Multi-Disciplinary Management of the Mangled Lower Extremity: Part II

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KEYWORDS

• Mangled extremity • Lower extremity • Polytrauma • Multidisciplinary • Management • Outcomes

KEY POINTS

- If a limb is not definitively indicated for amputation, salvage can be attempted.
- The outcomes for amputation and salvage differ based on injury location, structures involved, and patient factors such as socioeconomic status.
- Bone transport methods and options for delayed wound closure allow for staged interventions and more detailed planning before making operative decisions.

CONSIDERATIONS FOR LIMB SALVAGE VERSUS AMPUTATION

In deciding between mangled lower extremity salvage and amputation, several factors must be considered. Rubrics such as the Mangled Extremity Severity Score, Limb Salvage Index, and other scoring systems were previously used for this purpose. These metrics, however, employed small sample sizes and have failed to adequately predict functional outcomes and provide reliable methods of operative decision-making.[1] Injury mechanism and location are valuable prognostic factors, with proximal traction, torsional, or crush injuries demonstrating poorer outcomes than distal sharp injuries. Vascular status and nerve integrity must also be considered. In inadequately revascularized and unstable patients, or those with ischemia persisting over 6 hours or transected major nerves, life-saving amputation is indicated.[2] If the patient can be stabilized until initiating operative treatment, revascularization and innervation may allow for limb salvage and improved outcomes.

If immediate amputation is not indicated, limb reconstruction may be attempted. Recent literature has disproven previously accepted outcome prediction metrics, however, contesting the true benefit of limb reconstruction. Various clinical and social factors affecting the decision of limb reconstruction versus amputation have been studied. The Lower Extremity Assessment Project (LEAP) study, a landmark study in orthopedic traumatology, helped define the characteristics of those sustaining mangled lower extremity injuries, injury environments, and physical injury variables. This study also reviewed subsequent treatment, outcomes up to 7 years, and general postoperative health, establishing a broad foundation for mangled lower extremity management. This study demonstrated similar functional outcomes and self-scored disability indices by 2 years after injury, for patients receiving amputation over limb salvage.[3] Subsequent studies have since been published, further detailing important prognostic and treatment factors. The Major Extremity Trauma Research Consortium (METRC)

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Abbreviations	
BKA	below-knee amputations
LEAP	Lower Extremity Assessment Project
METRC	Major Extremity Trauma Research Consortium
ORIF	open reduction and internal fixation

has also studied several factors affecting outcomes in initial, staged, and long-term treatment. The LEAP and METRC studies serve the foundation of modern mangled extremity management and continue to guide injury management. Of the prognostic clinical factors, injury location and tissue involvement are more predictive of outcomes than surgical approach. Distal lower extremity injuries are more likely to fail in reconstruction. Below-knee amputations (BKA) demonstrate improved outcomes over reconstruction 2 years postoperatively in mangled foot and ankle injuries. Free flaps and arthrodesis used in such repairs increase patient morbidity, time to full weight bearing and return to work when compared to BKAs.[4] Patients undergoing limb reconstruction have also demonstrated increased risk for secondary hospitalization due to major complications, as demonstrated in the LEAP study.[3] Postoperative differences between reconstructed and amputated proximal injuries, such as open proximal tibia fractures, equalize at 2 years without significant differences between treatment modalities. Soft tissue injury severity better predicts outcome prognosis than treatment type.[5] Surgical approach is critical for reconstruction, as different operative variables significantly affect postoperative outcomes. Grafting within 3 months of injury in Type III open diaphyseal tibia fractures requiring bone grafting has demonstrated improved outcomes. Skeletal stabilization methods also dictate functional outcomes based on soft tissue characteristics, with such injuries demonstrating similar outcomes between immediate external fixation and intramedullary fixation. External fixation should be avoided if muscle or free flaps are required, as this has demonstrated worse outcomes than in amputation.[6]

