Lower Extremity Combat-Related Amputations

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Since the onset of combat activity in Iraq and Afghanistan, there have been over 1100 major limb amputations among United States service members. With a sustained military presence in the Middle East, continued severe lower extremity trauma is inevitable. For this reason, combat surgeons must understand the various amputation levels as well as the anatomic and technical details that enable an optimal functional outcome. These amputations are unique and usually result from blast mechanisms and are complicated by broad zones of injury with severe contamination and ongoing infection. The combat servicemen are young, previously healthy, and have the promising potential to rehabilitate to very high levels of activity. Therefore, every practical effort should be made to perform sound initial and definitive trauma-related amputations so that these casualties may return to their highest possible level of function. (Journal of Surgical Orthopaedic Advances 19(1):35–43, 2010)

Key words: amputation, combat trauma, residual limb, war wounds

Since the onset of combat activity in Iraq and Afghanistan, there have been over 1100 major limb amputations among United States servicemen (1). With a sustained military presence in the Middle East, continued severe lower extremity trauma is inevitable. For this reason, combat surgeons must understand the various amputation levels as well as the anatomic and technical details that enable an optimal functional outcome.

Combat trauma-related amputations are unique. They are usually the result of a blast mechanism and are complicated by broad zones of injury with severe contamination and ongoing overt or latent infection. Other limb injuries, systemic illness, and a delay to definitive care for intercontinental flight complicate the care of these amputees. These patients differ significantly from the more common elderly, dysvascular amputee population; they are generally younger and previously healthy and have the promising potential to rehabilitate to very high levels of activity (2).

Therefore, every practical effort should be made to perform sound initial and definitive trauma-related amputations so that these casualties may return to their highest possible level of function. Adherence to established amputation principles at each anatomic level can dramatically affect the outcome and ultimate function of the amputee (3). Long-term follow-up of these patients should be sought to ensure that the residual limb continues to be capable of tolerating prolonged prosthetic wear at a high-demand level.

Early Surgical Goals

The initial surgical goal in the treatment of a patient with a severe lower extremity combat injury is the thorough debridement of all contaminated wounds. All devitalized muscle, skin, and bone must be excised during the early surgical treatments in theater. Conversely, any and all viable muscle and fasciocutaneous tissue should be saved for possible use in the definitive soft tissue reconstruction. There is essentially no indication at this time to perform a "guillotine" amputation. This is an antiquated technique which leaves no soft tissue coverage to maintain the amputation at that length or level (Fig. 1).

Soft Tissue Management

Proper management of the soft tissue envelope is critical. The best predictor of the timing of definitive closure,

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FIGURE 1 Guillotine amputation with no soft tissue coverage available. Patient will need revision to a more proximal transfemoral level.

final limb length, and prolonged prosthetic use is the presence of adequately robust soft tissue coverage. Myofascial and myoplasty closures are frequently used in the dysvascular and civilian trauma populations (4–7). These techniques, however, should serve only as secondary measures in most amputations and should virtually never be used as the sole form of muscle stabilization in combat-related amputations (Fig. 2).

Alternatively, myodesis is the preferred technique of soft tissue stabilization following trauma-related amputation (8, 9). Myodesis is performed via suturing the muscular fascia to the end of the bone either through drill holes or directly sutured to the periosteum. This restores the physiologic muscle tension, secures the deep soft tissue padding, and prevents instability of the muscle unit. Myoplasty and myofascial closure may then be used to augment the primary myodesis or myodeses. Tenodesis is also an acceptable form of muscle stabilization at appropriate amputation levels.

Management of Nerves

Symptomatic neuromata accompany 0%–25% of major limb amputations and remain a frequent indication for reoperation (2, 10, 11). Stimuli such as stretching, pressure, vascular pulsation, or other irritation to the terminal neuroma bulb can be painful and often limits prosthesis wear. Multiple techniques have been developed in an attempt to decrease the risk of a symptomatic neuroma formation, but no method has convincingly demonstrated any improved outcome over a carefully performed traction neurectomy with burying of the cut nerve end deep in the proximal soft tissues. A traction neurectomy places the neuroma away from the region of the definitive closure and scarring as well as the ligated vessels. It is recommended for all named and other grossly visible nerves of the lower extremity at the various amputation levels. When performing a proximal transfemoral amputation, the sciatic nerve may require ligation prior to transection to avoid bleeding from the substantive vaso nervosum (Fig. 3).

