Chapter 8

GENERAL SURGICAL PRINCIPLES FOR THE COMBAT CASUALTY WITH LIMB LOSS

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INTRODUCTION AND HISTORICAL PERSPECTIVE

As Hippocrates eloquently stated, "War is the only proper school for a surgeon." Surgeons following historical armies learned firsthand the care of complex, open orthopaedic injuries. Amputations have long been and remain common sequelae of warfare. During the US Civil War, nearly 20,000 amputations were performed on Union troops alone, with approximately 60% of these involving the lower extremities. World War II saw equally high numbers, leading the US Army to establish several "amputation centers" to provide longitudinal care to injured servicemen who had sustained major amputations. Because penetrating thoraco-abdominal and head injuries were almost universally lethal in earlier conflicts, survivable extremity injuries with open, contaminated wounds were often treated with amputation. Transosseous amputation proximal to the area of gangrene with the use of compression dressings and vessel ligation for hemostasis became commonplace, with cauterization used as a last resort. As surgical management of combat extremity injuries improved, circular amputation became popular during the Vietnam War and subsequently evolved to the currently recommended technique of length-preserving open amputations to aid with eventual coverage with traditional or atypical myofasciocutaneous flaps. With advances in both vascular and orthopaedic reconstructive surgery, limb salvage has frequently become an option for limbs that would previously have been amputated. The introduction of modern blood replacement, aseptic surgery, antibiotics, and primary vascular repair and external fixation techniques, in concert with rapid evacuation to well-equipped far forward surgical hospitals, has greatly improved opportunities for limb salvage. Nonetheless, amputation is still required in many cases of unsalvageable injury, and soldiers sustaining traumatic amputations often survive what might previously have been lethal injuries.

Most near amputation injuries sustained during the current conflict are secondary to blast injuries from improvised explosive devices (IEDs). These injuries are universally grossly contaminated and often involve neurovascular compromise, frequently including damage to other extremities in addition to traumatic brain injury and other multisystem comorbidities. The physiologic status of the whole patient, not merely the mangled limb, must therefore be considered in the initial medical resuscitation and surgical management of the combat-injured patient, always insuring the salvage of life over limb. As of early 2008, over 700 patients have sustained major limb loss (nearly a quarter of which involve the upper extremity) during Operations Iraqi Freedom/Enduring Freedom (OIF/OEF), with approximately 20% having multiple limb involvement. Surgical management, therefore, must be tailored toward initial limb preservation and the utilization of length-sparing amputations when amputation is required, maximizing possible future reconstructive options and potentially offering injured service members the greatest opportunity for choice and eventual informed consent.

The major amputation rate during the US Civil War was in excess of 12%; post-Vietnam, however, the rate in modern conflicts has remained fairly constant, ranging from 1.2% to 3.4%.[1] Even this rate has resulted in thousands of survivors requiring long-term care, including delayed surgical revision and prosthetic modification, which often evolves based on patient experience and expectation. In the near future, functional outcome analyses, both physical and psychological (ie, evaluation of soldier self-efficacy), will be critical to the ongoing improvement of surgical treatment and rehabilitation protocols.

WOUND MANAGEMENT AT POINT OF INJURY

Tourniquet Use

The combat surgeon frequently faces dramatic war wounds in multiply, and often extremely severely, wounded patients. In these situations, preservation of life must always take priority over salvage of a limb. Toward this end, the development of a practicable field tourniquet, its universal distribution, individual training in its application, and a paradigm shift away from considering the tourniquet as the last resort have greatly facilitated the survival of critically injured patients. Tourniquet use is a relatively safe and often critical adjunct in resuscitation with great potential to contribute to improved survival rates.[2] On the modern battlefield tourniquet application rapidly corrects compressible hemorrhage and can be safely used during timely patient transport to a forward surgical facility.

Limb Salvage Versus Amputation

When receiving a patient with a tourniquet, forward surgeons often face difficult choices with respect to limb salvage versus completion of an amputation. A variety of scoring systems have been developed to assist the surgeon in surgical decision-making. However, none of these have been shown to reliably predict the salvageability and functional viability of an injured limb.[3,4]

On the modern battlefield, a variety of factors critically impact these difficult decisions. First and foremost among these is the individual patient. Most injured soldiers are young and previously healthy but now have severe, often life-threatening, injuries. In a hemodynamically unstable patient, amputation may be critical in saving the soldier's life. Additionally, when the limb is mangled, particularly if segmental concomitant vascular injury exists, provisional repair and reconstruction may be neither possible nor feasible with the available skill sets and resources in a combat theater. In the past, concomitant nerve injury had been considered an indication for early amputation. However, preliminary data from the Lower Extremity Assessment Project (LEAP) study (a multicenter study of severe lower extremity trauma in the US civilian population) recently demonstrated satisfactory 2-year results following tibial nerve injury and limb salvage with, in the absence of visualized transection, poor correlation between initial neurologic examination and final outcome.[5] Therefore, isolated nerve injury should no longer be considered an indication, in and of itself, for amputation. The final individual factor for amputation versus limb salvage is the extent of muscle and skeletal damage. Because even severe open and segmental fractures with bone loss can be provisionally stabilized with external fixation, recent advances in limb salvage have been remarkable. The goal of limb salvage thus remains to provide a functional limb with reasonable sensation and mobility. The challenge, then, is to predict those limbs that have the potential for achieving this goal. The degree of muscle loss appears to be the best predictor of function. Massive loss, involving multiple compartments or an extensive zone of injury, carries a grim prognosis, and primary amputation is most likely the best decision in such cases.

Another aspect of combat amputations and surgical decision-making involves the larger spectrum of limited hospital resources. The acutely injured patient, initially managed by buddy aid (level-I casualty care), receives a tourniquet, hemorrhage control, and rapid evacuation. Level-II facilities, a battalion aid station or possibly a forward surgical team, provide advanced trauma life support, possibly including damage-control surgery, stabilization or open amputation, and approximately 10 to 20 units of blood. It should be noted that in civilian settings, the average trauma resuscitation requires around 30 units of blood. Most Army combat support hospitals (level III) typically have enough equipment to perform two to four simultaneous surgical procedures and maintain less than 100 units of blood, enough for two or possibly three major trauma resuscitations. Therefore, lengthy and extensive procedures may lead to surgical delays, which could have devastating consequences for incoming patients in dire need of surgical stabilization. The concept of "damage control surgery" in a combat zone or mass casualty situation demands brief, focused, initial stabilization for as many patients as possible. This applies to the soldier with a mangled limb as well. Often, salvage is questionable, and additional cases are waiting. This situation forces difficult choices: life must be favored over limb, and occasionally the decision-making process for an individual patient must also include assessment of patients in the holding area as well as those in the operating suite. Whenever possible, the optimal decision is to initially spare the limb, stabilize any surgical injuries, and establish conditions for subsequent reassessment and informed discussion.

Surgical Goals

Surgical goals during the initial treatment stage are to thoroughly excise contaminated wounds, retain viable tissue for subsequent reconstruction or amputation coverage, and ultimately leave the wounded warrior with the highest potential for a useful limb, either salvaged or with a prosthetic device. The three most critical principles to follow when combat wounds necessitate amputation are (1) to thoroughly debride the residual limb, (2) to preserve as much salvageable tissue as possible, and (3) to leave the wound open.[6] Historically, war surgery often meant a "guillotine" amputation, in which the blade sliced through all tissues at the same level (Figure 8-1). This antiquated technique leaves no residual tissue for later closure, coverage of the bone, or potential for modern pros-

Figure 8-1. Open bilateral transfemoral guillotine amputations. The failure to leave any additional viable tissue for coverage limited subsequent reconstructive options, and the patient required substantial shortening of both residual limbs to achieve a functional myodesis and soft tissue coverage.

thesis management at the initially amputated level. Somewhat more recently, the concept of an open circular amputation has been advocated. This technique incises the skin, followed by skin retraction, then the muscle at a higher level, and, after muscle retraction, bone sectioning is conducted so that all planes roughly corresponded to a transverse amputation. Current consensus among war surgeons recommends removal of nonviable tissue at the lowest level, retaining irregular yet viable tissues (Figure 8-2). Rather than fashioning formal tissue flaps, this technique should include preservation of viable tissue to optimize later definitive closure and maximize ultimate residual limb length.

Orthopaedic surgeons often focus erroneously on the bone, whereas in most amputations the best predictor of length, final closure, and ultimate function is the soft tissue. A stable, well-padded residual limb with adequate soft tissue coverage is far more predictive of functional prosthetic use than simple residual limb length. In the immediate setting, preservation of bone length provides soft tissue support, minimizes edema, and seems to be least painful. It is not unreasonable to externally fixate fractures proximal to an amputation, as long as the nonviable soft tissue is completely debrided. In fact, when critical length can be maintained through proximal fracture fixation, this technique is warranted and should be advocated. All frankly devitalized skin, muscle, and fat must be removed. If there is question of viability, the authors recommend leaving skin, removing questionable fat and fascia, and applying the "four Cs" (developed during the Korean War) to muscle: color, consistency, circulation, and contractility.[7] Residual devitalized deep tissue, left for subsequent surgeons throughout the evacuation chain, results in a risk of sepsis, myoglobinuria, and systemic inflammatory response, which can be fatal. If bone has periosteal attachments, it should be retained, and whenever possible externally stabilized.[8]

Nerve Management

The management of sectioned nerves remains a controversial aspect of amputation surgery. The free end of a divided nerve heals by forming a neuroma. Neuromas can frequently become symptomatic, and no described technique has been convincingly proven to prevent or ameliorate this process (neuroma preventative treatment and management is discussed later in this chapter). In the acute setting, even transected or injured nerves should be preserved in patients in whom limb salvage is attempted, potentially permitting later repair or reconstruction without creation of prohibitively large segmental defects. Transected nerve ends may be tagged with suture to assist in later identification for surgeons further up the evacuation chain.

For traumatic amputations or limbs deemed unsalvageable and undergoing amputation at the initial point of operative care, the surgeon's goal is to retain and employ as much useful nerve function in the residual limb as possible, just as with the conservation of muscle tissue in the residual limb. Nerves should be transected sharply under gentle tension and allowed to retract into viable soft tissues proximally. This process may prove to be definitive management of some nerves, and maximizes patient comfort during subsequent transport, dressing changes, or operative procedures. Sensory branches generally depart motor

a b

Figure 8-2. (a) Open, length-preserving transradial amputation. **(b)** The salvage of viable distal soft tissues permitted closure with an atypical flap of native tissues, not requiring flaps or grafts and retaining a functional transradial residual limb length.

nerves well proximal to their corresponding area of cutaneous innervation, but residual limb sensibility should not be compromised by overzealous nerve transection well proximal to the amputation. This consideration is important in segmentally injured limbs in which a nerve may be injured or exposed well proximal to the ostensible level of final amputation.

Care should be taken not to perform group ligation of vessels and adjacent nerves. Likewise, inadvertent deinnervation of remaining viable muscle groups, which can compromise residual limb control or result in eventual muscle atrophy and inadequate resulting soft tissue padding, should be avoided. This consideration is particularly critical in the upper extremity, where myoelectric prostheses are frequently desired and utilized. Furthermore, several investigators are currently evaluating reinnervation, nerve transfers, and even the potential for neural-prosthetic interfaces. Thus, in upper extremity amputations, particularly those proximal to the elbow, it is reasonable to forgo traction-assisted nerve transection and salvage transected nerve length by simply burying the cut nerve end within or deep to adjacent muscle.

Open Wound Management

Combat wounds must always be left open. A dry bulky gauze dressing, the historical standard, can be readily applied in all situations. Occasionally, skin traction can be applied, but the authors have not found this to be a strong contributor to accelerated functional limb closure. No strong evidence exists to support skin traction technique in contemporary war injuries subject to the stresses of evacuation. Rigid dressings or external fixation, as stated earlier, can stabilize soft tissue, and may assist with pain reduction during transport. Recent advances in open wound management have been applied to open amputations. Negative pressure wound therapy is an aggressive method to provide optimum wound-healing potential. This concept enhances vascularity, minimizes additional tissue necrosis and wound contamination, and has been widely used to temporize management between serial debridements.[6,9] Currently, protocols are underway to investigate the safety and effectiveness of negative pressure wound therapy as the patient traverses the air evacuation chain. If these prove successful, the therapy's application in theater is likely to eliminate any need for skin traction techniques.

Upper Versus Lower Extremity Considerations

The surgical considerations involving lower and upper extremity combat injuries are different. The weight-bearing nature of the lower extremity requires adequate soft tissue and a flexible and hopefully sensate residual limb, whereas the motion and intricate functional demands of the upper extremity are quite different. Additionally, prosthetic technology for upper and lower limb amputations is also vastly different. Lower limb prosthetic demands primarily involve durability and preserving energy expenditure during ambulation, whereas upper limb prosthetic demands are focused on lightweight devices that can adapt to multiple diverse functional activities. Therefore, in the upper extremity, surgical length often takes a higher priority than achieving robust soft tissue padding. In addition, definitive closure using partial thickness grafts is generally well tolerated for the upper limb. These differences in residual limb coverage and prosthetic management must be considered by the initial combat surgeon to maximize patient outcomes.