Considering patient characteristics and socioeconomic status is crucial, as patient desire and overall patient burden significantly influence the choice between amputation and reconstruction. The economic burden for mangled extremity treatment is substantial, with significant differences between total costs for lower extremity amputation and reconstruction. A study by MacKenzie and colleagues demonstrated that reconstruction produced an overall smaller short-term economic burden, with a 2-year cost of $81,316 for reconstruction and $91,106 for limb amputation. Long-term costs with amputation are substantially higher ($163,282 vs $509,275) due to prosthesis maintenance costs, particularly in younger patients.[7] Despite significantly higher midterm to long-term costs of amputation, various studies demonstrate benefits to amputation over reconstruction. In soldiers with blast injuries, amputations led to improved functional outcomes with a 50% lower rate for posttraumatic stress disorder and a 2-fold increase in the likelihood of sports participation after recovery. Socioeconomic variables are also valuable prognostically, with minority race, poverty, poor education, and lack of social support producing poorer outcomes.[8]

STAGED INTERVENTIONS

Postoperative complications significantly affect mangled extremity treatment, with infection being the most prevalent complication following initial treatment. Infection can lead to nonunions or osteomyelitis, complicating future treatment.[2] Aggressive and frequent staged management of infection is necessary to eradicate infection, protect soft tissue, and halt injury expansion. Repeat irrigation and debridement with prophylactic tetanus antitoxin and antibiotics allow for superficial and deep infection management. External fixation may be used to initially stabilize the patient. Once stable, open reduction and internal fixation (ORIF) should be performed to ensure fracture union and improve patient function.[9]

Patients with open fractures face a higher risk of developing posttraumatic osteomyelitis from postoperative infection.[10] The debridement necessary for osteomyelitis treatment may produce substantial bone loss. Bone grafting to prevent shortening may be indicated for major defect repair after infection eradication. Stable bone autografts or allografts may be used for defects ≤4 cm and vascularized autografts for defects ≥6 cm.[11] Options are limited for defects over 8 cm, as organic bone grafts may lack adequate length and infection risk and soft tissue injury may prevent their use. In such cases, bone loss may be addressed using bone transport or biomaterial replacements.[12,13] Bone transport, using the Ilizarov method, is a common primary approach in open fractures and lower extremity polytrauma patients. Double level bone transports are recommended for defects over 8 cm or comprising over 40% of the total bone length, demonstrating improved bone healing and functional outcomes with fewer treatment stages over traditional single level transports.[14] Synthetic or biomaterial bone replacements can also remediate major bone defects. Three-dimensional printing shows promise for bone repair, providing various advantageous options for grafting. Ti64 titanium alloy prints are stiff and promote osteoblast attachment, optimizing cortical bone growth and segmental defect repair. Heparin-loaded hydroxyapatite/polycaprolactone implants promote osteoblast proliferation and can be useful for femoral condyle defects. Polycaprolactone prints have demonstrated efficacy as biocompatible scaffolds, promoting trabecular bone regrowth in long bone injuries.[15]

Techniquesusing biomaterial spacers, such as the induced-membrane (Masquelet) technique, provide another effective approach toward segmental defect repair. The Masquelet technique involves a 2-stage repair following infected bone debridement. In the first stage, an antibiotic-infused polymethylmethacrylate cement spacer is placed between debrided ends and periosteum growth is induced in order to prevent spacer resorption. This wound is then closed under tension until the membrane fully forms without recurrent infection. Once the infection is cleared, the membrane is opened and the spacer is removed. The remaining spacer cavity is then filled with morselized corticocancellous bone graft, the bone is fixed via intramedullary nail, and the wound is closed with absorbable suture.[16] The Masquelet technique provides several advantages for the treatment of osteomyelitis and segmental defects, treating bone loss of varying lengths, clearing infection using antibiotics, and allowing delayed treatment after the surrounding soft tissue heals. This technique has demonstrated higher rates of bone union and may be effective in long bone injuries.[17]

DELAYED INTERVENTIONS

Techniques such as the Masquelet technique and antibiotic bead placement enable delayed treatment in soft tissue reconstruction. Previously, soft tissue reconstruction and wound closure were performed within 72 hours of the injury to ensure proper vascularization and infection prevention. Presently, soft tissue reconstruction demonstrates efficacy up to 14 days postinjury without compromising functional outcomes.[18] With these technical advancements, large urgent flaps are less frequently favored over smaller local flaps. This restructuring in the mangled extremity treatment timeline allows for similar functional outcomes with improved cosmesis. While skin grafts may be used for small defects or cosmesis, they lack vascular supply, progenitor cells, and growth factors. As a result, they inadequately cover larger, deeper soft tissue defects and are less commonly employed than skin flaps for deep soft tissue reconstruction.