FIGURE 2 (**A**) Transfemoral amputation relaxed with a normal-appearing residual limb. (**B**) The same patient with active muscle contraction revealing an unstable quadriceps-hamstring myoplasty.

An association between acute postoperative pain with chronic amputation-related pain has been studied and identified. Patients who report the highest acute phantom limb pain are more likely to have phantom limb pain at 6 and 12 months following surgery (12). For this reason, attempts have been made to reduce the acute postoperative pain experienced by amputees. While the long-term positive impact of these techniques is debated, the short-term benefits of anesthetic intervention include increased patient comfort and a decreased narcotic requirement and may allow for slightly earlier mobilization. Current anesthesia guidelines continue to focus on methods to prevent central neuroplastic changes from occurring through the

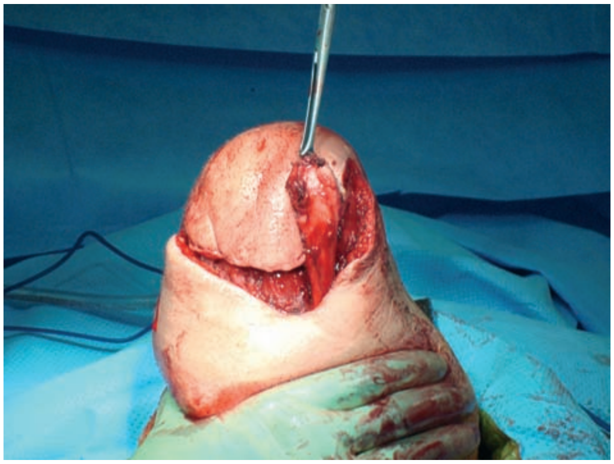

FIGURE 3 Transfemoral amputee with a symptomatic sciatic neuroma at revision surgery. The nerve had been incorporated into the patient's hamstring myodesis and was anchored to the most distal aspect of his residual limb immediately adjacent to his femoral bone cut.

use of preventive multimodal analgesic techniques to include nonsteroidal anti-inflammatory drugs, local anesthetic nerve sheath injections, alpha-2 agonists, ketamine, opiods, preemptive epidurals, and regional nerve blocks (13).

Level of Amputation

There is an increasing oxygen cost of ambulation as the site of amputation moves to more proximal levels (14). In an attempt to conserve energy, the average walking speed of an amputee self-adjusts to maintain a similar overall oxygen consumption to control patients without limb loss (15). For this reason, better outcomes are usually associated with longer residual limbs. However, this dictum often does not hold true in cases of severe foot and ankle trauma when a transtibial amputation is often indicated over a more distal foot or ankle amputation because of better prosthetic fit and component options.

With combat trauma-related amputations, the level of the most significant soft tissue injury usually determines the level of the amputation. When determining the final level of limb length and closure, the following tenets of Pinzur should be observed (16).

1. Optimal residual limb length without osseous prominences should be chosen.
2. Reasonable function in the joint proximal to the level of the amputation should be present in order to enhance prosthetic function.
3. A durable soft tissue envelope should be achieved and a full-thickness myocutaneous flap to cushion areas of high pressure and shear is desired.

Preservation of Length

Combat trauma-related amputations are usually performed within the zone of injury. The Lower Extremity Assessment Project (LEAP) study authors noted that 17 of 19 knee disarticulations were performed through the zone of injury and that 38.2% of the total study patients had atypical flap coverage of the residual limb in their series (17). This atypical coverage within the zone of injury is the rule rather than the exception with combat-related amputations and, despite the LEAP study findings to the contrary, it is associated with a substantial increase in wound complications and heterotopic ossfication in the combat wounded (18).

Multiple methods of preserving amputation length with creative soft tissue coverage have been developed (19–28). Split-thickness skin grafting is the simplest mechanism to preserve length when robust muscle coverage is present. Soft tissue expanders may also be used in conjunction with split-thickness skin grafting in order to achieve early, provisional closure and a delayed, durable coverage at a later date (29, 30). Finally, more complex, pedicled or free tissue transfer can be used to preserve limb length with good success when indicated (20, 31). These length-preserving procedures are, however, associated with delayed prosthetic fitting and frequent revision surgery (28, 32). They are most commonly indicated around the knee to maintain a transtibial level of amputation.

Lisfranc, Chopart, and Syme Disarticulations

Amputations through the foot and ankle can be considered when a patient has sustained severe forefoot trauma with sparing of the hindfoot plantar skin and soft tissues. The potential benefits of these levels are the long lever arm, an ideal cosmetic appearance of the foot amputations, and the potential ability to continue to bear weight and walk for short distances without the use of a prosthesis (3, 33).