INDICATIONS AND TIMING FOR DEFINITIVE CLOSURE

Wound closure is undertaken only when strict criteria for residual tissue viability are met. In the absence of better indicators, military practitioners should use the four Cs to judge the viability of muscle.[7] Wounds cannot be closed over nonviable muscle, and it often takes several debridements for residual tissue to declare itself. This is particularly true in burn patients, who must have all nonviable and grossly contaminated tissue excised. In blast wounds, debris tracks proximally along fascial planes. This contamination may be masked by the elasticity of skin, and is easily missed in mass casualty situations. Once the patient arrives at a level-5 facility, the resources are available to ensure a calm, meticulous, and systematic surgical evaluation to determine the complete extent of the injury. Several additional debridements may be necessary to ensure that all nonviable tissue is excised. Fortunately, military resources allow for a less aggressive initial surgical approach than the treatment advocated by the International Committee of the Red Cross, which has published the most recent civilian discussion of treating war wounds, and is directed toward saving life over limb, especially in circumstances of limited resources.[10]

Negative pressure dressings are very useful during the period before wound closure, maintaining a favorable wound environment and promoting the formation of granulation tissue. When performing dressing changes using traditional bulky dry dressings, the presence of greenish drainage or some odor does not equate with infection, if the wound appears otherwise healthy. Similarly, growth on microbiologic cultures does not *per se* indicate infection. War wounds are often colonized without being "infected" and can be successfully closed when (*a*) the wound appears clean, (*b*) the patient shows no signs of systemic illness, and (*c*) no necrotic tissue remains. However, if the wound is colonized by multidrug-resistant organisms, antibiotic therapy is generally warranted. Empiric antibiotics should usually be continued for 72 hours after closure of wounds that are culture-negative or without gross evidence of infection. Topical wound care solutions can also decrease bacterial colonization for many severe open wounds. Although some topical solutions have fallen out of favor in most civilian wound care centers because they may slow granulation or epithelial cell growth, control of bacterial colonization must be achieved. In severe trauma, especially that seen in military combat, aggressive topical wound care solutions still have an important role.

Nutritional support plays a critical role in achieving successful wound closure and the ongoing resuscitation of wounded service members. The wound healing process has a catabolic effect on the individual, which combined with long transport times, sedating and nauseating medications, long periods of intubation, concurrent abdominal or facial injuries, and multiple returns to the operating room interrupting intake, nutritional deficits that impair wound healing develop rapidly and almost universally. Weight loss of 30 lb in 2 weeks is not uncommon. Serum albumin and prealbumin levels should be monitored and maintained above 3.5 g/dL and 20 mg/dL, respectively, if at all possible. Gastric feeding is preferable to parenteral nutrition because it reduces the incidence of multisystem organ failure and parenteral nutrition-related complications.

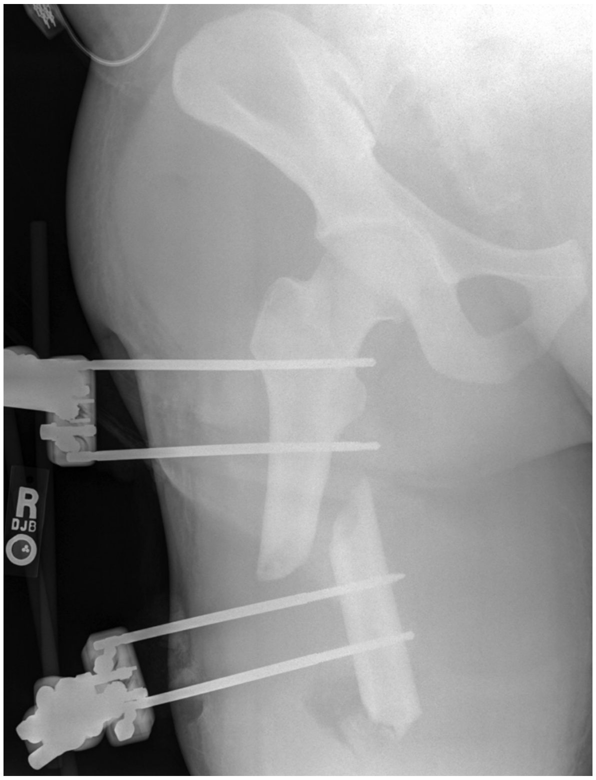
Limbs that have sustained traumatic amputation in combat are frequently injured at multiple levels. Length and levels should be preserved whenever possible. The soft tissue injury dictates the final level of amputation, not the level of bony injury—a problematic transtibial amputation will likely function better than a long transfemoral amputation, and a long transfemoral amputation in the zone of injury usually functions better than a short transfemoral amputation above the zone of injury. It is important to keep an open mind, approaching each patient's situation unencumbered by traditional concepts of "appropriate" fracture fixation and "standard" closures. In accordance with International Committee of the Red Cross guidelines, the authors advocate length-preserving amputation techniques with closure by nontraditional flaps whenever possible (Figure 8-3).[11] Military surgeons have been successfully inventive in preserving length in the face of fractures and soft tissue defects. One example of this is the use of pediatric flexible intramedullary rods to fix fractures of the femoral diaphysis in transfemoral amputees (Figure 8-4).[12] Similarly, rotational and free tissue flaps are used whenever possible to retain an otherwise unsalvageable level or critical diaphyseal length. Especially in the multiple injury patient, preserving a viable, but unsalvageable, extremity until the time for definitive closure allows the amputated

a

b

Figure 8-3. Open, length-preserving transfemoral amputation in a bilateral transfemoral amputee **(a)**, permitting eventual closure with atypical flaps **(b)** in an injury pattern that might otherwise have required hip disarticulation if a guillotine or open circular amputation had been performed in theater.

a



b

Figure 8-4. Radiographs of a transfemoral amputation with a proximal fracture provisionally stabilized with external fixation **(a)** and after definitive revision and closure following stabilization with flexible intramedullary nails **(b)**.

part to serve as a source of autograft bone and skin to facilitate reconstruction of the other perhaps more functional residual limbs.

Retained bone must have soft tissue attachment and must bleed when ronguered. Exceptions are made if there is a large amount of articular cartilage on a dysvascular fragment, which may be initially retained in the interest of preserving articular congruity. However, in the face of deep wound infection, these fragments must be excised. Similarly, every attempt should be made to retain nerves and vessels, for without these structures, distal tissues will not survive with useful residual function.

Orthopaedic surgeons have long been taught, in treating civilian blunt trauma, that coverage must be achieved within 7 days to maximize patient outcome. This principle does not fully apply to combat wounds, where it is more important to have all nonviable tissue removed and no evidence of infection prior to definitive closure. Unfortunately, no objective criteria can reliably indicate the optimal timing for wound closure, so careful surgical judgment is needed.

The treatment of retained fragments or foreign bodies also requires careful judgment. Injuries caused by explosively formed projectiles, IEDs, or antitank mines may lead to dozens of retained foreign bodies in the patient. Fragments may include pieces of the explosive device itself, spall from the interior of a vehicle, or soil and gravel from the surrounding site of the blast. Removal of every foreign body is often impractical due to the damage it would cause to the surrounding soft tissues. Many fragment wounds will heal uneventfully with only local wound care, and a scar will generally encapsulate the fragment. These wounds should generally be treated with "watchful waiting," debriding only those fragments that become infected, are painful, or negatively impair function. Exceptions to this principle include intraarticular fragments, which may damage the joint mechanically or by the toxicity of heavy metals, and large, superficial fragments that may interfere with prosthetic fit.

Heterotopic ossification (HO) has been a significant problem for service members with an amputation from combat injuries sustained in OIF/OEF. It is believed that the greatest risk of HO formation occurs when the amputation is performed through the zone of injury. Revision surgery because of HO complications may occur in approximately 15% of patients.[13] The pathophysiology, prevention, and optimal treatment of HO is currently under investigation. A more complete discussion of this topic can be found in Chapter 9, Special Surgical Considerations for the Combat Casualty With Limb Loss.

In summary, decisions regarding definitive closure are guided by established general principles, but best executed with the gestalt gained by experience. The soldier who sustains an amputation is best served by the surgeon who follows accepted general tenets of debridement, who is experienced enough to differentiate the subtleties between infection and colonization, and who is skillful enough to employ inventive techniques for fracture fixation and soft tissue coverage—allowing preservation of functional length and levels to achieve a sound, painless, durable residual limb.

MANAGEMENT OF SOFT TISSUE AND MUSCLE

Muscle

In the treatment of extremities injured by the various implements of war, the surgeon is often forced to use what muscle and fasciocutaneous tissues remain and are viable. However, the basic principles of amputation surgery remain the same, with the goal of providing a functional residual limb that can be fit by a prosthetic socket. To achieve this goal, the residual limb is best covered with muscle to provide padding and sometimes aid in control of the terminal extremity. An important component of this principle is defined by how the muscle is treated when closing the amputation. A muscle that is not secured under physiologic tension and does not have fixed resistance will atrophy over time, becoming weaker and providing less padding over the bony prominences. Many of the muscles used in amputation surgery cross a proximal joint (eg, adductors, quadriceps, and hamstrings in transfemoral amputations or the gastrocnemius in transtibial amputations), providing function and stability. Several different techniques for maximal muscle treatment have been utilized, each with relative benefits and deficiencies.

Myofascial Closure

To provide a soft tissue envelope over the distal bone via myofascial closure, the outer fascial envelope over the top of the muscles is approximated. This technique approximates only loose tissues, providing minimal tension and stability to the underlying muscles. In dysvascular patients the absence of muscle and tissue tension provides a possible benefit,[14–16] and the technique is also thought to maximize the remaining blood flow to optimize healing. However, even in dysvascular and diabetic patients, the benefits of this technique are more theoretical than proven. Because of the loose attachment, myofascial closure alone does not generally provide a limb suitable for prosthetic fitting and use. Therefore, muscle stabilization is critical to a successful surgery and is almost always possible.

Myoplasty

Most amputations seen in war surgery are diaphyseal (mid-bone) in nature. Whether the muscles are severed at this level by the blast, fragments, or other projectiles or surgically transected, the muscle belly is often encountered in cross-section without distal fascia, aponeuroses, or tendons. This is seen in most transhumeral, transradial, transfemoral, and transtibial amputations. To provide closure with the myoplasty technique, the muscle from the opposing muscle groups (quadriceps and hamstrings in a transfemoral amputation) are sewn to each other, covering the transected bone end. Although this is much easier than attaching the muscle to bone and provides more stabilization of the muscle than a myofascial closure, it is not recommended for routine amputation closure. Unless the muscle firmly adheres to the underlying bone and tissues, the myoplasty unit may move with contraction of either opposing muscle group, and a painful bursa can develop either between the muscle and bone or muscle and overlying soft tissues. Faulty adhesion can be detected on physical examination by palpating the muscle motion over the bone with the accompanying crepitus from the problematic bursa. Likewise, deliberate or inadvertent contraction of the involved muscle groups may lead to motion and shifting of the overlying skin within a prosthetic socket, leading to irritation and friction-related complications.

Myodesis

To avoid the complications associated with either myofascial closure or myoplasty, the muscle fascia of the padding or controlling muscle groups within a given residual limb should in most cases be attached to the end of the bone, a technique termed myodesis. Myodesis prevents motion over the bone end and provides padding between the bone and overlying prosthetic socket. One of two methods is utilized to perform this part of the amputation procedure: (1) connection of the muscle to bone through drill holes, or (2) connection of the muscle to the periosteum (Figure 8-5). Once the myodesis is performed, the remaining muscle fascia can be approximated using the techniques described above for myofascial and myoplasty stabilizations (Figure 8-6). In the typical transfemoral amputation the muscle bellies are transected and only the muscle and investing fascia may be available to attach to bone, and getting suture to hold in the muscle tissue and overlying fascia can be difficult.[17] In such cases, a muscle-grabbing suture technique can be used, achieving muscle-bone opposition under reasonable tension without undue tissue strangulation.

Tenodesis

Depending on the level of amputation, tendon may be associated with the muscle intended for attachment to bone. The presence of such tendon provides the ability to achieve good purchase with suture, allowing for the most effective type of muscle stabilization. Unfortunately, most amputations require transection of the muscle belly, leaving no tendon associated with the remaining muscle to allow bony attachment. However, in disarticulations and some transtibial and transradial amputations, tendon may still be present at the level of the amputation. This tendon can then be directly connected to the transected bone, as is the case for knee disarticulations, where the patellar ligament may be sutured to the origin of the cruciate ligaments. Additionally, for long transtibial or Syme amputations the tendon of the gastrocnemius muscle may be connected to the posterior tibia.[18] Lastly, for transradial amputations, several muscle groups may be utilized to perform multiple myodeses to bone, maximizing distal soft tissue and residual limb control.

