Updates in the Management of Orthopedic Soft-Tissue Injuries Associated With Lower Extremity Trauma

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Abstract

Management of traumatic soft-tissue injuries remains a challenging and ever evolving field within orthopedic surgery. The basic principle of addressing life before limb in the initial assessment of critically injured patients has not changed. Although arteriography remains the gold standard for vascular injury screening, computed tomography angiography is being used more often to determine limb viability, and its sensitivity and specificity for detecting vascular lesions are reported to be excellent. Thorough debridement and irrigation with early institution of antibiotics are crucial in preventing infection; debridement should be performed urgently once life-threatening conditions have been addressed. Increasing use of vacuum-assisted closure therapy has created a trend down the reconstructive ladder, with improvements in resulting wound closure. Although the orthoplastics approach and new microsurgical techniques have made limb salvage possible in even the most severely injured extremities, it is important to clearly identify the zone of injury and to inform patients and their families of the outcomes of limb salvage versus amputation. Results from the LEAP (Lower Extremity Assessment Project) trials and similar studies should guide orthopedic surgeons in the management of these complex injuries. Nevertheless, it is important to individualize management plans according to patient factors.

Managing orthopedic soft-tissue injuries is a troublesome and challenging area for all surgeons. The basic principles of soft-tissue debridement and irrigation followed by bony stabilization have not changed in recent years. However, there is no universal consensus as to set protocols for type and amount of irrigation. Wound-closure techniques continue to evolve, and different methods for effective closure of the soft-tissue envelope have been developed. The LEAP (Lower Extremity Assessment Project) trials and other recent studies have also increased awareness about the functional successes of amputation and limb-salvage procedures.

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Management

Initial Assessment

Traumatic soft-tissue injuries often result from high-speed motor vehicle collisions or falls from heights. Head, chest, abdomen, and pelvis injuries often occur simultaneously. According to the advanced trauma life support protocol, life-threatening injuries are addressed first and extremity injuries second. Evaluation of a severely injured extremity begins with assessing the viability of the extremity. Clinical examination continues to be of paramount importance and should include detailed evaluation of distal pulses, skin color, capillary refill, and sensory and motor function.

Multiple studies have shown that the ankle brachial index (ABI), when used in conjunction with the physical examination, is effective in assessing limb arterial viability.[1-3] Stannard and colleagues[4] demonstrated the usefulness of the physical examination in determining the need for selective arteriography in patients with knee dislocation. They reviewed the cases of 126 patients (134 knees) admitted for serial neurovascular examinations. An examination revealing a decrease in pedal pulses or lower extremity color/temperature, or an expanding hematoma about the knee, was considered abnormal. Ten patients with an abnormal examination subsequently underwent arteriography. Of these 10 patients, 9 were found to have popliteal artery damage, for an overall incidence of 7% (9/126). Seventeen patients in the study who had a normal physical examination still underwent arteriography because the treating surgeon was concerned about possible vascular injury. None of their angiographic findings necessitated vascular surgical management. In addition, in all 99 patients who had a normal examination and did not undergo arteriography, there were no vascular complications or problems over a minimum follow-up of 6 months. Statistical analysis of all 126 patients demonstrated that the physical examination had positive predictive value of 90%, negative predictive value of 100%, sensitivity of 100%, and specificity of 99%, and was significantly ($P<.001$) associated with clinically important arterial injury.

Mills and colleagues[5] prospectively evaluated 38 patients with knee dislocation. They used ABI and clinical pulse examination to evaluate the extremity for possible arterial injury. Eleven patients had ABI lower than 0.90, subsequently underwent arteriography, and had arterial injury that required surgical management (sensitivity, specificity, and positive predictive value were 100%). Twenty-seven patients had ABI of 0.90 or higher, were admitted and observed with serial physical examinations, and had no evidence of vascular injury on serial clinical examinations or duplex ultrasonography.