These amputations are, however, associated with difficult prosthetic fitting and a severe disruption of the musculotendinous balance of the foot (33). The loss of the forefoot lever length and the normal dorsiflexor insertions allows the powerful triceps surae to overpower the foot. This often leads to an equinovarus deformity that is very difficult to both prevent and correct. Achieving a tendinous balance so that the foot remains in its functional position for comfortable prosthetic wear is challenging despite concerted efforts at tendon reattachment and perioperative splinting or external fixation. Additionally, with regard to the Syme amputation, studies have repeatedly shown that 30%–50% of patients are unable to bear full weight through their residual limb without a prosthesis, which is one of the putative benefits of this amputation level (33, 34).

Lisfranc/Chopart Disarticulations

The Lisfranc disarticulation removes the forefoot through the tarsometatarsal joints (35). The bases of the second and fifth metatarsals should be left in order to preserve the transverse arch of the foot as well as to leave the insertion of the peroneus brevis intact. Careful preservation of the tibialis anterior and the peroneus longus tendons must also be accomplished. The Chopart disarticulation is an amputation through the talonavicular and the calcaneocuboid joints. In this procedure, all of the ankle dorsiflexors are transected and one must be very diligent in performing a proper tendinous reconstruction in order to counteract the overpowering triceps surae. Multiple methods of tendinous reconstruction and stabilization of the foot have been described, but most commonly the tibialis anterior is placed through drill holes in the talus and is secured with suture or a staple (36–38).

With both the Lisfranc and Chopart disarticulations, a rebalancing of the foot must then be performed to avoid an equinus contracture. Percutaneous heel cord lengthening followed by rigid casting or temporary external fixation in a dorsiflexed position should be performed in an effort to prevent this. For difficult cases, even fusion of the midtarsal joints to prevent their secondary dislocation has been suggested (39, 40).

Syme Ankle Disarticulation

When planning a Syme ankle disarticulation, there are a number of very important technical details to consider to achieve optimal outcomes. Revision surgery for the Syme disarticulation is common, in the range of 8.5%–50%, with revision to the transtibial level being relatively frequent among dysvascular amputees (33, 41–44). Two absolute contraindications exist to performing this surgery; specifically, if either the heel pad or its blood supply, the posterior tibial artery, are damaged, this amputation should not be performed (45, 46).

At the time of surgery, the distal medial and lateral malloli are transected flush with the distal tibial articular surface or just proximal to this if distal tibial transection is performed. The malleolar flare of the tibia and fibula may also be reduced to decrease the mediolateral diameter of the residual limb, but some of the malleolar flare should optimally be retained in order to assist in prosthetic suspension (43, 47). The heel pad must then be maintained directly below the distal tibia to avoid painful instability. This should be accomplished by a tenodesis of the Achilles tendon to the distal tibia through drill holes at the time of surgery. This neutralizes the strong triceps surae pull on the heel pad and may prevent posterior heel pad migration (48).

Due to the multiple problems associated with these levels, as well as the high functional outcomes of transtibial amputees, foot and ankle amputations have often been given little consideration in the young United States combat patient. In the authors' experience, these amputations often perform relatively poorly and have limited indications for the young active patient. Although the number of patients treated with these amputations during the current conflict has been small, many have requested revision amputation to the transtibial level after being unsatisfied with their function at these levels. Critical considerations include the status of the soft tissues of the midfoot and heel pad, patient and family wishes after detailed counseling, associated ipsilateral and contralateral lower extremity injuries, and the ability to perform satisfactory tendon stabilization appropriate to each of these levels.

Transtibial Amputation

The transtibial amputation is the most common level of amputation for trauma patients and frequently has the best functional outcome. The gait of a transtibial amputee is minimally disturbed due to the preservation of the knee and less energy is required for ambulation when compared with more proximal levels (49, 50). These patients are often able to ambulate at a normal speed due to their increased exercise capability, despite a 20% higher oxygen consumption (51–53). They also have a high rate of prosthetic use and are very physically active, and a large percentage of them consider themselves only minimally or nondisabled (54).

In 2001, Dougherty reported a 28-year follow-up of United States servicemen with transtibial amputations. SF-36 scores in the group of patients who had isolated amputations were similar to age- and gender-matched control individuals (55). In a recent study evaluating Iranian veterans, Taghipour found slightly contrasting results. Despite finding that the transtibial amputees had lower SF-36 scores than a control group, the SF-36 scores for transfemoral amputees were significantly lower. The improved general health outcomes scores over transfemoral amputees appears to remain constant throughout the literature (55–57).