Various skin flaps can be used in this stage, each with specific indications. These flaps include skin substitute flaps such as Integra (Integra Lifesciences) or Acell (Acell Incorporated) dermal substitutes, vascularized flaps such as rotational or free flaps, or nonvascularized skin grafts. Skin substitutes such as the Integra or Acell are collagen wound matrices used as dermal regeneration templates. These dermal substitutes temporarily dress lower extremity wounds, facilitating granulation tissue formation and preventing further damage to exposed nerves or vasculature.[19] Dermal substitutes combined with thin split-thickness skin grafts can close skin-only defects, cover exposed hard tissue or tendons, or provide coverage for flap donor sites.[20,21] Although effective in these instances, dermal substitutes are expensive and require temporary immobilization for adequate wound incorporation and successful acceptance of a secondary skin graft.

Compromised soft tissue defects may require vascularized flaps, such as fasciocutaneous, muscle-only, or myocutaneous flaps. These flaps can be local to the injury or harvested from a donor site. Free flaps may be preferred for extensive soft tissue damage and underlying exposure to achieve adequate flap sizing. For smaller regions of injury, local flaps such as rotational fasciocutaneous flaps may suffice. In this case, nearby soft tissue is rotated around a pedicle to provide wound coverage. Recommendations for local flap usage have been described previously, dividing coverage into 3 zones. Pedicled gastrocnemius or distal pedicled anterolateral thigh flaps may be used for upper third tibial wounds. Pedicled proximal gastrocnemius, hemi-soleus, or perforator flaps may be used for middle third wounds. Pedicled perforator flaps may again be used for lower third wounds.[22] Prior studies suggest poorer outcomes in local over free flaps, possibly due to confounding variables. Local flaps are limited by wound orientation, size, and the availability of viable soft tissue. In devascularized areas, the donor tissue may be inadequate for reconstruction. Additionally, local flaps may increase risk of edema, neuromata, and infection by interrupting superficial vasculature and lymphatic tissue.[23,24] The advantages of local flaps for soft tissue reconstruction include shorter, simpler procedures, and the lack of specialized training required for utilization. Local flaps also involve significantly fewer flap revisions and overall complications compared to free flaps, without significant differences in overall flap survival and return to full ambulation.[24] Currently, local flaps are recommended for lower energy tibial fractures with intact vascularity. They can also be used in urgent cases, or for patients who cannot physically sustain longer operations.[25]

Free flap usage demands more specialized training and longer procedures. However, these flaps provide flexibility in surgical planning, improve cosmesis, and improve outcomes. In this case, vascularized donor tissue is resected and transferred to the wound site.[26] The donor tissue's vascular bed and nerve supply are connected to the wound site and the donor site is closed directly. This approach enables easier surgical treatment planning, precise wound fit, and improved wound healing due to intact vasculature, growth factors, and progenitor cells. Additionally, both donor and wound sites are less deformed postoperatively. Both muscle-only and fasciocutaneous flaps are used for free flaps, with debate over each flap's superiority. Muscle-only tissue is more flexible, reducing hematoma formation incidence.[27] Experimental studies suggest improved fracture union and bone formation in muscle-only compared to fasciocutaneous flaps, but this has not yet been shown clinically.[28] Fasciocutaneous flaps offer cosmetic advantages for large wounds, as the skin can be contoured to the wound, better matches color, and is more easily sutured. Overall, the viable tissue and intact vasculature in free flaps result in lower rates of flap loss and are especially effective for secondary intervention following osteomyelitis.[23,29]

OUTPATIENT CONSIDERATIONS

The postoperative rehabilitative period is crucial for patients in preserving limb function after a mangled lower extremity. Although the limb's baseline function may never return, proper outpatient care and physical therapy can maximize functional outcomes. Mangled lower extremity injury rehabilitation generally comprises protective, early mobilization, and strengthening stages. Bracing is recommended over immobilizing casts to ensure union and stability of the reconstructed hard tissues while allowing for early mobilization during the protective stage. Early mobilization promotes joint movement and tendon gliding to prevent contractures, tissue edema, excessive scar formation, and hematoma formation.[2] Benefits to early mobilization have previously been documented, improving functional outcomes and reducing patient mortality in comparison to immobile stabilization following reconstruction.[30] Later stage limb strengthening is performed using physical and occupational therapy. Because outpatient care requirements vary considerably between patients, the care provided must be tailored to each patient with a focus on each patient's comfort and recovery.