Duplex ultrasonography can also be used when ABI is lower than 0.90 or when ABI is difficult to obtain. Duplex ultrasonography is relatively inexpensive and is easy to perform in the emergency department. Fry and colleagues[6] found 100% sensitivity and 97.3% specificity for this test, which was successfully used in detecting 18 vascular injuries in 225 cases.

Arteriography remains the gold standard for vascular injury screening. Schwartz and colleagues[7] determined that pulse deficit and ABI lower than 1.00 were significant predictors of arterial injury, and they recommended arteriography for patients with these findings.

Computed tomography angiography (CTA) has recently become more popular in detecting vascular injury. Proponents of CTA argue that arteriography is expensive, invasive, and delays definitive care.[8] CTA is considered safer, more cost-effective, and less time-consuming than arteriography, and has excellent sensitivity and specificity in detecting vascular injury.[9] Seamon and colleagues[10] prospectively used CTA to evaluate 22 extremities with potential vascular injury and found 100% sensitivity and specificity for clinically relevant vascular injury detection. Similarly, Inaba and colleagues[11] found 100% sensitivity and specificity for use of CTA in evaluating lower extremity vascular injury.

Once limb viability has been established, the assessment can be focused on the extent of the soft-tissue injuries. Size and depth of injured area should be measured, associated fractures ruled out, mechanism of injury determined, and neurologic function examined in detail. Plastic surgery consultation regarding possible soft-tissue reconstruction options is appropriate.

Antibiotic Therapy

In 1974, Patzakis and colleagues[12] were the first to demonstrate that early administration of antibiotics after open fractures is the most important determinant of infection prevention. A 2004 Cochrane review[13] concluded that antibiotic therapy reduces the incidence of early infection in open limb fractures. Antibiotic therapy is now considered the standard of care for open fractures of all grades. Although orthopedic surgeons agree that use of antibiotics is effective and necessary for infection prophylaxis, they continue to debate the duration of antibiotic use, the need for gram-negative organism coverage, and the appropriate route of administration.

There is general agreement that patients with Gustilo-Anderson grade I, II, or III open fractures should be intravenously administered a first-generation cephalosporin for up to 48 hours, as highlighted by the surgical infection guidelines of Hauser and colleagues.[14] It is also common practice to repeat 24-hour courses of perioperative antibiotic prophylaxis after repeated irrigation and debridement procedures. However, many studies have shown no superiority of multiple-dose antibiotics over single-dose antibiotics in preventing infection.[14] Hauser and colleagues reviewed more than 100 studies and found no evidence supporting prolonged use of antibiotics (>24 hours), repeated short courses of antibiotics, or routine coverage extending to gram-negative species.

A role for extended gram-negative coverage has been established as well. In the 1980s, Patzakis and colleagues[15,16] reported a 4.5% infection rate when both gram-positive and gram-negative coverage were provided with cefamandole and tobramycin after open tibia fractures, compared with a 13% infection rate with use of only cephalothin. More recently, in 2000, Patzakis and colleagues[17] demonstrated that patients who were treated with ciprofloxacin alone after grade III open fractures were 5.33 times more likely to develop an infection than patients treated with cefamandole and gentamicin combined. Gentamicin 80 mg was administered every 8 hours as part of combined therapy. Although many authors report administering gentamicin every 8 to 12 hours, the safety and efficacy of once-daily dosing have also been established in patients with open fractures. Sorger and colleagues[18] randomized 76 patients with grade II or III open fractures into 2 dosage groups: gentamicin 6 mg/kg once daily and gentamicin 5 mg/kg twice daily. These groups showed no statistical difference in infection rates. Similarly, Russell and colleagues[19] monitored gentamicin serum levels and clinical outcomes for 16 patients who sustained grade II or III open tibial fractures and received gentamicin 5 mg/kg once daily. Mean time to fracture union was 8 months, no patient developed nephrotoxicity or ototoxicity, and only 1 superficial wound infection and 2 deep wound infections were recorded.