This level of amputation should be selected, when practicable, for most combat patients with severe foot or leg trauma. The most commonly utilized technique was originally described by Bickell and then popularized by Burgess in 1943 (58, 59). Burgess reported that 2.5 cm of residual tibia should be left for every 30 cm of a patient's height (60). This usually ranges from 12.5 to 17.5 cm of residual limb length; we recommend erring slightly toward the higher end of this spectrum when soft tissue coverage is adequate and wound characteristics permit surgeon selection of amputation level, with the caveats that robust soft tissue coverage should be achieved and 10.5–11 inches (27–28 cm) of ground clearance is required for more advanced prosthetic components. Despite this optimal length guideline, a high transtibial amputation may be performed as long as the tibial tubercle is preserved. There is no current role for preserving the knee joint if one is unable to achieve at least this length. The tibia and fibula should then be cut at the desired level with a sagittal saw. The fibula is sectioned and beveled posterolaterally about 1–2 cm proximal to the tibia cut to ensure that the fibula does not become prominent and painful with prosthetic wear. Likewise, the sharp anterior tibia must then be beveled and smoothed for the same reason. All named nerves (tibial, superficial and deep peroneal, saphenous, and sural) should be identified, isolated, dissected proximally, placed under tension, transected sharply, and permitted to retract into the proximal soft tissues. Following this, attention is paid to the remaining soft tissue flap to be used for distal coverage. Ideally, a long posterior myocutaneous flap is present, but sagittal and skew flaps can be utilized, when necessary, with reasonable outcomes expected (61). Prior to gastrocnemius myodesis, the soleus may require thinning or removal, depending on the patient's anatomy, to ensure that the residual limb is not too bulky, closure is possible, and redundant soft tissue does not remain once swelling subsides and atrophy occurs. The myodesis is then performed and the remaining gastrocnemius fascia is secured to the anterior crural fascia of the leg. Despite the LEAP study finding that only 22.8% of transtibial amputees had a myodesis performed, we emphatically stress the importance of this step because we have frequently revised amputations due to an inadequate or poorly performed myodesis that has led to painful prosthetic wear.

Distal Tibiofibular Synostosis

The concept of producing a synostosis between the tibia and fibula was first proposed by Bier in 1892 and then popularized and further developed by von Ertl (3). Von Ertl felt that his modification of the transtibial amputation procedure allowed for a more normal end-bearing residual limb (62). Since the original description of the tibiofibular synostosis procedure, multiple authors have suggested modifications to the original technique (63, 64).

The bone bridging procedure has been heavily debated in and out of the literature and has both ardent supporters and fervent critics. In 2006, Pinzur et al. (65) suggested that patient-perceived functional outcomes may be improved by performing the distal tibiofibular synostosis. In a more recent study, however, Pinzur was unable to demonstrate an advantage when compared with the traditional Burgess technique (66). Despite the controversy and uncertainty of an improved outcome with the bone bridging procedure, patients who demonstrate tibiofibular instability clinically or radiographically should have some form of tibiofibular stabilization performed (Fig. 4).

Knee Disarticulation

The LEAP study data have recently cast a negative light on through-knee amputations. The LEAP study patients with through-knee amputations were found to have the lowest walking speed and self-reported outcomes. Despite these findings, other studies have reported better walking stability, a decreased metabolic cost of ambulation, and higher scores on the physical component of the SF-36 as compared with transfemoral amputees (56, 67, 68).

When originally developed, the knee disarticulation was very popular because of its ability to be performed quickly and safely in the preanesthetic era. There was a decreased risk of infection and severe bleeding at this level as compared with more proximal or distal levels. This level did, however, fall out of favor because many patients were unable to bear weight through their residual limb due to poor soft tissue coverage consisting only of subcutaneous tissue and skin (3).