Muscle Tension

During stabilization, it is important to secure muscle under appropriate tension to ensure the maximum benefit. Appropriate tension may be difficult to determine in the operating room, because physiologic resting tension of the muscle is not studied in most surgical training programs. Experience gained from tendon transfers in the hand and foot can be a useful guide. Too much tension may cause pain because of persistent stretch on the muscle, and, in the absence of stable myodesis performed through robust, suture-holding tendon and fascia, lead to failure of suture fixation. Additionally, in instances where the muscle would normally cross two joints, proximal deformity and contractures may occur. For example, in transfemoral amputations overtensioning the quadriceps may lead to a hip flexion contracture because of the attachments above the hip joint. However, these instances are rare, and the surgeon should place a moderate amount of tension on all muscle attachments, especially when the muscle is important in stabilizing the residual limb (eg, adductor myodesis for transfemoral amputations). As a general rule, the surgeon should err on the side of too little rather than too much tension.

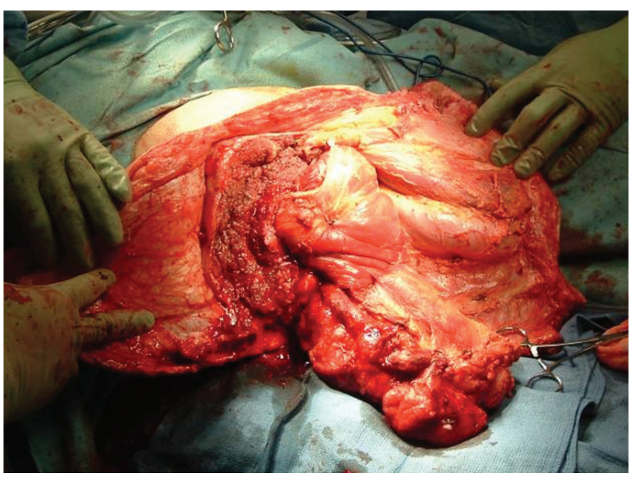


Figure 8-5. Transfemoral amputation with atypical skin flaps demonstrating use of the myodesis technique through drill holes in the femur to attach the adductor magnus muscle to the bone.

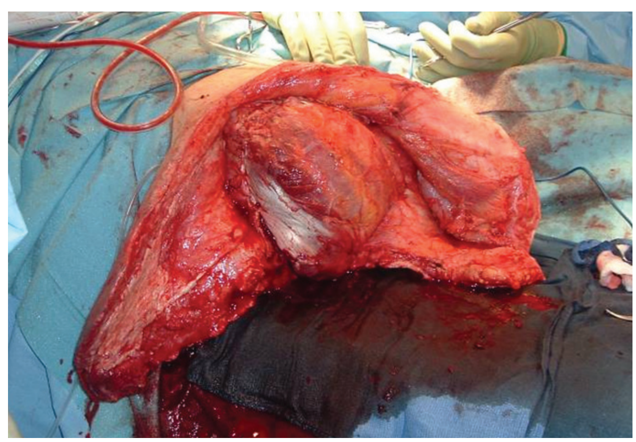


Figure 8-6. The amputation in Figure 8-5 after myoplasty of the quadriceps and hamstring muscles over the adductor muscle previously attached to bone (myodesis).

Skin Traction

One of the basic tenets of amputation surgery is that residual limb length directly correlates with patient function. Although this concept is generally true,[5] exceptions remain. For example, a very long transtibial amputation may limit the accommodation of advanced foot and ankle components. Similarly a very long transfemoral amputation may not accommodate more advanced knee components, thereby potentially limiting an individual's ultimate functional capacity. Despite these exceptions, it still remains the surgeon's goal to salvage as much of the limb as possible, especially when a joint is involved.

As previously stated, most traumatic amputations caused by explosive ordinance do not leave an abundance of viable tissue to work with. In past conflicts, it was commonplace to perform an open circular or guillotine amputation above the zone of injury, often followed by skin traction techniques to slowly pull the skin and dermal tissues over the end of the bone. The primary benefits of this technique included length preservation of the residual limb and low infection rates. Essentially, the limb was maintained in traction with daily dressing changes that allowed for application of various topical agents (eg, Dakin solution) and provided an environment inconducive to bacterial infection. The primary, and very important, downside to this technique, however, was the formation of an adherent, scarred, and thin covering over the distal residual limb, causing difficulty for prosthetic fitting. Therefore, this technique is currently not advocated for routine use.[19–21]

A newer variation on the use of skin traction is currently being applied to the treatment of residual limbs. As discussed previously, to preserve as much length as possible, circular amputations should be avoided. As much bone and soft tissue as possible should be left after the debridement is performed, even if only atypical muscle and fasciocutaneous flaps remain. A thorough debridement, typically performed through the entire zone of injury, is utilized to remove any devitalized tissue. After each debridement the tissues are partially closed over a vacuum-assisted closure device sponge (VAC; KCI, San Antonio, Tex) with vessel loops or no. 2 nylon, providing tension over the end of the bone (Figure 8-7). This technique prevents the muscle and fasciocutaneous tissues from retracting. Antibiotic beads may be placed in the deep tissues if infection is a significant concern. These beads may be tailored to the bacteria isolated in previous cultures. When operating within the zone of injury, it is often unclear which tissues will remain viable; therefore, multiple debridements must be performed to ensure that all nonviable tissue is removed. When the amputation is ready for closure, typical myodesis and tenodesis techniques should be applied. Even when atypical skin flaps are present, the skin should be primarily closed, except when skin grafts are necessary.

Although the application of skin traction with the VAC saves length and amputation levels, it is not without complications or deficiencies. It is an extremely labor intensive technique, requiring multiple debridements and/or dressing changes under sedation every 2 to 3 days. Additionally, the formation of HO may be associated with amputations through the zone of injury and the use of pulsatile irrigation or VAC dressings. Traditional skin traction techniques permitted dressing changes at the bedside, infrequent visits to the operating room, and a less frequently reported incidence of HO formation, but did not offer the ability to save as much residual limb length as today's techniques.

Figure 8-7. Technique using the vacuum-assisted closure (VAC) device and vessel loops for skin traction over the remaining bone.

MANAGEMENT OF NERVES

When performing an amputation at any level, the surgeon is faced with the decision of how to manage the transected nerves, with the primary goal of preventing a *symptomatic* neuroma. Every transected nerve will heal by forming a neuroma, which has the potential to become a source of pain in the residual limb with stimuli such as pressure, stretching, vascular pulsation, or other types of physical or physiologic irritation to the terminal neuroma bulb. Numerous techniques to minimize symptoms associated with neuroma formation have been described, but none have proven to be superior to any of the others, and the choice of technique remains a controversial aspect of amputation surgery.

Traction neurectomy involves identifying and isolating all major nerves in the limb, then applying moderate tension prior to dividing them. The nerves are then allowed to retract proximal to the wound into the muscles of the residual limb. This technique provides a technically simple way to move the eventual neuroma away from the expected areas of scarring, pressure, and pulsating blood vessels. Surgeons occasionally implant the end of the transected nerve into muscle or bone in an attempt to "give the nerve something to do."[22] Although both of these techniques have had good results reported when dealing with painful neuromas in nonamputated limbs,[23] their application in primary amputation surgery is not well documented. When performing an amputation, the latter technique, implanting the cut nerve into muscle or bone, involves transecting relatively less of the nerve so that the surgeon can perform a tensionless attachment of the nerve end into the muscle or bone, although usually still within the amputation wound. Because the nerve cannot retract as far proximally as it could with a well-done traction neurectomy, this technique may, in fact, contribute to the development of a painful postsurgical neuroma. Nerves within wounds are exposed to tension, pressure, anoxia, infection, and delayed wound healing, have been found to have increased amounts of connective tissue, and may be prone to painful neuroma formation.[24] Additionally, because of the nerve proximity to the end of the residual limb, they may be more prone to pressure, friction, and tension from a prosthetic socket.

Other described techniques for managing transected nerves include cauterization of the nerve end, ligation, nerve capping, and end loop anastomosis, but no definitive evidence exists demonstrating that these are more effective than a carefully performed traction neurectomy. Management of the sciatic nerve, however, is unique because of its own intrinsic large blood vessel. This nerve requires ligation prior to transaction to prevent significant bleeding, which may be associated with critical blood loss, hematoma formation, or wound breakdown.

Nerves frequently run parallel with major pulsating blood vessels, and the surgeon performing the amputation should take great care to prevent group ligation of nerves and blood vessels. Although no definitive proof exists, it seems logical that the presence of a pulsating vessel adjacent to a neuroma could lead to the throbbing pain reported by many amputees. In such situations, a revision surgery aimed at separating the nerve and artery vessel, re-ligating the vessel, and performing a better traction neurectomy, will allow the nerve to separate from the pulsating vessel and alleviate these symptoms.

A new and innovative technique in the management of nerves in amputation surgery, called targeted reinnervation, is now being investigated.[25–29] Preliminary results are very promising when the technique is applied to transhumeral and shoulder disarticulation amputees. The technique involves the dennervation of specific nonessential muscle bellies located within the residual limb, followed by the transfer of a freshly transected major mixed nerve of the upper extremity into the motor end point of the freshly dennervated muscle. Reinnervation of the muscle occurs very predictably with the transferred nerve, and the brain signals associated with the intuitive activation of that nerve lead to specific patterns of muscle contraction in the newly innervated muscle belly.

This procedure has been employed to achieve an increased number of surface myoelectric sites with more intuitive control. Thinning the adipose tissue under the skin also improves myoelectrical recording capability. Subsequent mapping of the contraction patterns associated with specific upper extremity functions, and wiring these surface electrodes to certain advanced myoelectric prosthetics, allows the use of an upper extremity prosthesis with multiple degrees of freedom at the shoulder, elbow, wrist, and digits. The end result can be far more efficient in performing fluid motion and manipulative tasks than previous generations of myoelectric prostheses. Although additional research is needed before this technique can be recommended for widespread application, the early results are promising and compelling.

DRESSINGS

Most surgeons are a product of their cumulative experiences, and when a clear standard has not been convincingly established through evidence-based medicine, multiple treatments are frequently recommended and rendered for any given condition. Such is the case with postoperative dressings after amputation surgery—while one surgeon may prefer a splint or cast, another would use padding and an elastic bandage on the same residual limb. The basic considerations for postoperative dressings are soft dressings, rigid dressings, and immediate postoperative prosthesis (IPOP). Each dressing technique has its own benefits and limitations.

Balanced compression of the residual limb is important, particularly in the early postoperative period. This helps to control swelling, which further minimizes postoperative pain and promotes a stable limb volume. Support of soft tissues is also important because the muscle and skin flaps require a tension-free environment for optimal healing. Some combination of compression and support is provided by each category of dressing.

Soft Dressings

A soft dressing is commonly applied in the care of the young combat amputee. Often first applied in the operating room, it provides a sterile dressing covered by an elastic bandage. The classic application of the elastic bandage is in the "figure 8" pattern. While using one hand to support the myofascial and fasciocutaneous flap, the bandage is applied with care taken to evenly distribute compression and to relieve tension on the flap and suture line (Figure 8-8). This type of dressing, with modifications, can be applied to any residual limb.

Careful application is paramount to avoid overcompression or a possible tourniquet effect, particularly near joints. With a transtibial or transradial amputation, the elastic bandage can act as a tourniquet, particularly at the joint level as the patient flexes and extends the joint immediately proximal to the amputation. In the perioperative phase, abundant padding with Webril (Kendall Company, Mansfield, Mass) or similar material under the elastic dressing, as well as extending the dressing well above the knee or elbow, helps to avoid this complication. Transition to a shrinker sock should be initiated as soon as possible.

Although soft dressings provide easy access to the wound, many surgeons feel that they do not provide sufficient compression or support to the residual limb to promote proper healing through soft tissue rest. No studies have shown a clear advantage of one type of dressing over another, but several have shown a trend toward better healing with rigid dressings.[30–36] However, soft dressings may facilitate unencumbered early mobilization of patients and allow focused early rehabilitation of more proximal muscles and joints within the residual limb. As stated above, dressing selection is very dependent on the surgeon as well as regional and hospital preferences.