Debridement

After all life-threatening emergencies are addressed and the patient is medically stabilized, operative surgical debridement and irrigation can be initiated. Thorough removal of all nonviable skin, soft tissue, muscle, bone, and foreign bodies is crucial in obtaining a clean wound bed, reducing bacterial contamination, and preventing subsequent infection. Consistency, color, contractility, and circulation are used to determine muscle viability. Skin should be excised to leave a fresh-bleeding skin edge.

The 6-hour period after injury has long been considered critical for performing debridement and preventing infection. Kindsfater and Jonassen[20] studied grade II and III open tibia fractures and found the infection rate to be significantly higher for patients treated after 5 hours (38%) than for patients debrided within 5 hours (7%). Using an animal wound model, Owens and Wenke[21] showed that early wound irrigation (ie, 3 hours after wound inoculation) was superior to late wound irrigation (ie, 12 hours after inoculation) in reducing bacteria counts.

Controversy remains about the timing of wound debridement. Recent literature suggests that, with proper use of prophylactic antibiotics, there is no obvious advantage in debriding within 6 hours versus 6 to 24 hours after injury.[22-24] Werner and colleagues[25] reviewed multiple studies and found no difference in infection rates when open fractures were debrided within 6 hours or within 24 hours. Ultimately, the surgeon, patient, and hospital all have a role in determining when to debride. Efforts to debride wounds within 24 hours after injury should be undertaken.

The Versajet hydrosurgery system (Smith & Nephew, Key Largo, Florida) uses high-velocity pressurized water and a vacuum to hold and cut targeted tissue. Its use as a debridement tool has been on the rise in recent years. In a case series of 15 patients, Gurunluoglu[26] demonstrated safe and efficient use of the Versajet system in debriding necrotic tissue in traumatic lower extremity wounds, venous ulcers, pressure sores, and burn wounds. Cubison and colleagues[27] used this system to help preserve dermal tissues during surgical debridement of pediatric burn wounds. However, the usefulness of the system has not been consistently demonstrated in cases of deeply embedded contamination. Furthermore, the cost of a disposable handpiece is roughly $500. Further investigation is needed to determine the efficacy of this technique in orthopedic acute traumatic soft-tissue wound debridement and its cost-efficiency over standard methods.

Irrigation

Irrigation is crucial in the surgical management of open fractures and soft-tissue trauma. Many researchers have compared the efficacy of normal saline irrigation, antiseptic solutions, antibiotic solutions, and nonsterile soaps. Before the antibiotic era, soap solutions were often used because they interfere with bacterial adhesion to wound surfaces. Although Owens and colleagues[28] found the largest reduction in bacteria counts with use of castile soap irrigation, this method had the highest rebound of counts 48 hours later. Antiseptic solutions effectively kill bacteria in a wound, but are associated with local tissue toxicity and are seldom used today.

Antibiotic solutions were theorized to be effective in reducing infection rates and promoting healing, but prospective randomized trials comparing soap and antibiotic solution irrigation have shown no advantage for antibiotic solutions over nonsterile soap solution.[29] In fact, wounds irrigated with antibiotic solution had a significantly higher rate of wound healing problems than those irrigated with castile soap. In addition, in a critical review of clinical and experimental studies, Falagas and Vergidis[30] found an insufficient number of evidence-based studies to recommend routine use of antibiotic solutions for wound irrigation.