For limb amputation patients, different prosthetics are available with varying costs and resulting functional outcomes. The goals for the postoperative care and prosthesis for amputation patients are to preserve functional length and use and to prevent infection or ulceration of the limb. Prosthesis recommendations vary by amputation level. Amputations at the ankle for distal foot injury (ankle disarticulation), below the knee for severe distal tibial injury (transtibial amputation), at the knee for proximal tibial injury (knee disarticulation), or above the knee for femoral injury (transfemoral articulation) each require individual considerations. Ankle disarticulations produce length discrepancy between limbs, so the prosthetic must equalize length and offload force onto the distal limb. In transtibial amputees, patient functionality dictates ankle joint mechanisms. Knee disarticulation patients face similar limb discrepancies, requiring individual prosthesis adjustment. Prosthetics for transfemoral amputations depend on ambulatory status and must be assessed using thorough rehabilitation and mobility assessments.[31] As with outpatient care and rehabilitation for limb reconstruction patients, the care for amputation patients must be individually focused to maximize patient satisfaction and functionality.

Additionally, psychological and social support is paramount in proper postoperative care for mangled extremity patients. The LEAP study demonstrated higher correlation between functional outcomes and social, economic, and personality characteristics than with interventions provided, regardless of treatment modality.[3] Patients have demonstrated significant acute and chronic psychiatric symptoms. Immediately after injury, 94% of patients experienced nightmares, flashbacks, phantom limb, inability to concentrate, and preoccupations with death. Two months following the injury, nightmares,

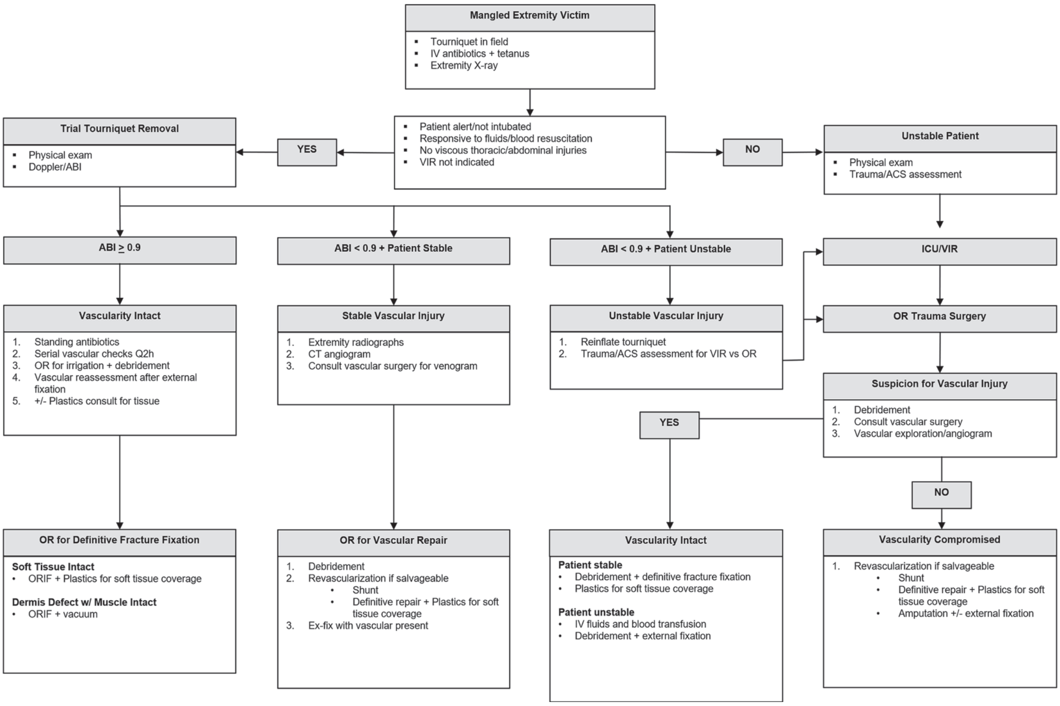

Fig. 1. Treatment algorithm for patients with a mangled lower extremity.