Rigid Dressings

The dressing of choice for most surgeons for the transtibial amputation has traditionally been the rigid dressing, either in the form of a splint or cast. Early in its history this type of dressing was modified to include IPOP, which will be discussed in the next section. It is generally believed that injured tissues heal more consistently and with less pain when placed at rest. The three basic principles applied here are immobilization, application of gentle distal pressure, and infrequent dressing changes. These principles have

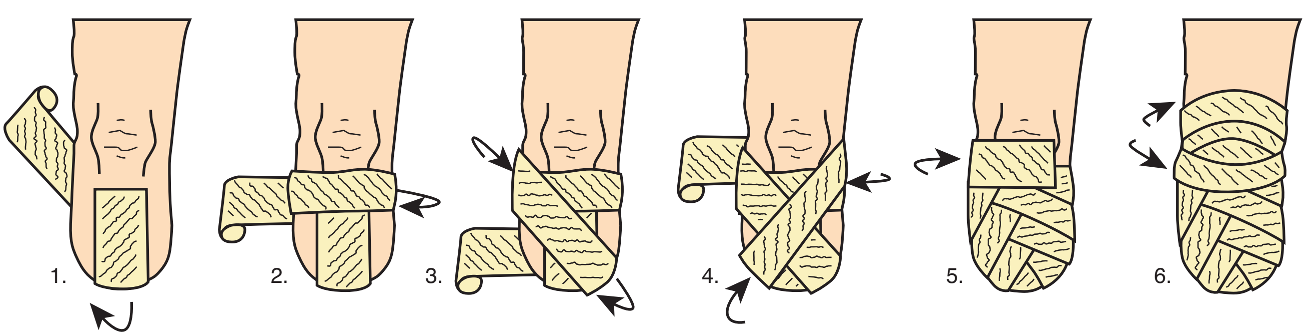


Figure 8-8. Application of a typical "figure 8" dressing. This provides support to the underlying tissues as well as compression.

been shown over time to be effective in the treatment of residual limbs.[37]

During the application of this type of dressing, several technical tips are warranted. Failure to follow the tenets of splint or cast application can lead to significant adverse complications. Extra padding should be placed over the patella when placing rigid dressing for transtibial amputations to prevent skin irritation and pressure necrosis in that area. Alternatively, the patella can be omitted entirely from the splint, with distal compression provided through a combination of plaster and soft dressing while the splint material assists in flexion contracture prevention (Figure 8-9). Although less of an issue and less frequently utilized for transradial amputations, the olecranon should also be meticulously padded for the same reason. The distal end should be well padded to maintain balanced pressure and gentle circumferential compression. Closed-cell foam or other similar material can be used for this purpose. A supracondylar mold is necessary to keep the dressing in place, avoiding distal migration of the cast or splint. With loss of distal-to-proximal pressure, unrelenting terminal edema can occur, resulting in severe wound complications. Patients and staff must be educated to avoid this situation and can assist by placing distal pressure with a looped towel or pulling up the dressing during straight leg raises.

One drawback of rigid dressing application actually contradicts one of the stated benefits, which is the need for infrequent dressing changes. In the combat amputee with an amputation performed through the zone of injury, the possibility of infection is a major concern. Many times the patient has undergone multiple thorough debridements, with healthy-appearing tissue prior to closure. Nonetheless, in these cases the authors have seen a high incidence of wound infections at 3 to 5 days after closure. Early detection of these cases is paramount to preventing tissue necrosis and salvaging soft tissue and possibly amputation level. Frequent dressing changes are therefore necessary, and rigid dressings have often been avoided for this reason. However, after the immediate postoperative period, soft dressings can be transitioned to rigid ones and wounds can generally be monitored via attentiveness to fluctuations in patient signs (eg, fever) and symptoms (eg, increasing pain).

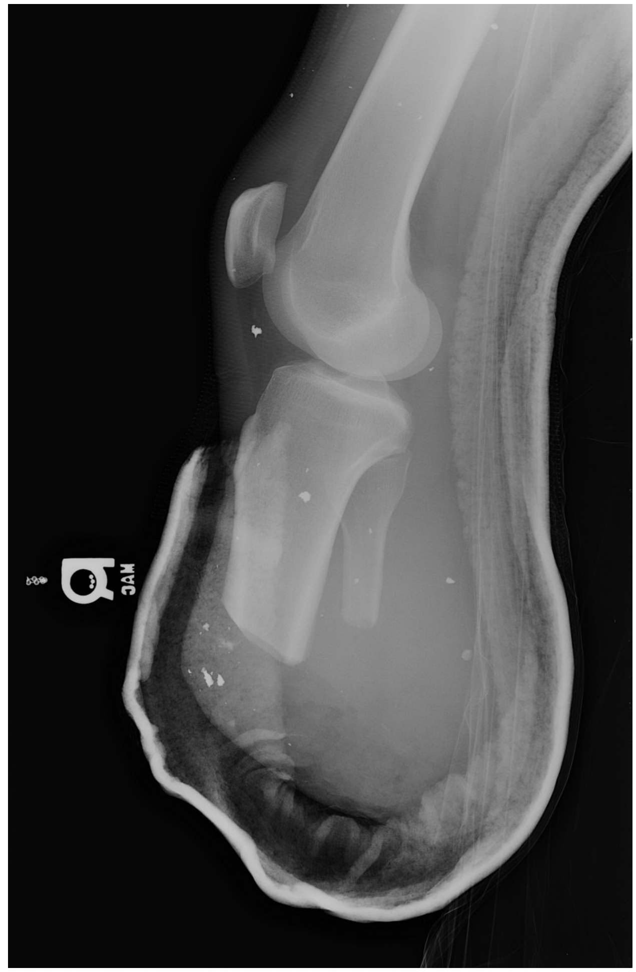


Figure 8-9. Lateral radiograph of a well-padded transtibial amputation in a posterior splint designed to prevent knee flexion contracture but avoid potential patella-related complications.

Immediate Postoperative Prosthesis

A frequently cited source of controversy in amputee care has been the IPOP. The concept of early weight bearing through a rigid dressing was proposed by Wilson shortly after the end of First World War.[38] Many others have used and modified this technique over the years, especially following the Second World War, Korean War, and Vietnam War.[39–42] This evolution has included modifications ranging from casts with lower extremity components applied in the operating room to padded prefabricated sockets with distal components. This technique can be utilized with almost any level of amputation in either the upper or lower extremity.

Regardless of the type of IPOP used, many benefits have been demonstrated. These range from the psychological benefit of having a prosthesis in place immediately after the amputation, with less perceived loss of function, to shorter hospital stays, fewer revisions, and faster time to initial prosthetic fitting.[31,35,43,44] However, most of these studies have been performed in patients who have undergone amputation for nonreconstructible ischemia or infection.

Despite these reported benefits, this technique has been infrequently used in the current treatment of combat amputees because of the extent of soft tissue and other remote injuries. Given the tenuous nature of zone-of-injury tissue damage and frequent use of flaps and skin grafts, early ambulation may compromise healing. Additionally, many of the other injuries sustained from combat, particularly blast injuries (eg, multiple other extremities, intra-abdominal) prohibit early mobilization. Most importantly, however, the authors have recognized that when the definitive amputation is performed in a setting where the patient will receive his or her rehabilitation, the patient has immediate contact with the rehabilitation team as well as other individuals going through amputee rehabilitation, making it much easier to see what the patient's potential function will be. This situation largely outweighs the potential psychological benefit of IPOP use.

UPPER LIMB

Amputations in the upper extremities from combat wounds generally involve massive trauma due to blast munitions, with a large resulting zone of injury. The decision to attempt limb salvage should be based on the technical feasibility of doing so and on the chance of providing a limb that maintains some useful function. Unlike the lower extremity, the upper extremity is nonweight bearing, generally allowing it to function very well despite decreased sensation. When addressing limb salvage versus amputation or residual limb length decisions in an individual with severe upper limb trauma, it is most important, however, to focus on the potential functional rehabilitation of the entire patient, especially giving significant considerations to the impact of other commonly associated severe injuries. In general, the goals of amputation surgery in the upper extremity should be the following: (*a*) preservation of functional length, (*b*) preservation of useful sensibility, (*c*) prevention of symptomatic neuromas, (*d*) prevention of adjacent joint contractures, (*e*) minimal and short morbidity, (*f*) early prosthetic fitting (where applicable), and (*g*) early return of patient to work and recreation.[45]

Hand and Carpus

The severity of amputations involving the hand ranges from single digit tip amputations to multiple digit amputations, loss of the thumb, and partial hand amputations. For most digital amputations distal to the flexor digitorum superficialis (FDS) insertion, skeletal shortening with primary closure or allowing the wound to heal secondarily will provide for early mobilization of the digit and yield a durable tip with excellent sensation and an acceptable appearance. Local advancement or pedicled soft-tissue flaps have limited application in the combat amputee for treatment of fingertip and distal amputations of digits. The adjacent tissue has usually also been injured to some extent by the blast, and attempting to mobilize it for wound coverage may lead to necrosis and further soft tissue loss. Additionally, these techniques usually require the restriction of adjacent joint and/or adjacent digit motion during the first 3 to 4 weeks following the flap procedure, risking the development of contracture and stiffness, and further limiting the use of the upper extremity in early phases of the patient's rehabilitation.

When a digit is severely injured proximal to the FDS insertion, the surgeon should make every attempt to salvage the important proximal interphalangeal joint. A stable skeletal core and functional arc of joint motion under active flexor/extensor control, with a viable, sensate, and durable soft tissue covering, are the desirable end points. However, when the degree of injury is too severe to salvage the proximal interphalangeal joint, the surgeon is faced with the decision of amputation through the proximal phalanx versus metacarpophalangeal joint (MCPJ) disarticulation or metacarpal ray amputation. Preservation of as much proximal phalanx as possible is desirable, because the remaining segment will be under the control of the intrinsic muscles and the extensor digitorum communis. Active flexion of the proximal phalanx up to 45° is possible with the intrinsics, and the remaining digit can participate in grasping and holding within those limitations.

If a relatively long portion of the proximal phalanx can be preserved, a flexor tendon tenodesis (FDS and/or flexor digitorum profundus) to the A2 pulley under normal resting tension of the muscle-tendon unit (if possible) can give extrinsic flexor control to the remaining proximal phalanx, and make MCPJ flexion up to 90° possible. This adds significant capability for grasping and holding small objects within the palm. If, however, the amputation occurs near the base of the proximal phalanx, the ability of the remaining segment to participate in meaningful grasp and hold is minimal, and the resulting gap (particularly when the long or ring finger is involved) often allows small objects to fall out of the palm. In this situation, consideration should be given to MCPJ disarticulation or more proximal metacarpal ray amputation.

The decision between MCPJ disarticulation and ray amputation is more complex, involving factors such as which digit is injured, palm breadth and strength (particularly grip and pronation), cosmetic appearance, thumb web space impedance, and gap presence. This decision is individualized, and should be based on total rehabilitation needs (ie, other injuries), occupational demands, hand dominance, and psychological impact of hand appearance. It is important to remember that most metacarpal ray amputations are rarely indicated in the acute setting and are performed under elective conditions.

Because of the vital importance of the thumb in grip, pinch, and opposition, every attempt should be made to preserve as much length as possible in thumb amputation. For amputations distal to the interphalangeal joint, it is extremely important to attain sensate, durable, soft tissue and skin coverage. Failure to do so will result in a hypesthetic, dysesthetic, or tender thumb tip, which the patient would likely exclude in performing activities with the hand. For amputations distal to the interphalangeal joint where no bone is exposed, healing by secondary intent gives the most reliable outcome for the demands of the thumb. If this method cannot be used, then cross-finger flaps or radially innervated fasciocutaneous sensory flaps should be considered. For more proximal injuries, the surgeon should attempt preservation of thenar musculature and all remaining joints practicable for later reconstruction efforts, which may include metacarpal lengthening, index pollicization, or toe-to-thumb transfer.

Combat-related injuries to the hand almost always involve more than a single digit, however. In amputations involving multiple digits or partial hand amputations, it is extremely important to save all viable tissue by whatever means possible and preserve it for later reconstructive efforts. Similarly, when traumatic amputations occur through the carpus, the surgeon should preserve all viable tissue at the time of injury to maximize residual limb length and function. Although prosthetic socket design and terminal device availability for amputations at this level are problematic, many patients find the ability to flex and extend the wrist to be very useful for holding and carrying objects against the body, without the need for a prosthesis. Other patients experience significant frustration with the limited terminal devices available for carpus-level amputations and desire the ability to pinch and grasp with a standard terminal device available for transradial amputations. Patients rarely have the ability to make an informed decision about these issues at the time of injury. The surgeon should therefore preserve everything salvageable and allow the patient to evaluate his or her resulting function before proceeding to a more proximal amputation.

Wrist and Forearm

Wrist disarticulation continues to be a controversial procedure. Advantages include retention of most forearm pronation and supination, due to preservation of the distal radioulnar joint, and improved suspension of the prosthetic device, due to the radial styloid flare. Disadvantages include an excessively long and wide prosthetic socket, difficulty fitting in a wrist component, and fewer choices for the terminal device. Additionally, when myoelectric devices are used, there is little room at the distal end of the socket to conceal the electronics and batteries with wrist disarticulation compared to transradial amputations. In performing a wrist disarticulation, it is important to avoid injury to the triangular fibrocartilage and distal radioulnar joint, because preservation of these structures is vital to preserving the potential advantages of the disarticulation versus a transradial amputation.

When performing a transradial (below-elbow) amputation, attempts should be made to preserve as much length as possible because residual pronation and supination of the forearm is directly proportional to the length of remaining radius and ulna. Retaining as much of this function as possible can have a significant impact on the amputee's ability to position the prosthetic terminal device for functions involving pinch and grasp. For individuals with combat wounds, the level of amputation is dictated by the integrity of the soft tissue. Bony length should not be spared at the expense of providing a durable, stable, soft-tissue covering. In very proximal forearm amputations, all efforts should be made to preserve the elbow joint. In this situation, detaching the biceps tendon from the radius and reattaching it to the proximal ulna may allow the surgeon to excise the radius and gain a larger soft-tissue envelope for closure (Figure 8-10). At the very least, this technique preserves elbow flexion and may provide for easier prosthetic fitting at very proximal levels—even 5 cm of ulnar bone length is sufficient to permit transradial prosthetic fitting. Because of the significant advantage of retaining residual elbow flexion, the use of pedicle or free tissue transfers to provide durable soft tissue coverage over a preserved elbow joint is considered by most surgeons and prosthetists to be preferable to elbow disarticulation or transhumeral amputation.