Svoboda and colleagues[31] demonstrated that high-pressure pulsatile lavage was more effective than bulb syringe irrigation in removing bacteria. An animal wound was inoculated with *Pseudomonas aeruginosa* and then irrigated with normal saline in 3-L increments for a total of 9 L. Bacteria counts were taken after each stage of washing. Pulse lavage was more effective than bulb syringe after each of those stages. However, it has also been shown that, when compared with low-pressure irrigation, high-pressure irrigation causes more soft-tissue damage, removes less debris, and drives some contaminants deeper into tissue.[32] Low-pressure irrigation involves bulb or gravity tubing. Although high-pressure irrigation and low-pressure irrigation were equally effective in removing bacteria within 3 hours of wound contamination, the effectiveness of low-pressure irrigation after 6 hours was questionable.[33] A study in which goat wounds were inoculated with *P aeruginosa* and then irrigated at high or low pressure with castile soap, benzalkonium chloride, normal saline, or bacitracin solutions, showed that normal saline, combined with a low-pressure device, produced the lowest overall bacteria counts at 48 hours.[28]

Although animal studies have demonstrated a linear relationship between increasing irrigation volumes and removing particulate debris, there are no standardized irrigation volumes based on degree of injury.[34-36] Anglen[37] recommended 3 L for grade I open fractures, 6 L for grade II, and 9 L for grade III. No randomized prospective studies have compared different irrigation volumes with respect to decreasing infection rates. However, studies have shown that 4-L pulse lavage is effective in removing bone and polymethylmethacrylate debris particles generated during total knee arthroplasty.[38] Results from the Fluid Lavage in Patients With Open Fracture Wounds (FLOW) trial showed that a majority of international orthopedic surgeons favor both normal saline and low-pressure lavage for initial management of open fracture wounds.[39] Ongoing studies with the FLOW trial will better elucidate evidence-based guidelines for irrigating orthopedic soft-tissue wounds.

The Reconstructive Ladder and the Orthoplastic Approach

The "reconstructive ladder" concept was developed to aid reconstructive surgeons in organizing operative options to address difficult soft-tissue injuries.[40] Each rung on the ladder represents a wound-closure option. The lowest rung is the simplest (ie, primary closure) and the highest is the most complicated (ie, free flap). Surgeons are advised to choose the lowest rung that offers successful wound management and soft-tissue coverage.

Some have questioned the usefulness of the classic reconstructive ladder and have argued that it has less clinical utility now. Lineaweaver[41] argued that, given the advances made in microsurgery, the ladder's top rung is often the simplest, most direct route to satisfactory wound healing. Gottlieb and Krieger[42] wrote that "reconstructive elevator" is a more apt concept. Surgeons should not adopt a stepwise algorithm for closing a wound; rather, they should skip rungs when necessary and "take the elevator to the next floor," to the coverage option that optimizes form and function for a given wound. Others have advocated a "revised reconstructive ladder" that incorporates, at the highest rung of the ladder, vacuum-assisted closure (VAC) therapy (V.A.C. Therapy System; Kinetic Concepts, San Antonio, Texas), acute bone shortening, and bone transport.[43] Increased use of VAC therapy has also resulted in the trend of moving down the reconstructive ladder, to less use of skin flaps and more use of delayed primary closures and skin grafts.[44]

In the orthoplastic approach, an orthopedic surgeon and a plastic surgeon work together to manage complex lower extremity injuries.[45] The importance of this team effort was highlighted in management guidelines published by the British Orthopaedic Association and the British Association of Plastic Surgeons.[46] Several studies have shown better functional outcomes in patients treated at trauma centers that have both orthopedic and plastic surgeons and higher rates of complications and revision surgeries at hospitals that do not combine orthopedic and plastic services.[47-49]