flashbacks, and other symptoms of PTSD and depression decreased in severity and frequency with larger reductions in incidence in patients receiving psychiatric treatment. Thus, outpatient psychiatric treatment may be initiated alongside physical rehabilitation.[32]

SPECIAL CONSIDERATIONS

In cases of high energy traumatic injuries such as motor vehicle collisions, falls from height, or blast injuries, polytrauma may occur. Rapid stabilization using the Advanced Trauma Life Support (ATLS) protocol must be performed within the first hour after the event. A team-based approach is critical for these patients. During assessment and stabilization, vascular and orthopedic surgeons consulted must treat any life-threatening injuries. In emergent cases, rapid structural stabilization may be required and longer, more functional procedures may not be feasible. Shortly after wound irrigation and debridement, external fixation and plating may be chosen over ORIF or the Masquelet technique. Wound coverage may also be a higher priority, to protect the tissue, prevent infection, and provide circulation to the wound before initiating further interventions. Addressing the injuries in order of threat to life and closing wounds loosely with monofilament suture to prevent ischemia, infection, and compartment syndrome are critical for these patients.[33]

If the traumatic event causes complete primary nerve transection and produces a flail lower extremity, amputation may be indicated. If nerve resection is possible, early and immediate construction of even complete traumatic amputations can produce functional limbs. Early treatment with thoughtful surgical and rehabilitative planning has demonstrated better outcomes than delayed treatment.[2] Treatment of flail limbs or completely amputated limbs, however, must be addressed only after life-threatening injuries or injuries to other organs have been treated. This may not be realistic in a polytrauma patient, and only late-stage reconstruction may be possible. In this instance, amputation with prosthesis may produce better outcomes than delayed limb reconstruction. If amputation is necessary, proximal amputation with early prosthetic fitting has demonstrated improved outcomes.[34]

SUMMARY

The mangled lower extremity is a life-changing injury for patients and a significant challenge for their surgeons. Improvements in functional outcomes of limb salvage have not grown correlatively with advancements in improvements to infection management, fracture stabilization, and soft tissue reconstruction. Contention on the subject of multidisciplinary involvement may be one cause of this stagnation in advancement. However, approaching the injury with a multidisciplinary team comprised of trauma, orthopedics, vascular, plastic reconstruction surgeons, and further supported by prosthetists, physical and occupational therapists has been shown to optimize outcomes. The algorithm presented in the figure that follows provides a detailed outline for mangled extremity treatment (Fig. 1).

Ultimately, mangled extremity treatment must be approached with 5 key concepts. First, life must always be prioritized over limb. Second, well-planned treatment must begin before the patient enters the operating room. Prompt administration of antibiotic and tetanus prophylaxis has been shown to reduce infection risk and improve outcomes. Photographs, radiographs, and vascular studies must be taken immediately after patient stabilization to detect any life-threatening injuries requiring treatment. Third, initial wound irrigation and debridement must be performed after adequate fluid resuscitation according to ATLS guidelines. Fourth, the extremity must be reconstructed or preserved whenever possible. Organized planning and a team based approach allow for early intervention, and produces more functional limbs postoperatively. If amputation is deemed necessary, amputations performed more distally produce more favorable outcomes. Disarticulations can result in poorer outcomes and more functional barriers and should be avoided. Fifth, social factors have been shown to better predict outcomes than previously established injury severity scores. The treatment team must thoroughly consider the patient's education level, age, physiologic capacity, socioeconomic status, substance use history, and availability of social support. Access to social support and psychiatric treatment following major injuries may drastically improve patient rehabilitation and recovery. Economic factors also require careful consideration, as the costs of reconstruction and amputation vary greatly and must be weighed with potential outcomes. These factors play significant roles in mangled extremity treatment and recovery and are much better predictors of outcomes than existing grading systems. Employing this evidence-based, multidisciplinary approach to mangled extremity management with consideration of individual patient characteristics may significantly improve postoperative outcomes for mangled extremity patients.

CLINICS CARE POINTS

- A multidisciplinary approach to the treatment of mangled lower extremity patients is paramount in prompt stabilization, fixation, and optimization of outcomes.
- The patient's life must be prioritized over the salvage of limbs
- Previously underemphasized factors such as mental health outcomes, socioeconomic status, and health care burden have been shown to significantly influence patient outcomes.

DISCLOSURE

The Authors have nothing to disclose.

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