Elbow and Humerus

Disarticulation of the elbow, like disarticulation of the wrist, is a controversial treatment option and amputation level. Its advantages include better suspension and control of the prosthesis, as well as improved

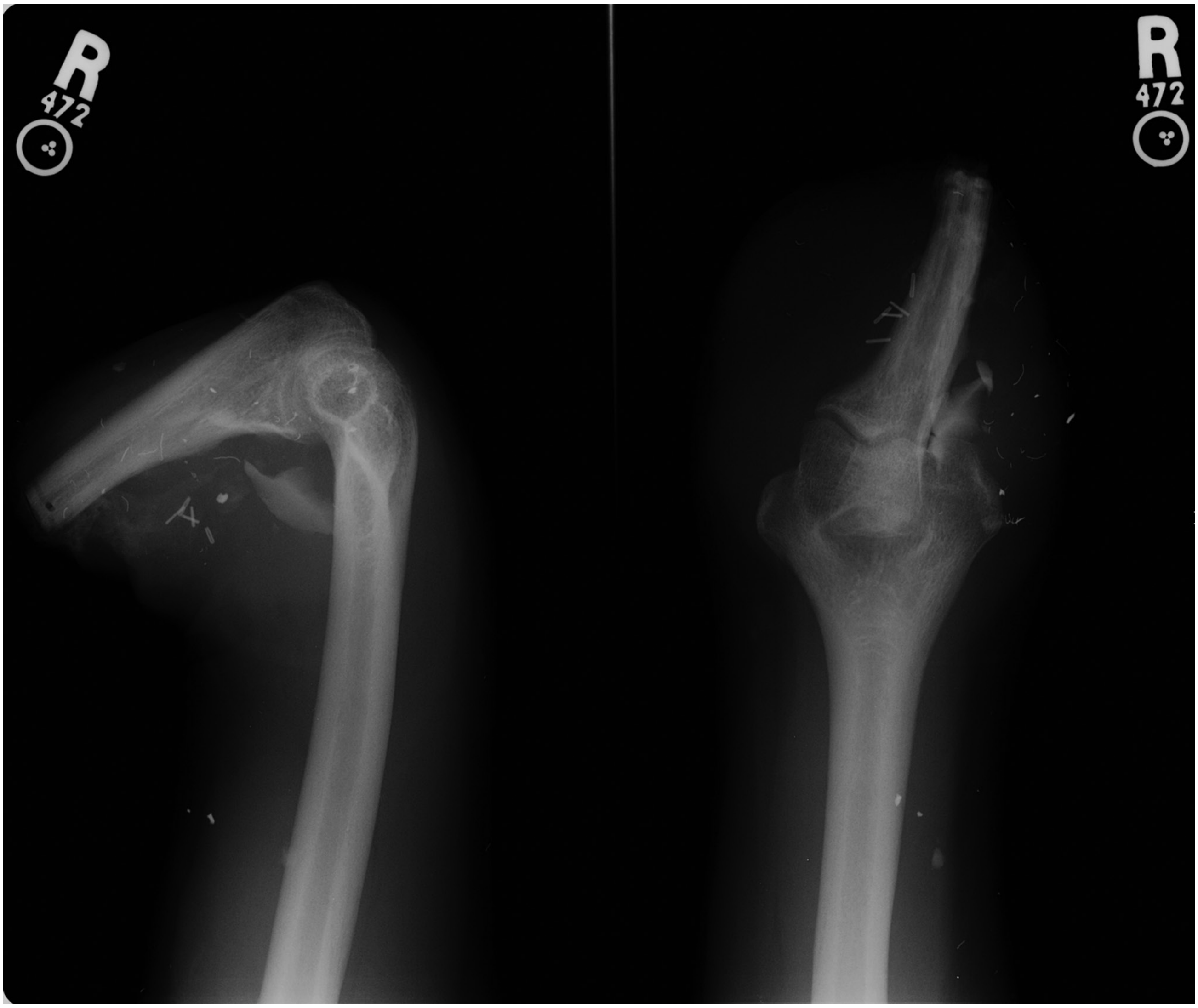


Figure 8-10. Radiograph of a short transradial amputation. The radius was excised due to a comminuted proximal fracture and inadequate available local soft tissue for closure, and the biceps tendon was transferred to the proximal ulna, providing the patient with satisfactory elbow flexion and extension.

function of the residual limb when not wearing the prosthesis due to the longer lever arm and preserved myotendinous units secured to the distal humerus with a tenodesis. The main disadvantages of elbow disarticulation involve prosthetic fitting and appearance. The prosthetic socket is larger than a traditional transhumeral prosthetic socket, and the placement of the prosthetic elbow joint is, by necessity, several centimeters distal to the anatomic joint, creating a disproportionate appearance to the upper extremities. This can be a difficult body image for some patients to accept. Despite the disadvantages of elbow disarticulation, better function and control with and without a prosthesis lends most surgeons and prosthetists to prefer this level over the more proximal transhumeral amputation when adequate soft tissue coverage can be attained.

Transhumeral (above-elbow) amputations should be performed with the goal of preserving as much bone length as possible. The circumferential nature of muscle around the humerus, as well as the fact that it is not, generally, a weight-bearing extremity allows even the use of split-thickness skin grafting over adequate subcutaneous tissue to maintain humeral length. Traumatic amputations, particularly from blast-related wounds, generally have more proximal levels of skin and subcutaneous tissue loss than bone loss, but the surgeon should approach a more proximal bone transection to achieve primary closure with caution. The shorter the residual humeral length, the less control the amputee will have over the prosthesis.

Additionally, it is important to remember that the biceps and triceps both work across the glenohumeral joint, and a secure myodesis of these muscles distally is essential to retain their function in glenohumeral motion. Amputations at the level of the axillary fold and higher function effectively as shoulder disarticulations because essentially all useful glenohumeral motion is lost. At this level, it is important whenever possible to retain the humeral head, which can improve shoulder contour and the fit of clothing as well as prosthetic suspension systems. Some surgeons have even recommended arthrodesis of the glenohumeral joint in extremely short transhumeral amputations to prevent the abduction and flexion contracture that occurs in many of these patients and to provide further prosthesis stability. Although results of this procedure can be gratifying, internal fixation for formal arthrodesis is best performed in delayed, elective fashion in the setting of a contaminated, blast-related wound.

Shoulder disarticulations are generally performed in emergency situations when the patient's life is at stake due to severe proximal trauma. Once hemostasis is obtained and the patient's life is no longer in jeopardy, the clavicle and scapula should be retained if at all possible. Although not necessary or advocated at the initial point of care, the surgeon should strongly consider internally fixing fractures of the clavicle to retain the rigid strut suspending and supporting the scapula and maintain shoulder contour. Because the disfigurement of forequarter amputations is so severe and the fit of clothing so difficult for these patients, extreme measures to save the clavicle and scapula should be undertaken in this circumstance. These injuries, particularly in combat wounds, should not be closed primarily, and the abundance of muscle from the latissimus, deltoid, and pectoralis major make coverage and salvage of the clavicle and scapula possible in the vast majority of instances.

Handling of the median, radial, and ulnar nerves in transhumeral and shoulder disarticulation patients is gaining importance as research on targeted reinnervation definitively proves the potential of this technique in the management of shoulder disarticulation patients. If the surgeon, physiatrist, and prosthetist believe a particular patient to be a good candidate for this protocol, then it becomes important to leave adequate length of these nerves until the definitive transfer is performed. This approach does entail the risk of leaving the transected nerve ending relatively superficial within the scar, where a symptomatic neuroma may develop. However, this problem can be definitively addressed on an elective basis regardless of whether or not targeted nerve transfer is ultimately attempted. This approach at least preserves an alternative for the patient until that alternative can be discussed and an appropriate determination made.

LOWER LIMB

The location of the most severe injury sustained by a traumatized limb usually determines the level of amputation in extremity blast trauma.[46] Optimizing functional outcome is the goal when deciding upon definitive amputation or revision level. Improved function is usually associated with levels that require less energy consumption, which generally equates to preservation of length. Moreover, preservation of joint function should be attempted to improve a limb's mechanical advantages and preserve the benefits of articular and distal limb proprioception for the amputee. More proximal amputations are associated with increased energy consumption (Table 8-1).[47,48]

Traditionally, more functional amputation levels, in order of decreasing length, are transmetatarsal, Syme, transtibial, knee disarticulation, transfemoral amputation, hip disarticulation, and hemipelvectomy.[49] Lisfranc (tarsometatarsal) and Chopart (tarsotarsal) amputations may be the exception to improved outcome with preserving length. In many cases, these amputations have the disadvantage of causing progressive

TABLE 8-1

ENERGY EXPENDITURE FOR AMPUTATION

Amputation Level	Energy Above Baseline (%)	Speed (m/min)	Oxygen Cost (mL/kg/m)
Long transtibial	10	70	0.17
Average transtibial	25	60	0.20
Short transtibial	40	50	0.20
Bilateral transtibial	41	50	0.20
Transfemoral	65	40	0.28
Wheelchair	0–8	70	0.16

Data sources: (1) Waters RL, Perry J, Antonelli D, Hislop H. Energy cost of walking of amputees: the influence of level of amputation. *J Bone Joint Surg Am*. 1976;58(1):42–46. (2) Czerniecki JM. Rehabilitation in limb deficiency: gait and motion analysis. *Arch Phys Med Rehabil*. 1996;77:S3-S8.

equinus and inversion foot deformities that result from difficulties obtaining proper muscle balance and overpull of the Achilles tendon. Additionally, difficulties can accompany fitting some energy storage feet for high-activity-level amputees who have received a very long transtibial or Syme amputation.

Closure

Because of the contaminated nature of traumatic extremity injury sustained in battle, most traumatic amputations are left open, preferably as a tissue-sparing and length-preserving amputation in which nontraumatized, viable soft tissue, muscle, and skin flaps are retained to aid in delayed definitive revision and closure. In either case, following serial irrigation and debridement, a plan for bony level and soft tissue closure should be formulated considering the local "flaps of opportunity." Because preservation of joint function is paramount, attempts to save an amputation level with use of skin grafting for local soft tissue coverage are warranted. Historically, skin grafts did not often withstand shear forces after prosthetic fitting in the lower extremity, and a plan for tissue expansion and eventual coverage with native skin was often required.[50,51] However, gel liners and improved prosthetic interface materials have improved the results of prosthetic fitting for amputated limbs with skin grafts in many individuals injured in the OIF/OEF conflicts.

Additional challenges in closure of traumatic blast wounds have been reported from the military centers treating returning blast victims. Amputation closure within the zone of injury approaches a 67% wound complication rate.[52] Additionally, approximately 63% of blast-related amputations are complicated by the formation of HO, which is most closely correlated with closure through the zone of injury.[13] These considerations must be factored into the decision-making process and included in patient and family counseling discussions.

Preoperative prophylactic antibiotics should be administered. In the absence of frank wound infection in which culture-specific antibiotics are preferred, antibiotic selection should be standard perioperative prophylaxis for a noninfected surgery. In an effort to prevent the formation of chronic postoperative phantom and stump pain, many centers continue to employ the techniques of preemptive epidurals and early regional nerve blocks, although these procedures are not completely supported by available controlled trials.[53]

The use of a pneumatic tourniquet has been shown to reduce blood loss and transfusion requirements during elective amputation and may have the extra benefit of a reduced rate of revision due to the resultant hemostasis and easier visualization.[54,55] In the management of combat-related amputees, in whom multiple, repeated surgical procedures and multisystem trauma is the rule rather than the exception, judicious tourniquet use may further limit the need for serial transfusions with their attendant immunosuppression and other potential systemic complications. An assessment of perfusion without the tourniquet inflated should, however, be performed at least once before definitive closure to ensure both adequate hemostasis and residual tissue viability via capillary bleeding.

During secondary closure, the skin should be closed without tension. The scar should be placed to avoid adhesion to bone and trauma from pressure points in the prosthesis. Bone should be beveled distally to prevent a sharp end from causing discomfort or soft tissue breakdown with prosthetic wear. As mentioned previously, myodesis or myoplasty should be performed to provide better muscle balance and prevent atrophy.[56] Nerves should be sharply transected after gentle distal traction and allowed to retract into the deep padded soft tissue. Individual wound closure techniques will be discussed by section; however, all combat-related amputations should be managed with deep drains at the time of definitive closure to prevent postoperative hematoma formation and subsequent wound complications or infection.