Wound Coverage

Timing of Coverage

After thorough irrigation and debridement, a wound can be assessed for primary versus delayed closure. Although no level I studies have examined the possible independent role of the timing of soft-tissue coverage, it is generally accepted that early coverage (<7 days after injury) is critical in preventing infection and flap failure.[50] Others have identified the critical period for soft-tissue reconstruction as the first 72 hours after injury. Godina[51] found that rates of infection and microsurgical failure differed significantly between wounds reconstructed within 72 hours of injury and those reconstructed afterward. The rates of infection (1.5%) and free-flap failure (0.75%) for wounds with microvascular reconstruction performed within 72 hours of injury were significantly lower than the rates (2% infection, 12% flap failure) for wounds reconstructed between 72 hours and 3 months after injury. Gopal and colleagues[52] proposed the "fix-and-flap" protocol, in which wounds were reconstructed with muscle flaps within 72 hours of injury. They reviewed 84 patients treated with debridement and muscle-flap coverage after a severe open tibia fracture and demonstrated that wounds covered within 72 hours had a lower complication rate than those reconstructed later (6% vs 29% deep infection rate). Using a multivariate regression model, Pollak and colleagues[53] found that soft-tissue coverage timing was not an independent predictor of short-term complications; instead, injury severity and flap type were the critical factors in predicting complications.

Vacuum-Assisted Closure Therapy

Since its introduction in 1997, VAC therapy has revolutionized initial management of orthopedic soft-tissue injuries.[54] VAC dressings are easily applied after initial debridement and irrigation. The VAC system mechanically induces negative pressure over the wound bed. Negative pressure removes fluid from the extravascular space, improves blood supply and oxygen delivery, and promotes formation of granulation tissue within the wound bed.[55] These combined effects improve wound healing and decrease bacteria counts. Compared with a wet-to-dry dressing, VAC therapy showed a nearly 80% increase in granulation tissue formation.[56] The efficacy of VAC therapy in promoting granulation tissue formation has resulted in less need for free-tissue transfers. With these wounds reduced in size, defects can be closed with delayed primary closure, split-thickness skin grafts (STSGs), or local flaps. VAC therapy led to successful primary closure of 71 of 75 lower extremity wounds with exposed tendon, bone, or orthopedic hardware,[56] and has become the cost-effective alternative to free-tissue transfer. As VAC therapy reduces infection rates and the need for complex microsurgical procedures, its use has led to lowered hospital costs.[57] According to a recent study, between 1992 and 2003, use of VAC therapy increased from 0% to 47% in the management of all open fractures, and to 74% in the management of grade III fractures.[44]

VAC therapy has also lengthened the "critical period" for wound closure. There is no established period within which a wound managed with VAC therapy requires definitive closure. Conflicting studies have tried to establish a critical period of 7 days or less, but, with small retrospective studies, drawing definitive conclusions is difficult.[58-60] In a group of 38 patients with grade IIIB open fractures, soft-tissue defects managed with VAC therapy and then closed within 7 days were associated with a significantly lower rate of infection (12.5%) than wounds closed after 7 days (57%).[61] Steiert and colleagues[60] showed that flap coverage delayed to a mean of 28 days after injury was associated with failure rates of 2.6% in free flaps and 25% in pedicle flaps, which compare favorably with reported flap-failure rates. Rinker and colleagues[59] showed that use of VAC therapy as a bridge to free-flap reconstruction was associated with decreased infection and flap-related complications in patients with grade IIIB or IIIC open tibia fractures.

Reported rates of infection after open fracture range from 25% to 66%.[12-15] In a prospective randomized study, Stannard and colleagues[62] found that high-energy trauma wounds managed with VAC therapy developed significantly fewer infections than did wounds managed with standard gauze dressing (5.4% vs 28%). A retrospective study of 50 grade III open tibia fractures showed that the infection and nonunion rates associated with use of VAC therapy as a temporizing measure were similar to the rates associated with use of historical wound dressings.[61] Use of VAC therapy had no detrimental effects and had major potential benefits for soft-tissue closure. A recent study of injuries sustained in the Iraq war showed that use of VAC therapy protected wounds from the war environment and was associated with no reported infections or wound complications.[63] VAC therapy facilitated delayed primary closure, and closure with local flaps or STSGs, a mean of 4.24 days after injury.

