeon are of obvious importance, patient rehabilitation is maximized by the participation of a multidisciplinary team of surgeons, nurses, therapists, prosthetists, mental health specialists, and social workers. Rapidly developing research that may lead to improved quality of life after an upper-extremity amputation continues to progress. This is illustrated by targeted muscle reinnervation, which was developed in response to the improvements in mechanical prostheses and biomechanical interfaces. Research on composite tissue allotransplantation, which became possible because of microsurgical advancements and the ability to suppress tissue rejection, has also continued to rapidly expand. Surgical treatment algorithms for upper-extremity amputation must therefore continue to evolve in step with technological and medical advancements.


57. Lee WPA. Personal communication; 2010 Feb.