Partial Foot Amputation

The transmetatarsal amputation can produce a highly acceptable functional and cosmetic amputation level. A healthy, durable soft tissue envelope is more important than a specific anatomic amputation level, so bone should be shortened to allow soft tissue closure without tension, rather than to a specific, described surgical level. Bone contouring to replicate the anatomic forefoot cascade is desirable for weight bearing, and the bone ends should be beveled to prevent bony prominence. A long plantar flap is preferable (Figure 8-11), but equal dorsal and plantar flaps can function

Figure 8-11. Healed transmetatarsal amputation with long plantar skin flap.

well when adequate viable plantar tissue is absent.

Lisfranc-level amputation (tarsometatarsal) can provide adequate functional outcomes as well. However, careful evaluation should be made of the muscle balance around the foot, with specific attention to heel cord tightness and function of the tibialis anterior and peroneal muscles. Midfoot amputations significantly shorten the lever arm of the foot, so prophylactic Achilles tendon lengthening should be considered intraoperatively. Furthermore, tibialis anterior and peroneal muscle insertions should be reattached under appropriate tension, if they are released during bone resection, to prevent muscle imbalance, which will inevitably lead to foot deformity followed by eventual difficulty with prosthetic fitting and decreased function. Postoperative casting can help prevent deformities by preventing Achilles tendon contractures, allowing tendon reattachments time to heal, controlling residual limb edema, and preventing wound problems.

The Chopart (transverse tarsal) amputation removes the forefoot and midfoot while preserving the talus and calcaneus. Achilles tendon lengthening and tibialis and peroneal tendon reattachment and balancing are essential to prevent equinus and varus deformities at this level (Figure 8-12). Although described in the literature, tendon reattachment and balancing at this level can be quite humbling, with many patients progressing to hindfoot deformity necessitating further revision for functional limitations.[57] If available, plantar weight-bearing skin is best utilized as a flap for closure, with special attention paid to fastening the flap to bone to prevent shear and bursa formation. Postoperative casting is necessary to allow for tendon healing to bone. Although precise indications for revision to a Syme or transtibial amputation are

Figure 8-12. Intraoperative photograph of Chopart amputation. A Penrose drain is being utilized to pass the residual tibialis anterior tendon beneath a skin bridge to facilitate tenodesis distally.

lacking, a lengthy discussion with patients regarding rehabilitation and functional expectations is indicated prior to the decision to pursue a Lisfranc- or Chopart-level amputation.

Syme and Long Transtibial Amputation

Described by Syme[58] in 1843 and subsequently reviewed by Harris,[59] ankle disarticulation requires that the calcaneus and talus be removed. Care should be taken while dissecting out the calcaneus to preserve the heel skin and fat pad. The heel skin and fat pad are subsequently utilized as a durable end-bearing organ for ambulation, sometimes even without a prosthetic for short distances. It is important to stabilize the fat pad distally to prevent posterior and medial migration, which can compromise function. This can be accomplished several ways, including tenodesis of the Achilles tendon to the posterior margin of the tibia through drill holes, transfer of the tibialis anterior and extensor digitorum tendons to the anterior aspect of the fat pad, or removal of the cartilage and subchondral bone to allow scarring of the fat pad to bone.[18,60] Subsequently, the medial and lateral malleoli must be removed and contoured to allow prosthetic fitting. An effort to retain some moderate malleolar flare should be made to allow for self-suspension of the prosthesis.

A long transtibial amputation is an uncommonly used level for several reasons. Although it offers the potential advantages of improved lever arm and proproceptive control similar to the Syme level, the distal leg skin and lack of soft tissue for padding can be problematic. Patients with this amputation level generally cannot ambulate without a prosthesis, despite the putative benefits of a Syme amputation. Because the malleoli are absent, prosthetic fitting may not allow self-suspension. Moreover, similar to the Syme level, high-activity, athletic users often have difficulty fitting energy-storing feet typically used for running without cumbersome and heavy specialty attachments. This makes these levels less attractive in this particular patient population.

Transtibial Amputation

Arguably the most appealing level of amputation from a functional outcome perspective in the young active military population, the transtibial amputation (TTA) level has many advantages from a surgical perspective. Historically, many soldiers have been treated with this type of amputation. During World War II, from January 1, 1943, to May 1, 1944, five medical centers reported 627 TTAs and 550 transfemoral amputations, 35.7% and 31.3% of all amputations, respectively.[61]

Anteroposterior, lateral, and lateral oblique radiographs of the extremity should be obtained preoperatively. The lateral oblique radiograph allows assessment of preoperative tibiofibular distance to ensure that this distance remains constant during a bone-bridging procedure, if chosen. This view also allows for radiographic assessment of excessive distal tibiofibular diastasis, an indicator of proximal instability, which is an indication for either proximal stabilization or a distal bone-bridging procedure. A guideline of 2.5 cm for each 30 cm of height provides the appropriate residual limb length for the patient's stature. Typically, 12.5 to 17.5 cm below the tibiofemoral joint line is used as the final tibia length for nonischemic limbs.[62] For non-bone-bridging amputation, the fibula should be resected 1 to 2 cm proximal to the tibia. Definitive internal and external fixation of fractures has been used to preserve length in the traumatic amputee. Even segmental fractures can be stabilized to proximal segments, thereby preserving length. Amputation through the level of the highest fracture is not required, provided an adequate soft tissue envelope is present.[46]

Currently, most TTAs are performed utilizing a long posterior myocutaneous flap, which is based off the blood supply from the gastrocnemius muscle (Figure 8-13). A recent metaanalysis showed that the choice of

Figure 8-13. Gastrocnemius and soleus myodesis to the anterior tibia during definitive revision and closure of a transtibial amputation using conventional posterior myofascial and skin flaps.

amputation skin flap, including skew flaps and sagital flaps, had little impact on outcome when compared to the posterior myocutaneous flap.[63] A myodesis to bone holes of the gastrocnemius to the beveled distal tibia should be performed, with the knee in full extension to prevent flexion contracture. If the long posterior flap is compromised, available "flaps of opportunity" should be used to save length and level, including myodesis or myoplasty of anterior and/or lateral compartment musculature over the distal tibia to provide adequate distal soft tissue padding.

The distal bone bridge synostosis technique offers the theoretical advantage of providing a more end-bearing residual limb and has recently been shown to have some tangible benefits over traditional TTA in terms of prosthetic functional outcome.[64] Furthermore, the technique is valuable to treat a patient with tibiofibular instability, which can cause prosthetic fit issues from fibula widening and translation with weight bearing. For bone-bridging procedures, several modifications of the original Ertl technique can be performed to create a bone bridge between the tibia and fibula with either a fibula strut graft and/or a periosteal sleeve (Figure 8-14).[65,66] Distal bone bridging and modifications of the Ertl procedure are discussed in greater detail in Chapter 9.

Contemporary prosthetic sockets and suspension systems allow fitting and function of even the shortest functional TTA, up to and including levels just below the tibial tubercle. Occasionally, however, these levels prove difficult to manage and patient frustration with an inability to regain adequate control of the prosthetic limb warrants additional strategies. Attempts at lengthening short residual limbs with either monoplanar or Ilizarov fixators have proven successful and should be discussed with the patient as an option prior to resorting to a higher level amputation.[67,68] Due to concerns about wound healing and infection, however, these techniques should generally not be employed until after wound healing is complete and initial prosthetic fitting and rehabilitation has been attempted. At present, there are no indications for salvaging a short TTA in the absence of the tibial tuberosity or, at least, a reconstructible extensor mechanism.

Postoperative care following TTA has traditionally been a rigid dressing in the form of a splint or cast. It is generally believed that injured tissues heal more consistently and with less pain when placed at rest. Furthermore, rigid immobilization affords the added benefit of preventing knee flexion contracture.[57] How-

a

b

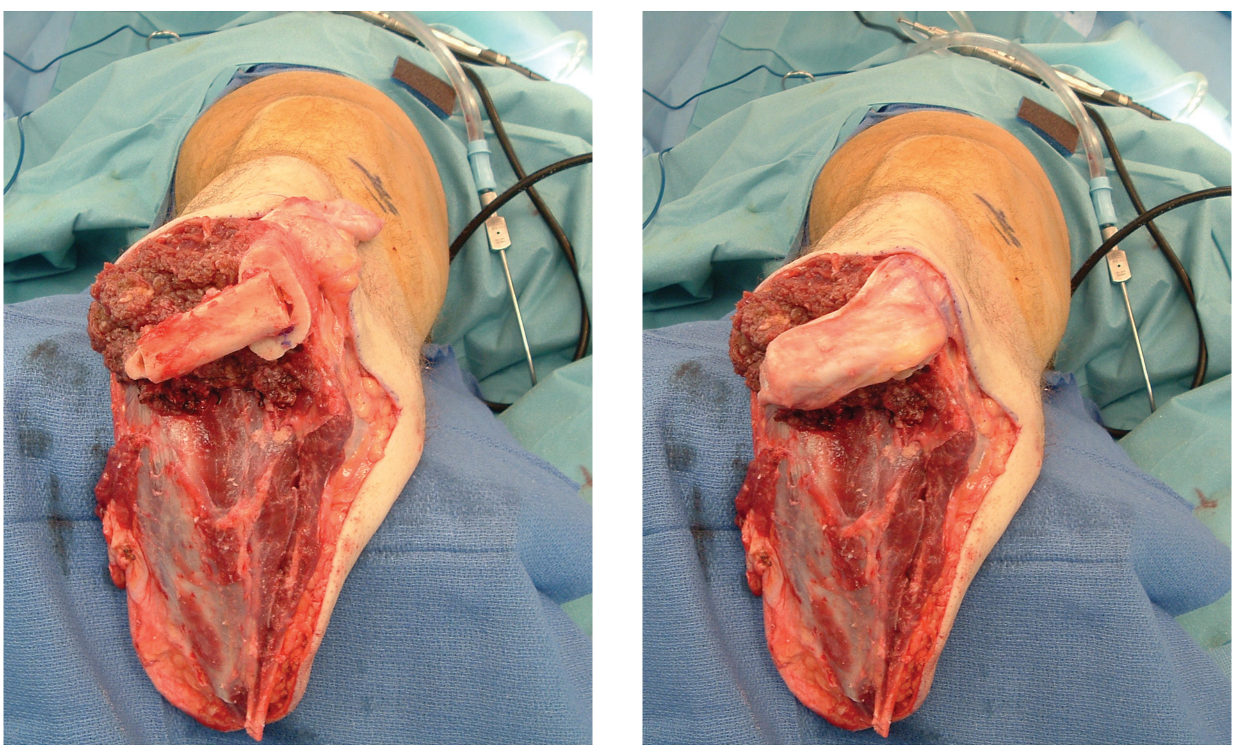


Figure 8-14. Demonstration of distal bone bridging technique for transtibial amputation utilizing a fibular autograft strut **(a),** which is then covered with a periosteal sleeve from the anteromedial tibia **(b)**.

ever, as mentioned earlier, rigid dressings have not been widely utilized during the current conflict due to concerns about early postoperative infection and the need for frequent wound examination during the period when such dressings would be most beneficial. Early postoperative rehabilitation should emphasize full knee and hip range of motion, including prone lying and stretching. Avoidance of pillows under the knee or a chronically flexed hip is critical to prevent functional limb length discrepancy associated with contractures.

Through-Knee and Transfemoral Amputation

Above-knee amputation includes amputations through the knee (knee disarticulation) and transfemoral amputations (TFAs). Although knee disarticulation is often avoided due to the drawbacks of knee level disparity, unsatisfactory soft tissue padding and patient function, the procedure's putative advantages include a simpler surgical technique, which potentially lessens operating room time and blood loss. The thigh musculature is not disrupted during the procedure and all muscle attachments remain, resulting in better functional control and biomechanics for walking.[69] Additionally, this level can provide direct end-bearing characteristics for the residual limb and improved self-suspension, with a resulting decrease in socket length. Previously, knee disarticulation created problems for prosthetic components because of the knee height difference compared to the uninjured side, but newer components, especially in knee designs, have largely solved these problems. Particularly with bilateral through-knee or transfemoral amputees, knee height disparity is not an issue.[70]

A posterior skin flap has traditionally been described for wound closure; however, recently the use of a long posterior myocutaneous flap has become popular because of the added padding of the gastrocnemius muscle and its associated contributory blood supply to the skin flap.[71] Furthermore, the LEAP study[5] demonstrated that through-knee amputations may not function as well as conventional transfemoral amputations, particularly if the gastrocnemius padding is absent. Thus, for an optimal through-knee amputation, nearly as much intact posterior myocutaneous tissue is required as for a short transtibial amputation. If both adequate proximal tibial bone and posterior soft tissue are present, the patient may be better served with a short transtibial amputation, potentially salvaging a functional knee joint.

To complete a through-knee amputation, the distal extremity is removed sharply through the knee joint capsule. Care should be taken to resect the patellar tendon off the tibial tubercle. The patella should be sharply dissected from the encasing quadriceps mechanism to decrease the risk of future patella-femoral pain and patella prominence. Additionally, the remnants of the cruciate ligaments should be left attached to their femoral origins. Excessively bulbous lateral and medial femoral condyles may be modestly trimmed with a sagittal saw. Posterior condylectomy may be required to advance muscle coverage, but is not routinely needed. Finally, the patella ligament should be sutured to the remnants of the cruciate ligaments for quadriceps balance, and the posterior muscle flap brought forward and sutured to the thick anterior joint capsule, prior to tension-free skin closure.