Skin Grafts and Substitutes

Many soft-tissue wounds require a STSG, a full-thickness skin graft (FTSG), or a flap to reconstruct the traumatized lower extremity. For them to “take,” skin grafts require a healthy, well-vascularized wound bed. As STSGs contain only a small portion of the dermis, the metabolic demand for healing is lower. STSGs can be harvested in ample amounts for use in large soft-tissue defects. FTSGs, on the other hand, contain the entire epidermis and dermis and, therefore, are thicker and more durable. They allow for increased skin sensation and retain the natural pigmentation of the donor site. Use of either type of skin graft can lead to some donor-site–related morbidity.

The recent introduction of dermal matrices has provided a new grafting option. Bioengineered, cell-free, dermal matrices have been successfully used to reconstruct soft-tissue defects in burn patients for more than 25 years.[64,65] Equal or superior results have been reported in the reconstruction of chronic leg ulcers, flap donor-site defects, skin cancer excision sites, contracture releases, and free flaps.[65-67] Although several different types of dermal matrices are commercially available, the Integra dermal regeneration template (Integra Life Sciences, Plainsboro, New Jersey) has been most extensively used in the management of orthopedic soft-tissue injuries. Integra is a permanent bilaminar dermal replacement that has no metabolic demand and is nonviable when grafted; the patient’s endogenous collagen forms a new dermis on this template.[65] Vascularization occurs over 3 weeks, after which a skin graft can be placed over the matrix. The “take rate” of this product falls in the 80%-to-100% range.[64-68] Purported advantages include no donor-site morbidity, immediate availability, unlimited quantity, and improved cosmesis and function. Major disadvantages include high cost, loss of intrinsic immunologic defenses, and limited use in wounds with bacterial colonization.[66-68]

In using Integra to manage 9 lower extremity burn injuries, Lee and colleagues[68] successfully avoided vascularized tissue transfers, staged procedures, and amputation. A combination of VAC therapy and Integra has led to improved graft survival, better aesthetic results, and shorter hospital stays.[44,69-73] Molnar and colleagues[73] used VAC therapy to shorten Integra vascularization and increase the take rate of subsequent STSGs in lower extremity wounds with exposed bone and tendon; wounds were closed with STSGs at 4 to 11 days (mean 7.25 days), compared with 14 to 28 days that generally required when VAC therapy is not used. In 15 of 16 patients with blast-related wounds and exposed tendon, the combination of Integra, VAC therapy, and STSGs provided successful wound closure.[70] Barnett and Shilt[69] managed 7 pediatric grade IIIB lower extremity injuries with use of Integra with VAC therapy. Jeschke and colleagues[72] found an increased take rate (98%, vs 78% for controls), improved clinical outcomes, reduced complications, and shorter hospital stays with combined use of fibrin glue, Integra, and VAC therapy.

Although these early, positive reports on the efficacy of Integra are exciting, the literature on using this product in the management of orthopedic soft-tissue injuries is very limited. Level I studies are needed to evaluate its role and to develop indications for its use in the management of soft-tissue trauma.

Flaps

The need for flap reconstruction in injuries with massive soft-tissue defects and exposed hardware persists, particularly in the case of type IIIB and IIIC open tibia fractures. Although size, location, and depth of soft-tissue injury all figure in determining the flap options for soft-tissue coverage, zone of injury is arguably the most important factor. Occasionally, zone of injury may include an area that involves components of a possible local flap, such as what occurs in some type IIIB and IIIC tibia fractures associated with severe damage to the gastrocnemius and soleus. Damage to these muscles generally precludes them from being used as flaps and may result in a move up the reconstructive ladder to more complex coverage options.

