Multidisciplinary Management of the Mangled Lower Extremity: Part I

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KEYWORDS

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

KEY POINTS

- Mangled extremity treatment remains controversial, despite a growing body of research and attempts to classify injuries to guide treatment.
- Existing injury severity scores inadequately predict treatment and subsequent outcomes.
- Initial stabilization of the patient must be addressed before focusing on any treatment of wounds to the extremities.

INTRODUCTION

The mangled extremity is an injury to at least 3 of the 4 types of tissue comprising an extremity: soft tissue, vasculature, nerves, and bone. Severe lower extremity injuries affected 139,405 patients in 2016 alone.[1] Furthermore, these injuries produce significant economic burden. Previous studies have demonstrated that 1759 work hours per person on average are lost following injury, producing a mean loss of $64,427 in wages.[2] Civilian mangled extremity injuries frequently result from blunt trauma in farm, industrial, and motor vehicle accidents.[3–5] These patients are commonly White males aged 20 to 45 who are less likely to have health insurance or graduated high school and are more likely impoverished.[6] A smaller portion of these injuries are caused by ballistic[7] and blast injuries, which more frequently occur within the military population.[8] Although the mechanism of injury is important and can infer the extent of injury, the wound and surrounding tissue's *zone of injury* must be defined. Although seemingly viable, microvascular insult often compromises tissue, requiring multiple debridements before definitive treatment.[9]

Mangled extremity management remains controversial. Despite advancements in trauma management, soft tissue grafting, and microvascular and nerve anastomosis, limb preservation outcomes may still be unfavorable over amputation. Morbidity, economic burden, or prolonged hospital care for reoperations must be considered. Numerous scoring systems using these considerations have been developed to guide mangled extremity management, with similarly incorporated variables between algorithms. The Mangled Extremity Syndrome Index grades damage to nerves, arteries, bones, and soft tissue to predict the necessity of amputation.[10] The Predictive Salvage Index uses the time to operation, arterial damage, and degree of bone, muscle, and skin injury.[11] The Mangled Extremity Severity Score (MESS) scores the extent of skeletal and soft tissue damage, limb ischemia, shock, and

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Abbreviations	
ABCDE	airway, breathing, circulation, disability, and exposure
ABI	Ankle-Brachial Index
ATLS	advance trauma life support
CT	computer tomography
CT-Angio	computed tomography angiography
GCS	Glasgow Coma Score
MESS	Mangled Extremity Severity Score

age.[12] The Nerve Injury, Ischemia, Soft-tissue Injury, Skeletal Injury, Shock, and Age of patient Score expands upon the MESS, incorporating nerve damage, ischemia, soft tissue damage, skeletal injury, shock, and age to predict amputation.[13] The Limb Salvage Index incorporates warm ischemia time and degree of vasculature, nerve, bone, and soft tissue damage.[14] The Lower Extremity Assessment Project evaluated previously published scoring indices, and found them to be unreliable in planning treatment or predicting outcomes.[15] These scoring systems were developed using small sample sizes and have since proven prognostically inadequate for functional recovery.[16,17]

Aspects of the multidisciplinary nature of mangled extremity care remain controversial. Each involved team (typically trauma, orthopedic, plastic, and vascular surgery) has different roles, treatment goals, and surgical algorithms. This review discusses the role of each surgical specialty, physical rehabilitation, and prosthetists to improve cooperation and optimize patient outcomes. Using an evidence-based approach, it proposes a treatment algorithm that may streamline care for mangled lower extremity injuries (Fig. 1).

INITIAL MANAGEMENT

Mangled extremity victims require rapid triage, with immediate treatment upon admission to optimize outcomes. In cases of severe trauma, life-saving measures and patient stabilization take precedence over limb preservation. Initial treatment addresses severe traumatic injuries before assessing extremity damage severity and administering secondary care. The Advance Trauma Life Support (ATLS) protocol, the most widely recognized trauma care guideline,[18] outlines a structured approach to urgent or emergent care, emphasizing primary interventions before secondary surveys and diagnostics.