Traumatic amputation through the femur can happen at any level. As the level migrates closer to the hip joint, function is compromised due to the decreased lever arm available for function and fitting, increasing disruption of the muscular attachments for thigh control and increasing the necessity for more complex proximal suspension systems for prosthetic use. When the skeletal muscle attachments are divided during amputation, muscle loses its mechanical abilities. Stabilization of the distal insertion of muscle can improve residual limb function. As noted, myodesis is the most effective technique to stabilize strong antagonistic muscle forces.

Care must be taken during transfemoral amputation to correctly identify the cross-sectional anatomy, which can be difficult because the thigh is usually externally rotated. A good reference point is the linea aspera on the posterior femur. Once the anatomy is identified, it is important to remember that the large adductor magnus inserts onto the femur as a direct posteromedial structure. The most critical step during myodesis is to place the femur across midline adduction without hip flexion while suturing the adductor muscle mass to the distal femur through bone holes. If this process is not performed correctly, postoperative control of the limb will be compromised during ambulation due to over-pull of the abductors.

The remaining muscle closure is usually performed as a series of myodeses or a hamstring-to-quadriceps myoplasty. Care must be taken to avoid excessive shortening of hip flexor musculature due to the position of the limb during surgery, which may result in a hip flexion contracture. The hamstrings and/or quadriceps may be further stabilized by adding a nonabsorbable suture to the adductor myodesis. This technique helps prevent shifting of the adductor myodesis over the distal femur with use, and can function as a myodesis-by-proxy of the hamstrings or quadriceps if additional attachments through drill holes for each muscle group are not made in the distal femur. At a minimum, the authors recommend formal myodesis of the semimembranosus, which is the strongest hamstring and typically the most robust muscle belly present at any transfemoral level. The quadriceps apron, if available, should be swung over the distal aspect of the remaining femur, for both stabilization and padding, as the last muscle layer closed.

Similar to length preservation in traumatic TTA, a proximal femur fracture can be stabilized to allow an eventual longer lever arm for TFA or knee disarticulation (Figure 8-15). Amputation through the level of the highest fracture is not required.[12] Additionally, lengthening of a particularly short TFA residual limb

a b

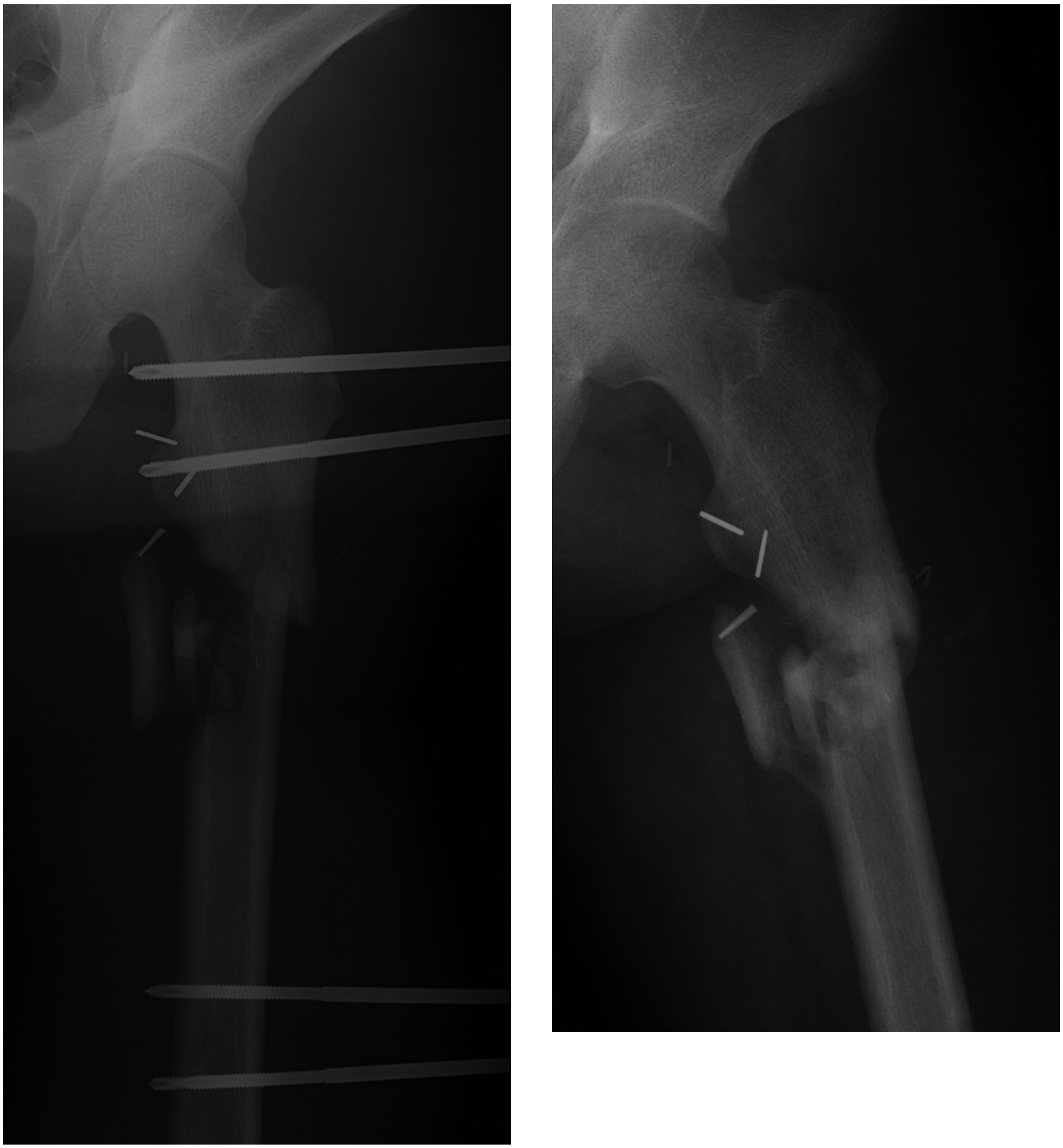


Figure 8-15. Radiographs of a through-knee amputation with external fixation of a proximal femur fracture. Due to soft tissue compromise and other injuries limiting potential early rehabilitation, the patient was treated definitively in this fashion until sufficient callous had formed to allow ambulation, with some additional support provided externally by the prosthetic socket.

can be accomplished with monoplanar fixation following corticotomy. If bone injury occurs proximal to the lesser trochanter, control of the limb is severely compromised and hip disarticulation or fusion of the short proximal femur to the acetabulum are usually the only remaining practicable options.

To avoid hip flexion contracture, postoperative rehabilitation with prone lying and stretching should begin early. Additionally, placement of pillows between the legs with abduction at the hip should be avoided to prevent less than optimal adductor control of the limb or early strain on the adductor myodesis.

Hip Disarticulation and Hemipelvectomy

Hip disarticulation and, in particular, hemipelvectomy, are amputations of last resort. Despite the historically dismal functional prognosis associated with these proximal levels, modern prosthetics and suction-fit suspension mechanisms have resulted in remarkable function in some of these patients. Therefore, attention to a few key points is warranted to maximize patient outcomes.

Hip disarticulation has traditionally been performed utilizing a posterior or posterolateral flap based on the gluteal musculature. The femoral and obturator vessels are identified, isolated, and double-ligated proximally as they exit the true pelvis. After removal or arthrodesis of the remaining (typically short or absent) proximal femur, the abductor musculature and/or pectineus can be sutured to the residual joint capsule or inserted directly into bone, filling the acetabular deadspace and reducing the risk of postoperative hematoma, seroma, and infection. Care is warranted to avoid dissection into the sciatic notch and violation of the gluteal vessels exiting there, which could compromise flap viability. The gluteus maximus tendon is then mobilized and sutured anteriorly to the inguinal ligament, resulting in a robust myofasciocutaneous flap over the residual hemipelvis.

Hemipelvectomy is rarely required in a posttraumatic or combat-related setting—most patients with traumatic amputations at this level do not survive, even on the modern battlefield, and in most surviving patients a hip disarticulation can be salvaged. When required, efforts to salvage as much of the residual ilium and ischium as possible are warranted, given the importance of these osseous supports for prosthetic support and sitting balance, respectively. The soft tissue management and techniques are essentially the same as those for hip disarticulation, except that greater vessel dissection is required. In males, all three blood supplies to the testicle travel within the spermatic cord, which should be salvaged, or a unilateral orchiectomy should be performed concurrently. The corresponding round ligament of the uterus in females can be sacrificed without sequelae.

For cases in which the gluteal musculature and skin are violated or absent, alternate coverage techniques are required. If possible, a femoral artery-based quadriceps anterior-posterior flap should be used.[72] The availability of this flap in a posttraumatic setting clearly relies on the initial performance of an open, length- and tissue-preserving amputation, which illustrates the critical importance of this technique. A modified abdominoplasty advancement fasciocutaneous flap can also be utilized for soft tissue coverage, although this flap lacks the muscle padding desired under optimal circumstances.[73] The authors have also had some success with rectus abdominus rotational flaps to augment soft tissue coverage in this region (Figure 8-16). Finally, in contradistinction to other lower extremity amputation levels, which are typically subjected to greater frictional and end-bearing forces with ambulation, split-thickness skin grafts can be utilized with relatively good anticipated results in this location.

Wound complication rates after either hip disarticulation or hemipelvectomy are quite high, even in an elective setting. Therefore, early rehabilitation consists largely of early patient mobilization to prevent secondary complications such as decubitus, thromboembolic phenomena, pulmonary dysfunction, and general deconditioning. Prosthetic fitting is typically delayed until wound healing is complete. However, as noted, recent advancements have made resultant function in some amputees at these levels quite surprising and gratifying.

Figure 8-16. Clinical photograph of a hip disarticulation in which soft tissue closure and coverage of the femoral vessels was facilitated by use of a rectus abdominis flap and partial thickness skin grafting.

MULTIPLE INJURED LIMB AMPUTEE

The combat amputee often has injuries to multiple extremities as well as other organ systems, including eyesight. Additional injuries and more proximal levels of amputation can have a profoundly negative impact on functional capacity. Even in an era of great technologic and prosthetic advancements, the multiple limb amputee has challenges with prosthetic donning, fit, wear, and sustained use. In the traumatic amputee, the oxygen consumption of the bilateral transtibial amputee approaches that of a unilateral transfemoral amputee, while the bilateral transfemoral amputee requires double the oxygen consumption to maintain 60% of normal walking speed.[74]

A bilateral transfemoral amputee is difficult to fit effectively with bilateral ischial-bearing sockets. The high sockets impinge upon one another not only when walking but also when seated. For this reason, if it is possible to maintain one side at a through-knee level, the comfort of prosthetic wear may be greatly enhanced. An even more appealing alternative would be to maintain a single knee joint, even if it is a very short transtibial level, to obviate the need for a knee hinge[75,76]; balance and control are greatly enhanced in this circumstance. It is even reasonable to consider a free tissue transfer for coverage of a transtibial or through-knee amputation level to avoid bilateral transfemoral amputations, depending on the patient's condition.

Traumatic lower extremity injuries, especially in combat, often result in bilateral transtibial amputations. Fortunately, current prosthetic technology coupled with rehabilitative training has allowed for a high level of function in many patients. In fact, some unilateral lower extremity amputees with severe injuries of the contralateral limb have requested elective amputations of the remaining limb to improve functional level and reduce pain. The long-term outcomes of these individuals have not yet been determined, and it is still generally preferable in a patient with severe bilateral lower extremity injury to amputate the more severe limb and attempt salvage of the other through whatever means available (circular frames, free tissue transfer, etc). If function in the salvaged limb is not satisfactory after reconstructive and rehabilitative efforts are exhausted, consideration for elective amputation may be entertained in a careful, deliberate fashion.

The lower extremity amputee with severe upper extremity injury deserves special mention. Depending on the functional outcome of the lower extremity amputation, the upper extremities may be required for mobility and ambulation assistance in both the short and long terms. Although obviously desirable, regaining full function of the upper extremity is often not possible. In such a circumstance, stability and relatively painless upper extremity function become more important, because the upper limbs are required for transfers and wheelchair use. Deliberate arthrodesis or permissive ankylosis of the wrist, elbow, or shoulder may be preferred to an unstable or painful limb that is more mobile.

The blind upper extremity amputee presents particular and unique challenges. Due to the lack of tactile feedback, current prosthetic technology requires vision for control of the terminal devices of upper extremity prostheses. A Krukenberg procedure, despite its cosmetic limitations, may allow for improved upper extremity function in these patients because of the presence of sensation in the terminal limb. If desired, a cosmetic limb may be provided for patient use in social settings.

It is not possible to cover the complete array of injury combinations that may present as a result of wartime trauma. However, decisions can be made based on the specific injury and patient needs. The surgeon and the rehabilitation team, working cooperatively with the patient and family, must make careful and considerate individual decisions based on multiple factors to arrive at optimal solutions in each case.