Soft-tissue flaps are extremely important because they provide the vascularization and protection needed to stabilize open fractures, resist infection, and promote fracture union. Standard flap options include both pedicled muscle flaps and free muscle flaps. Generally, under ideal circumstances, defects in the proximal third of the tibia are addressed with a gastrocnemius flap, and soleus flaps are used for defects of the middle third of the tibia.[71] Free flaps are generally needed for defects of the distal third of the tibia.[71,74,75] Gracilis free flaps are useful for small defects and cause less donor-site morbidity, whereas latissimus dorsi free flaps can cover larger defects but cause more donor-site morbidity.[76,77]

Recent microsurgical emphasis on angiosomes has improved and expanded the types of flaps available for local and free-tissue transfers.[78] The reverse sural flap has led to a decreased need for free-tissue transfer in foot and ankle surgery. This technique uses a reverse-flow island sural flap with the superficial sural artery. This flap has a high success rate and causes limited morbidity because of its relatively simple dissection and its preservation of major vessels.[79-82] Rios-Luna and colleagues[82] reported that 13 of 14 patients with coverage defects sustained after lower extremity trauma were successfully treated with use of reverse sural flaps. Afifi and colleagues[79] reported successful reverse sural flap coverage of foot and ankle defects in 24 of 32 patients. Buluc and colleagues[80] modified the original technique for this flap and achieved flap survival in 8 of 11 patients with foot ankle defects. Venous congestion was avoided by transposing the flap through a subcutaneous tunnel with the aid of a soft-tissue expander.

Perforator flaps are based on musculocutaneous perforator arteries and are composed exclusively of skin and subcutaneous fat. They are being used more often, but little is known about their functional outcomes, compared with the outcomes of traditional muscle flaps. Compared with muscle flaps, perforator flaps, such as the deep inferior epigastric artery perforator flap, which preserves the rectus abdominus muscle, spare functional muscle units, and the loss of even one of these functional units may not be inconsequential in a trauma patient. Rodriguez and colleagues[83] retrospectively reviewed 42 cases of lower extremity injuries managed with either free muscle flaps or perforator flaps. Quality of life and functional outcomes did not differ between the 2 flap groups, and time to bony union, union rate in presence of infection, and rate of flap infection were not related to flap type. Although donor-site sensation was diminished for all patients, the sensory loss was more significant at perforator flap donor sites than at muscle flap donor sites.

Mangled Extremities

Plantar sensation was one of the most important factors in decisions between limb salvage and amputation[84]—until the findings of the LEAP trials were published. MacKenzie and colleagues[85] found that the initial plantar sensory examination was not prognostic of long-term outcomes. Most patients who initially had an insensate foot regained plantar sensation 2 years after injury. The authors postulated that initial loss of plantar sensation may be secondary to neuropraxia or reversible ischemia and is not representative of permanent nerve damage. Instead, degree of initial soft-tissue injury was found to be the most important factor in determining the success of limb salvage.[86]

Numerous classification systems and predictive indices have been developed to guide surgeons in their decisions to salvage or amputate extremities. The Mangled Extremity Severity Score (MESS), the Limb Salvage Index (LSI), the Predictive Salvage Index (PSI), the Nerve Injury, Ischemia, Soft-Tissue Injury, Skeletal Injury, Shock, and Age of Patient Score (NISSSA), and the Hannover Fracture Scale-97 (HFS-97) are just a few of the scoring systems being used. Although scoring systems may help in estimating chances of successful salvage, most are limited by poor retrospective and underpowered studies.[87,88] Clinical use of MESS, LSI, PSI, NISSSA, and HFS-97 has not been validated. These systems have high specificity and low sensitivity. They can make useful predictions about limb-salvage potential but cannot reliably predict which limbs should be amputated.[89] Ultimately, patient factors (eg, age, physiologic reserve, associated injuries, preinjury functional level), injury characteristics (eg, soft-tissue injury and fracture characteristics), vascular insult, and other factors (eg, surgeon experience, available resources) all have an important role in the clinical decision-making.