The ATLS protocol's primary survey follows the mnemonic ABCDE (Table 1), standing for airway, breathing, circulation, disability, and exposure.[19] Airway assessment takes precedence, as airway obstruction is more threatening than pneumothorax-induced breathing difficulties.[19] Cervical spine immobilization via collar is crucial in preventing further vertebral injury. Airway patency can be quickly assessed by observing vocal quality. Weakness, hoarseness, gurgling, or stridor may indicate obstruction requiring further inspection.[20] Blunt or penetrating head trauma and cervical spine injury assessment is critical, as maxillofacial fractures or neck soft tissue deformities can further obstruct airways.[19] Endotracheal intubation is the most secure management of the airway, with some considerations. ATLS guidelines recommend an uncuffed endotracheal tube for a Glasgow Coma Score (GCS) ≤8 with a secure airway, while a cuffed endotracheal tube is necessary for insecure airways.[18]

Second, breathing adequacy and spontaneity must be assessed. Skin color, chest movement, and chest wall integrity following trauma can indicate breathing capacity. The patient requires thoracic and abdominal wall assessment for injury. Chest wall punctures can cause pneumothorax, hindering air exchange in the lungs. Internal thoracic bleeding can exacerbate pneumothorax and respiratory failure. Breath sounds should be auscultated bilaterally and if breathing is secure, supplemental oxygen or mechanical ventilation must be initiated. Following stabilization of breathing and ventilation, continuous monitoring can help maintain stability and prevent subsequent complications.[18,19]

Identifying and controlling hemorrhage is critical in mangled extremity management. Peripheral and central pulses must be assessed first, followed by blood pressure measurement. Hemorrhage sources should be identified and controlled to minimize fluid loss and prevent hemorrhagic shock.[19] In severe extremity injuries, external pressure and bone reduction may be required to control bleeding. Tourniquets can temporarily occlude blood flow to the zone of injury until surgical intervention is possible.[21] It is critical that the patient be closely monitored for sources of delayed bleeding even after achieving hemostasis. Abdominal and pelvic venous plexus injury present in an insidious manner, causing delayed decompensation and progression to hemorrhagic shock. Pelvic binders are effective in reducing blood transfusion volume and mortality in pelvic fracture-induced bleeds.[22] Hemorrhagic shock is categorized into