This is very likely the explanation for why the LEAP study amputations did so poorly. Seventeen of the 18

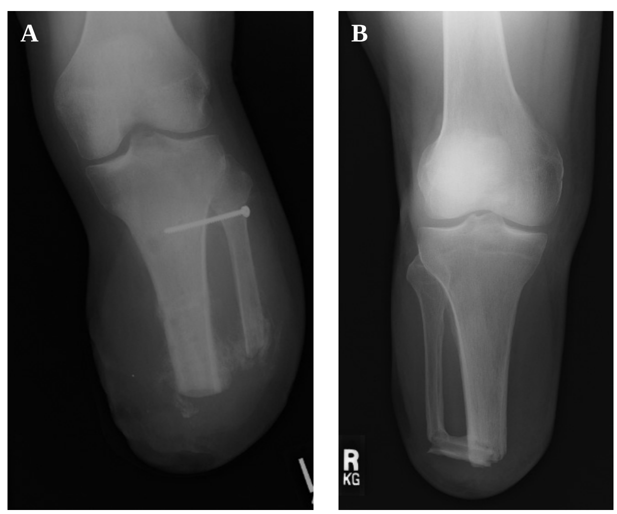

FIGURE 4 (**A**) Proximal tibiofibular stabilization performed with screw in a patient with distal wound contamination precluding a bridge synostosis. (**B**) Distal tibiofibular stabilization performed with a modified Ertl tibiofibular synostosis.

through-knee disarticulations were performed through the zone of injury and 12 of them had no gastrocnemius available for distal muscle coverage. A poor result is to be expected in this situation and most experts would have likely recommended a well balanced transfemoral amputation instead (3, 68).

In the development of the current through-knee amputation technique, the soft tissue coverage shortfall was noted and the posterior myofasciocutaneous flap was developed to more appropriately pad the residual limb. This has produced significantly improved outcomes and increased popularity at this level (69–72).

The well padded distal femoral condyles can be used for endbearing and allow for improved proprioception and walking stability. With this improved soft tissue coverage, other potential benefits of this level can be realized, including the long lever arm which allows for better sitting balance than more proximal levels, and the lower extremity muscle balance is maintained, leading to improved biomechanics and gait and obviating adductor concerns (73). Drawbacks of an optimal knee disarticulation include reduced room for prosthetic components versus other amputation levels and a knee joint cosmetic appearance and axis of rotation which differs from that of the contralateral limb.

To perform a through-knee amputation, the leg is removed sharply through the knee capsule and the patellar tendon is dissected off of the tibial tubercle. The patella may be removed from the encasing quadriceps at the surgeon's discretion to decrease the potential risk of patellofemoral pain. The medial and lateral femoral condyles may be trimmed modestly to decrease their bulk. A posterior condylectomy can be performed if necessary to increase coverage of the myofasciocutaneous flap. Care must be taken to isolate and ligate the popliteal vessels distal to the sural arteries supplying the gastrocnemius to avoid necrosis to the posterior muscle and skin flap. Finally, the patellar ligament is sutured to the cruciate ligament remnants to re-establish quadriceps tension, and the long posterior myofasciocutaneous gastrocnemius flap is sutured to the thick anterior joint capsule (70, 71).

Transfemoral Amputations

Transfemoral amputees have a less efficient gait, which results in a higher energy cost of ambulation (14, 74, 75). SF-36 scores have also been shown to be significantly lower for transfemoral amputees (56, 57). When a transfemoral amputation is necessary, it is imperative that the surgical and biomechanical principles that have been established are heeded so that the downsides of this level are minimized.

At the transfemoral amputation level, Gottschalk described that the loss of the adductor magnus insertion translates to an overall loss of 70% of the adductor moment on the femur (76). This results in an unopposed pull of the hip abductors, leading to an abduction deformity of the femur and gradual lateral drift of the femur within the soft tissue envelope (Fig. 5). This abducted position leads to an increased lurch and higher energy consumption during ambulation due to the inability to adequately support the pelvis. His work, along with other studies, demonstrated that without adequately stabilizing the residual thigh musculature there would be a decrease in thigh strength and progressive atrophy. These findings highlight the importance of performing at least an adductor myodesis during a transfemoral amputation (77–79).

Following reflection of the extensor mechanism just proximal to the patella, the adductor magnus tendon is identified, tagged, and released from its femoral insertion. The transfemoral bone cut is optimally performed and smoothed at 9–12 cm proximal to the medial femoral condyle. Longer cuts reduce space for prosthetic components and result in less padding of the distal residual limb. After appropriate management of the nerves (sciatic,