Limb Salvage Versus Amputation

Advances in microsurgical reconstruction and modern skeletal fixation have made limb salvage technically possible in even the most severely injured extremities. Approximately 70% of the lower extremities involved in high-energy trauma are now being salvaged, and more than 90% of patients prefer limb salvage.[90] The 7-year follow-up of the LEAP trials showed no functional differences between patients who underwent amputation and those who underwent limb salvage.[91-94] However, compared with amputees, patients with salvaged limbs have been reported to have more problems with pain and daily activities.[95] Patient satisfaction did not correlate with either procedure; it correlated instead with physical function, ability to return to work, overall clinical recovery, pain level, and postinjury mental health.[96] Overall, patients who have a limb salvaged undergo longer rehabilitation, require more operations and hospitalizations, have more complications, and incur higher initial health care costs.

Amputation is indicated in an ischemic limb with an irreparable vascular injury. Amputation level can have significant effects on functional outcomes. Waters and colleagues[97] were the first to report amputees' various energy expenditures based on amputation level. They reviewed 70 patients with unilateral traumatic and vascular amputations. Amputations above the knee, below the knee, and at the Syme level were compared in both amputee groups; a control group of 40 normal subjects was studied as well. In the amputee groups, the energy cost of prosthetic walking was significantly better the lower the amputation level. Gait velocity decreased the higher the amputation level in both traumatic and vascular amputees.

Through-the-knee amputees have been shown to have poor outcomes at both 2 years and 7 years after injury.[91-94] They also had the slowest timed walking speeds.[98] Although no significant differences were found in the sickness impact profiles of above-knee and below-knee amputees 2 years after injury, below-knee amputees had faster walking times and fewer problems walking on uneven surfaces.[98] However, faster walking time did not translate into any patient-reported improvements, in comparison with the above-knee amputees.[98] Interestingly, neither injury severity nor type of management (limb reconstruction or amputation) correlated with patient satisfaction. Poorer outcomes were associated with the patient factors of older age, less education (high school degree only), female sex, poverty, poor social support network, history of smoking, lack of private insurance, low self-efficacy, and disability.[91-93] Despite the fact that no differences were found between the groups, the general literature supports below-knee amputations over above-knee amputations.[97,99]

Limb salvage results in longer rehabilitation and more complications, surgeries, and hospitalizations, but its 2-year health care costs are similar to those of amputation.[48] Projected lifetime costs were $509,275 for amputees and $163,282 for limb-salvage patients.[48]

Unfortunately, the long-term functional outcomes for amputees and limb-salvage patients are poor. Both groups' physical and psychosocial functional levels deteriorate over time. Although 60% of patients return to work 7 years after injury, roughly 25% of these patients report performance limitations.[91,92] The increased number of complications associated with limb salvage procedures further highlights the overall severity of the injuries. In the limb-salvage group, wound infection, dehiscence, osteomyelitis, and nonunions accounted for a rehospitalization rate of more than 30%.[96] A revision amputation rate of 5.4% was reported for the LEAP trial amputees, and a late amputation rate of 3.9% was reported for the limb-salvage group.[96]

Summary

Management of traumatic soft-tissue injuries remains a challenging and ever evolving field within orthopedic surgery. The basic principle of addressing life before limb in the initial assessment of critically injured patients has not changed. Although arteriography remains the gold standard for vascular injury screening, CTA is being used more often to determine limb viability, and its sensitivity and specificity for detecting vascular lesions are reported to be excellent. Thorough debridement and irrigation with early institution of antibiotics are crucial in preventing infection; debridement should be performed urgently once life-threatening conditions have been addressed. Increasing use of VAC therapy has created a trend down the reconstructive ladder, with improvements in resulting wound closure. Although the orthoplastics approach and new microsurgical techniques have made limb salvage possible in even the most severely injured extremities, it is important to clearly identify the zone of injury and to inform patients and their families of the outcomes of limb salvage versus amputation. Results from the LEAP trials and similar studies should guide orthopedic surgeons in the management of these complex injuries. Nevertheless, it is important to individualize management plans according to patient factors.

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This paper will be judged for the Resident Writer's Award.