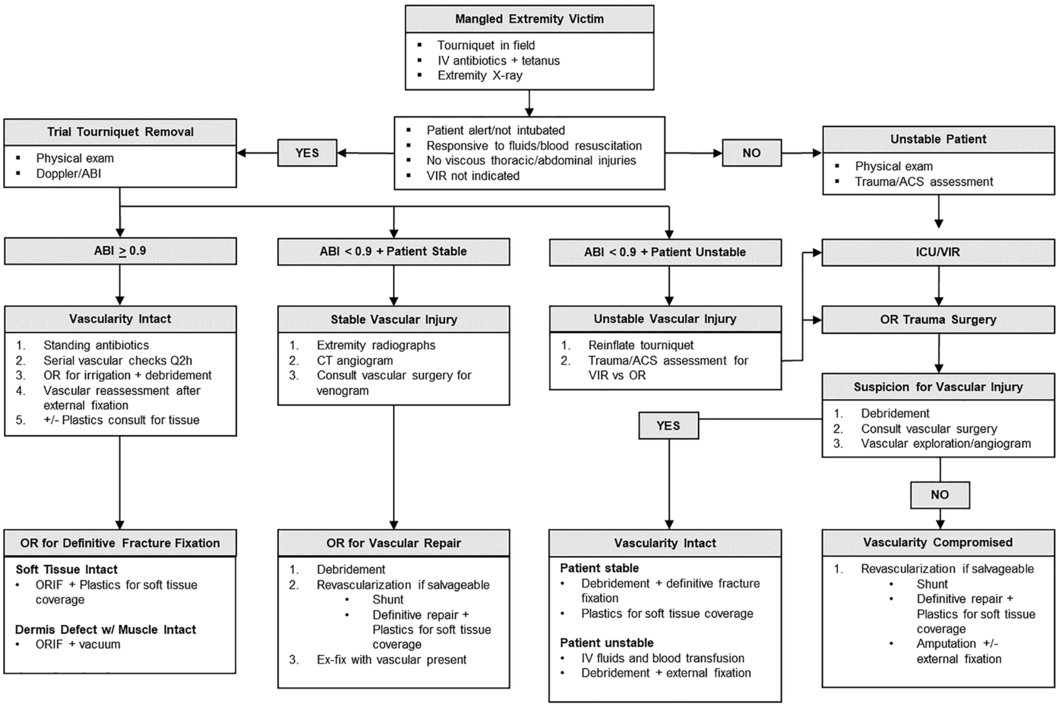

Fig. 1. A treatment algorithm to streamline care for mangled lower extremity injuries using an evidence-based approach.

4 classes by severity. These classes describe the extent of blood loss and associated examination findings, to optimize treatment and transfusion. Appropriate fluid volumes, perfusion pressures, and blood protein content are considered to maintain stability throughout treatment and determine the need for urgent surgery.[19] Additionally, intubated and sedated patients with concern for hemorrhagic or neurogenic shock should have their mean arterial pressure and neurologic examination monitored closely as decompensation can occur abruptly. Five minutes of severe hypotension can result in irreversible neurologic injury.[23] Once hemorrhaging is controlled and circulation is secured, lower priority injuries can be treated.

After securing airway, breathing, and circulation, neurologic status should be assessed and

Table 1
The advanced trauma life support airway, breathing, circulation, disability, and exposure approach basics[19]

	Assessment	Treatment
A–Airway	Observe vocal quality for weakness, hoarseness, gurgling, or stridor	Immobilize cervical spine Secure airway using cuffed endotracheal tube
B–Breathing	Observe skin color and chest movement Assess thoracic/abdominal wall injuries	Stabilize breathing using supplemental oxygen or mechanical ventilation
C–Circulation	Assess central and peripheral pulse rates and character Measure blood pressure	Determine hemorrhage sources and control bleeding Direct pressure by tourniquet or pelvic blinder may be used to temporarily occlude blood flow
D–Disability	Perform neurologic, pupil, and lateralizing signs examinations	Treat airway, breathing, and circulation issues and reassess
E–Exposure	Log-roll patient and complete full inspection for injuries	Provide warm fluids and blankets to preserve body temperature

environmental exposure effects mitigated. Neurologic, pupil, and lateralizing signs examinations and GCS calculation should be performed. Examination and GCS can indicate head trauma, hematoma, diffuse secondary brain injuries, or hypoxia resulting from airway or breathing impairment.[19] As such, airway, breathing, and circulation require reassessment before exposure assessment. After completing the ATLS protocol through the disability step, exposure must be addressed to ensure complete treatment and prevent hypothermia from blood and body heat loss. The patient must be disrobed and log-rolled for posterior injury evaluation. Normothermia may be achieved using warm fluids and blankets.[19] Special care should be taken to promptly remove the patient from the transfer board as this has demonstrated significantly increased pressure ulcer and skin necrosis incidence.[24]

NEXT STEPS

Following the initial ATLS survey, a secondary survey more thoroughly addresses nonemergent injuries. After stabilizing major fractures and emergent injuries, neurovascular status, and soft tissue integrity require assessment.[25] Without any definite indications necessitating amputation, limb salvage can be attempted.

Several lower extremity injuries, including supracondylar femur fractures, knee dislocations, tibia fractures, and penetrating thigh injuries, are significantly associated with vascular trauma.[26] Given their prevalence in mangled lower extremities, limb perfusion assessment is essential. This can be performed promptly by examining skin color, capillary refill,[27] and peripheral pulses on the injured limb. The American Association for the Surgery of Trauma grades peripheral vascular injuries from 1 to 5 by severity. Vascular injuries of concern in mangled lower extremity cases include pedis dorsalis artery, plantar artery/vein (Grade 1), saphenous vein (Grade 2), deep/superficial femoral vein, popliteal vein, anterior/posterior tibial artery, peroneal artery, tibioperoneal trunk (Grade 3), deep/superficial femoral artery, popliteal artery (Grade 4), or common femoral artery (Grade 5) injuries. Signs of injury to these vessels include pulsatile bleeding, expanding or pulsatile hematoma, lost or diminished pulse upon palpation, or bruits or thrills upon palpation.[28]