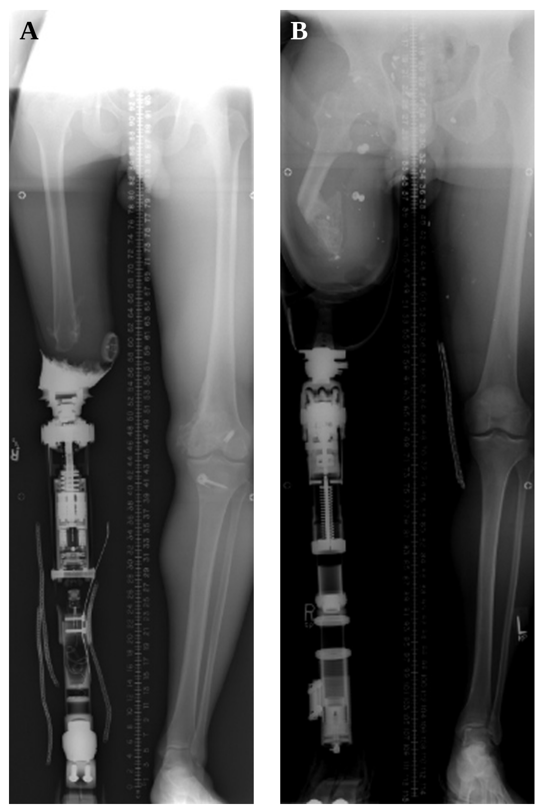

FIGURE 5 (**A**) Transfemoral amputee with a stable adductor myodesis and normal residual femur and limb alignment. (**B**) Transfemoral amputee with an inadequate adductor myodesis and lateral drift of the residual femur.

saphenous, and obturator, as well as the femoral and lateral and posterior femoral cutaneous nerves of the thigh at more proximal levels) and double ligation of the vessls, drill holes are placed into the lateral and anterior femoral cortex and, with the limb held in maximum adduction and slight extension, the adductor magnus tendon is myodesed to the lateral femur. Additional stabilizing sutures should then be utilized to ensure that the magnus tendon is stable and does not subluxate posteriorly. A semimembranosis myodesis is then recommended to prevent a flexion deformity as well as stabilize the subsequent myoplasty. Finally, the quadriceps apron is pulled distally over the residual limb and a myoplasty is performed. This provides quadriceps stabilization and provides a robust muscular padding over the residual limb.

Hip Disarticulation

The hip disarticulation is an amputation of last resort. Historically, this very proximal amputation had a dismal outcome, but functional potential has improved dramatically by modern suction-fit prosthetics and has allowed for remarkable function in some patients. Therefore, attention to a few key points is warranted to maximize patient outcomes.

The soft tissue coverage flap for the hip disarticulation is usually composed of a posterolateral flap including the gluteal muscles. Care must be taken during dissection around the sciatic notch to avoid injury to the vascular supply of the gluteal musculature. The femoral and obturator vessels must be identified and ligated as they exit the true pelvis. The femoral, sciatic, and obturator nerves must be identified and transected or ligated as far proximal as possible (ideally at their point of exit from the pelvis) to avoid symptomatic neuroma formation (3). The proximal femur is then removed or fused to the acetabulum and the abductor musclature and pectineus are sutured to the residual joint capsule or through bone tunnels in the acetabulum to fill the dead space. The gluteus maximus tendon is then mobilized and sutured anteriorly to the inguinal ligament, taking appropriate care not to injure the structures within. This provides a robust myofasciocutaneous flap over the residual hemipelvis.

Complications of Amputations

Despite attention to the perioperative and surgical details discussed in this review, amputations due to combat trauma are fraught with complications. These can range from minor dermatologic complaints to major complications requiring multiple return trips to the operating room. In the recent review of the complications from the LEAP study group in a civilian trauma population, over 85% of patients who had a trauma-related amputation had a significant complication within the first 6 months after amputation. Nearly half of all of the patients who underwent a trauma-related amputation had either a wound infection or wound necrosis. The other frequent complications included "stump" complications, symptomatic neuromas, and phantom limb pain (10). These findings and our own anecdotal experience have made it imperative to educate our patients of the very high likelihood of revision surgery in the first couple of weeks to years after the closure of combat-related amputations.

In our experience with combat-related and traumatic amputations we have witnessed virtually every complication reported in the civilian literature and have also dealt with a high frequency of complications outside of the first 6 months after amputation. These include heterotopic ossification, symptomatic neuromas, late infections, myodesis failures, and tibiofibular synostosis-related complications (18). We have found that surgical treatment of many of these complications at this late time (>6 months from primary amputation) can lead to better outcomes and improved prosthetic use with high patient satisfaction and function. Therefore, we highly recommend the long-term follow-up of all trauma-related amputees by surgeons familiar with amputation management and revision, ideally the surgeon who performed the definitive amputation.

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