DELAYED AMPUTATION VERSUS LIMB SALVAGE

The decision to proceed with limb salvage or amputation in the patient with a severely injured extremity or extremities will be a source of continued debate. Progress has been made every year in each of these areas, making it possible to save limbs that were previously unsalvageable as well as to provide more advanced prostheses with greater functional capacity. Another evolving concern is the cost of each treatment, although this factor may be a less significant consideration for the military amputee because of guaranteed lifelong care through military and Veterans Affairs healthcare systems. The most recent published cost analysis has demonstrated equivocal 2-year costs between the two groups, but a three-fold increase was shown for the lifetime cost of the amputee group.[77] Physicians have a responsibility to become knowledgeable about each of these areas to best advise patients and help them make these very difficult decisions. To be effective, physicians must learn to use a variety of tools and discussion points.

a

b

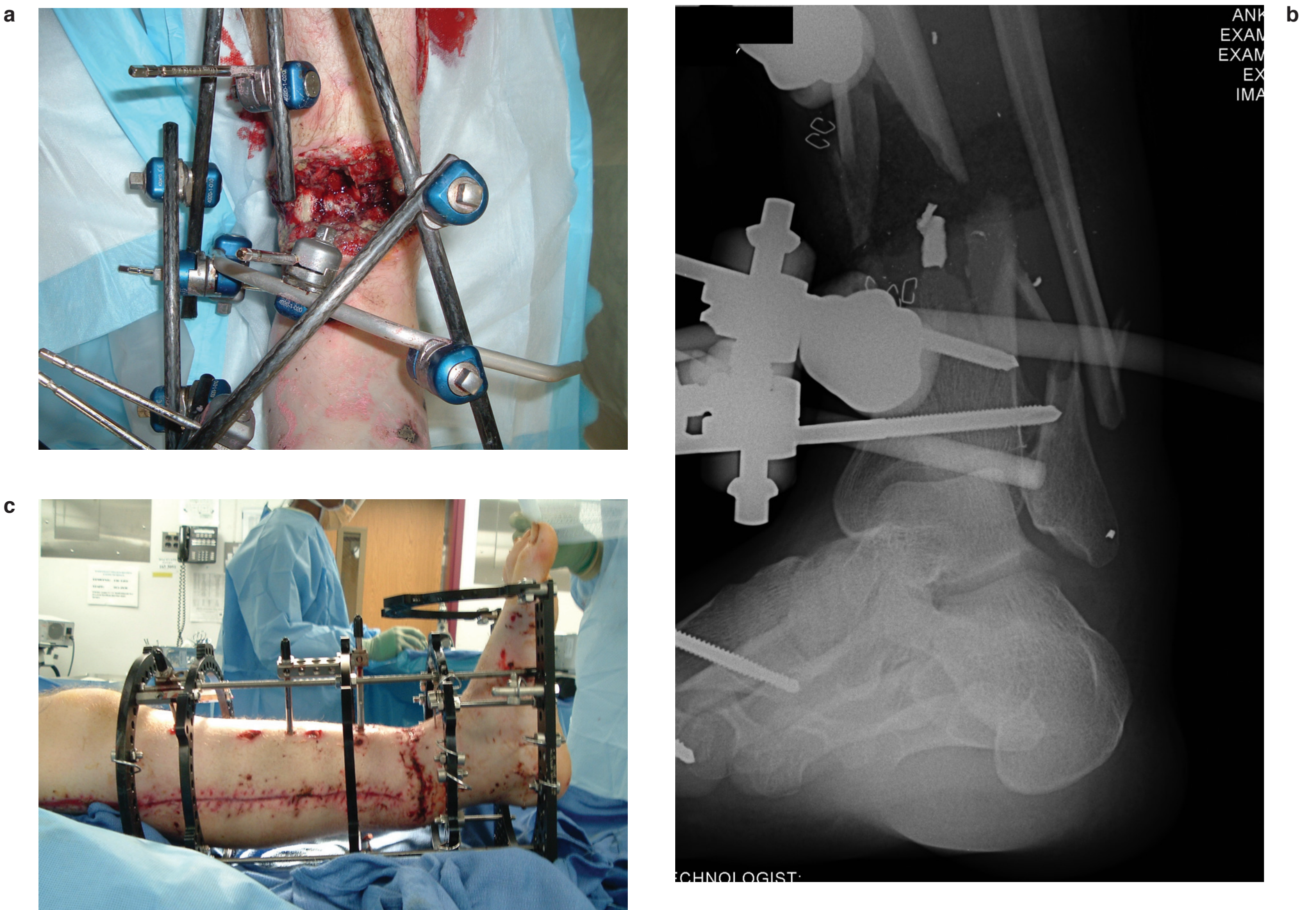
Figure 8-17. Example of proximal tibia fracture above distal amputation. Limited internal fixation allowed preservation of a good length for the residual limb.

Partners/Mentors

Most surgeons have not managed every type of injury or situation during training or regular practice to prepare them for the patient facing limb salvage or amputation. Even among experienced trauma surgeons, a specific patient's injuries, dilemmas, and considerations are usually unique. The collective knowledge of peers and consultants is important when faced with treating this type of injury and patient. Fortunately, today's digital media and communication allows advice to be sought quickly and securely, even across thousands of miles.

Amputee Counselors/Visitors

Peer visitors and certified counselors should be available at every major military treatment facility; they can be a tremendous assistance when treating patients in this situation. Many of these individuals have faced similar dilemmas and can provide specific insight that may not be readily apparent to the treating



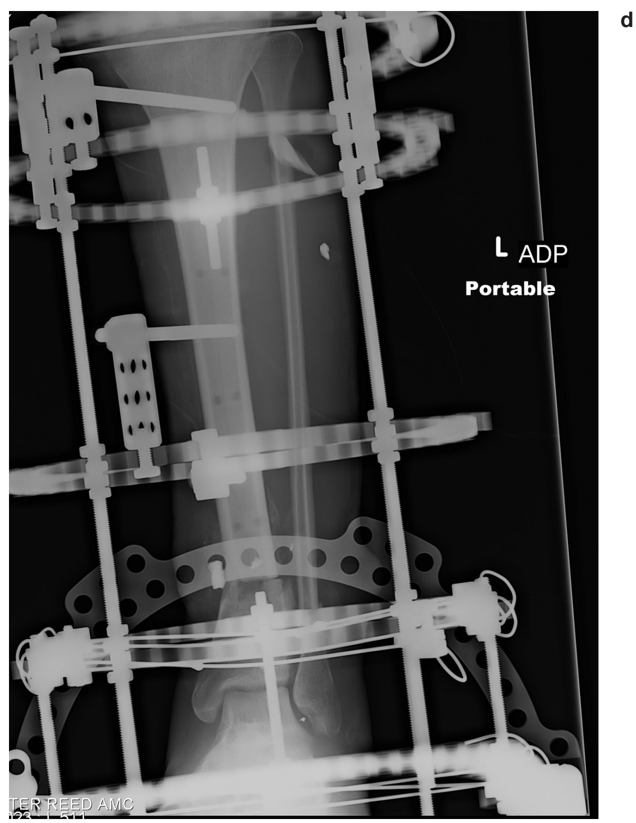


Figure 8-18. Clinical photograph (**a**) and radiograph (**b**) at presentation of a patient with a segmental distal tibial defect, near circumferential soft tissue injury, and contralateral transtibial amputation. Acute shortening was performed to facilitate wound closure and opposition of the bone ends **(c, d).**

physician. Patients may discuss concerns with a fellow service member in similar circumstances that they may not express to the physician. Examples include how each treatment will affect the soldier's military career, relationships with spouses and family, recreational activities, and acceptance within society at large.

Surgical Considerations

When planning an amputation after attempted limb salvage, one of the most important considerations is the level at which the amputation should be performed. Multiple factors must be considered, including the condition of the soft tissues, presence of bone defects, injury to and function of proximal joints, vascular injury, and the presence of contralateral injuries. Each of these factors affects the level and type of amputation,

a

b

Figure 8-19. Open bilateral lower extremity injuries secondary to an improvised explosive device blast. (*c and d on opposite page*)

c

d

as well as the ultimate function anticipated.

The condition of soft tissue may have a dramatic effect on the level of amputation. If soft tissue is not adequate to cover the residual limb, or it is extremely tenuous, amputation at a higher level is likely warranted. For example, through-knee patients considered in a study by MacKenzie et al[78] did not function as well as either transtibial or transfemoral patients. Lesser function was primarily observed in patients with poor soft tissue coverage, whereas patients with a good soft tissue envelope did comparably well with their transfemoral and transtibial counterparts. Although the results of this study do not support avoiding through-knee amputations, they illustrate the importance of achieving the optimal level to enhance patient outcomes.

Bone defects or persistent nonunion of fractures can play a significant role in both upper and lower extremity amputations and limb salvage, particularly in the lower limb because of its requirement for weight bearing. Consideration should therefore be given to performing the amputation through the bone defect or higher, provided that this will give the patient an adequate amputation level. Fixation of fractures above the amputation can be done in many cases, providing length to the amputation (Figures 8-17 and 8-18). However, for late amputations after failed attempts at limb salvage, little evidence suggests that an unresolved bone or soft tissue problem will fare any better within the residual limb after amputation, despite the external support and soft tissue padding that a prosthetic component may afford.

Injuries to joints above the level of amputation should be evaluated closely. Reconstructible joints should always be salvaged with the amputation performed below. A functional joint will always be beneficial to the patient in the long run. Total knee arthroplasty has been performed successfully in transtibial amputees, with restoration of independent ambulation.[79] Salvaging joints is even more important in patients with above-knee amputations, because hip disarticulation is much more disabling than almost any length of functioning residual femur.

Vascular injury can easily preclude the salvage of the lower extremity. Every attempt should be made to assist the general and vascular surgeons with these patients. Given the almost inevitable future amputation in these patients if vascular injury is not resolved, the relative benefits of vascular reconstruction far outweigh the risks in this patient category, provided that the patient is physiologically stable.

Limb Salvage Versus Bilateral Amputation

Injury to the contralateral limb may have strong influences on decision-making for limb salvage versus amputation. When one limb has sustained a traumatic amputation, in most cases every effort should be made to salvage the contralateral limb. In these situations, acute shortening of the involved limb for closure of soft tissue defects may be necessary. Achieving equal limb lengths is not a concern in this situation, because the a b

Figure 8-20. Right foot after reconstructive surgery for an open calcaneus fracture. The patient was unable to bear weight secondary to severe dysasthesias in the right foot, and elected to undergo late transtibial amputation.

a

b

Figure 8-21. Follow-up radiographs of the foot and ankle of the patient in Figure 8-20 prior to elective late transtibial amputation.

prosthesis for the contralateral limb can be adjusted to compensate for any shortening. Today's soldiers may be eager to undergo elective amputation given the advances in prosthetics and their desire to return to functional independence and higher activity levels more rapidly.

Injury to bilateral lower extremities with traumatic amputation on one side strongly, and appropriately, influences the caregiver to recommend initial limb salvage. Surgeons are reticent to proceed directly to amputation when any possibility of limb salvage remains, even in the direst circumstances. Although contralateral salvage may prolong the hospital stay and rehabilitation course of the patient, it remains the recommended course of action. Some patients with severe injuries unpredictably go on to near full functionality with an amputation and a marginal contralateral limb, while others with a seemingly good limb and amputation are severely disabled. Each individual patient has impairments from his or her unique injuries, but the final level of residual disability depends on multiple physical, psychological, and social factors. Salvaging the remaining limb allows the patient the opportunity and time to make an informed decision regarding future amputation. In the authors' experience, those who have attempted limb salvage and decide for late amputation have done very well.

A sample case is a 24-year-old patient who was sitting in the back of a Stryker combat vehicle when it was hit by a powerful IED. He sustained a right open subtrochanteric femur fracture, right open patella fracture, left tibial pilon fracture, bilateral open calcaneus and talar fractures, and multiple soft tissue wounds (Figure 8-19). Treatment of the right femur consisted of multiple debridements followed by intramedullary nail fixation, and skin grafting of the lateral thigh. The left lower extremity fractures were severe, requiring an early amputation. Multiple debridements were necessary to treat the right open calcaneus fracture and talar injuries. After several months, he remained unable to place weight on the right lower extremity secondary to severe neuropathic pain (Figures 8-20 and 8-21). A transtibial amputation was performed at the patient's request 9 months following the injury. Since that time he has returned to full activities including golf, work, and school.

CONCLUSION

Both early and late care of the combat casualty with limb loss remain challenging endeavors. Optimal early treatment, including initial decisions on limb salvage, open length-preserving amputations, thorough debridements, and provisional fracture stabilization techniques can dramatically influence reconstructive alternatives for surgeons at higher echelons of care as well as final patient outcomes. Subsequent treatment decisions are no less difficult, but can often be made with the assistance of physiatrists, prosthetists, therapists, patients, and families, as well as peers and the medical literature. By making informed, systematic determinations regarding final amputation level, nerve handling, and soft tissue reconstruction and closure in this fashion, satisfactory and occasionally excellent outcomes can ultimately be achieved for even the most challenging patients.

Acknowledgment

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