Vascular status assessment is essential. Emergently, obtaining pulse oximetry readings may be more practical. Immediately after hemodynamic stabilization, a Doppler pulse must be taken.[29] Vascular findings may be compared to the contralateral, uninjured extremity. Following doppler pulse reading, an Ankle-Brachial Index (ABI) must be obtained.[30] An ABI score below 0.9 indicates reduced lower extremity perfusion due to peripheral vascular trauma and warrants computed tomography angiography (CT-Angio) with vascular surgery consultation. Proper CT-Angio utilization can determine the extent of vascular injury and need for emergent or urgent interventions.

Peripheral neurologic assessment necessarily follows vascular examination. Nerve compression, traction, and transection injuries are common in mangled extremities due to the mechanism and energy level of sustained injuries.[31] Motor and sensory examination help identify injured structures and injury extent, as detailed in Table 2. Less prevalent injury mechanisms, such as ischemic or pressure injuries, more likely result from severe compartment syndrome.[32,33] Rapid identification and treatment of compartment syndrome is imperative, with significant risk immediately following injury.[29] Signs of compartment syndrome include disproportionately severe pain with passive muscle stretch. Visual indicators include skin-threatening hematomas or tense swelling adjacent to fractures.

Intravenous antibiotics and tetanus booster administration is crucial for open injuries. Antibiotic administration time significantly predicts subsequent infection rate. The implementation of new antibiotic protocols in 2017 has greatly decreased antibiotic administration time from more than 120 minutes to less than 60 minutes.[34] This protocol remains effective, with patients continuing to receive antibiotic treatment less than 60 minutes 2 years after implementation.[35] Surgical site infection risk has demonstrated higher correlation with time to patient presentation and antibiotic administration than with time to debridement and operative treatment.[36] A delay in administration exceeding 120 minutes for open fractures is associated with increased infection risk, emphasizing the importance of prompt antibiotic administration during triage.[37] Previous studies have also shown benefits in the utilization of intrawound antibiotic powders, significantly reducing deep infection rate in high-risk tibia fractures.[38] Antibiotic selection is also crucial, as detailed in Table 3.

After assessing the patient's vascular status bilaterally, performing motor and sensory neurovascular examinations, and initiating prophylactic antibiotic treatment, imaging must be conducted to identify fractures and guide the

Table 2
Motor/sensory examination findings and indications

Nerve Root	Motor Action	Sensation	Primary Nerves	Primary Muscles/ Tendons
L2	Hip Flexion/adduction	Anterior thigh Inner thigh	Femoral Obturator	Iliopsoas Hip adductors
L3	Knee extension	Anterior thigh Medial thigh Medial knee	Femoral	Quadriceps
L4	Ankle dorsiflexion	Lateral thigh Anterior knee Medial leg	Deep peroneal	Tibialis anterior
L5	Ankle dorsiflexion Foot inversion Hip extension Hip abduction	Lateral leg Dorsal foot	Tibial Deep peroneal Inferior gluteal Superior gluteal	Tibialis posterior Hamstrings Extensor hallicus longus Extensor digitorum Longus Gluteus maximus Gluteus medius
S1	Foot Plantarflexion Foot eversion	Posterior leg	Tibial Superficial Peroneal	Gastrocnemius Soleus Fibularis muscles
S2	Toe Plantarflexion	Plantar foot	Tibial	Flexor hallicus longus Flexor digitorum longus

operative plan. Chest and pelvis radiographs are routinely ordered for blunt trauma cases with high-energy injuries.[43] Despite their widespread utilization as screening measures, the use of these radiographs should be more carefully considered. While pelvic x-rays remain effective in screening during early planning,[44] chest X-rays have been found to be potentially unnecessary in initial evaluation. Reserving chest X-rays for those with clear clinical concerns may reduce treatment time and improve time and cost efficiency in patient care.[45] Mangled extremity radiographs should be taken using the *joint above and below* approach initially, to identify

Table 3
Fracture description and most effective antibiotic treatment[39–42]

Fracture Description and Type	Most Effective Antibiotic Treatment
Open fracture, clean wound ≤1 cm (*Gustilo-Anderson Type I fracture*)	Cefazolin or ceftriaxone
Open fracture, clean wound ≥1 cm without extensive soft tissue damage (*Gustilo-Anderson Type II fracture*)	Cefazolin or ceftriaxone
Open fracture with extensive soft tissue damage or traumatic amputation	Cefazolin or ceftriaxone with aminoglycosides
Open segmental fracture (*Gustilo-Anderson Type III fracture*)	Additional piperacillin and tazobactam reduce infection risk
Open fracture at risk of soil or fecal contamination (*Farm injury)*	Penicillin (clindamycin if allergic) in addition to antibiotics indicated based on Gustilo-Anderson classification
Open fracture at risk of freshwater contamination (*Aquatic injury*)	Fluoroquinolones (ciprofloxacin/levofloxacin) with 3rd or 4th generation cephalosporin (ceftazidime)
Open fracture at risk of saltwater contamination (*A injury*)	Doxycycline with ceftazidime or fluoroquinolones (ciprofloxacin/levofloxacin)

fractures and collateral dislocations along the injured extremity.[46] Advanced imaging, such as computer tomography (CT) scans, can provide superior detail to X-rays of fractures, particularly in pelvic, femoral, and spine injuries.[45] Consideration of the anatomy and location of each injury can also be useful in detecting damage and guiding treatment. Pelvic fractures may present with open groin injuries and visible air on imaging. High energy femoral fractures are often associated with ipsilateral femoral neck fractures, with imaging taken accordingly. Dislocations to the hip or knee can coincide with acetabulum fracture and sciatic nerve or popliteal artery injury, respectively. With CT-Angios, X-rays, and CT scans obtained, detailed operative decisions can be made.

INITIAL OPERATIVE PLAN

Operative decisions should prioritize 3 goals: life-saving, limb-saving, and limb-preserving procedures. Life-threatening complications, including shock, rhabdomyolysis, reperfusion injury, arrythmias, acute respiratory distress syndrome, or acute renal or multiorgan failure, must be prioritized. Viscous, central nervous system, or hemorrhagic injuries can be fatal and must be addressed immediately following examination of the patient. As such, gross hemorrhage and fluid resuscitation must be continuously monitored and managed. Once life-threatening injuries are managed, gross wound irrigation and debridement can begin.

Irrigation of the wound with saline should be performed upon arrival to the emergency department to remove environmental debris, release disconnected tissue, and improve injury visualization. Debridement after initial irrigation can be performed in the intensive care unit (ICU) for hemodynamically unstable patients or the operating room for stable patients. Pain during debridement must be actively managed, with preoperative pain medication administered 30 minutes before debridement and additional topical lidocaine solution administered as needed. Devascularized soft tissue, fascia, bone, and muscle, must be resected until the debrided ends bleed briskly. Lacerated large blood vessels should be shunted to preserve distal circulation. Lacerated nerves should preserved and tagged with nonabsorbable suture for later identification and repair.[47] Tissue oxygenation is an important indicator of wound healing ability and should be monitored via lactic acid levels throughout debridement and treatment. Lactic acid increases in hypoxic tissues, serving as a marker for wound infection.[48] Lactate levels over 2.5 mmol/L indicate tissue hypoxia or infection, which can worsen wound healing. Following debridement, the injuries must be copiously irrigated. High pressure irrigation should be avoided to prevent subsequent soft tissue damage and bacterial infection.[49,50] Low pressure (<15 PSI) pulsed lavage can increase irrigation efficiency. Topical lidocaine should be used as needed to manage pain during irrigation. Broad-spectrum antibiotics can be added to the irrigation solution to relieve immune system burden on purulent or infected wound surfaces.[51]

Revascularization is important in limb-saving treatment. Heparinized shunts may be used to temporarily restore blood flow if ischemia persists over 4 hours before primary revascularization.[27] Vascular repair should proceed proximally to distally, starting with suturing of compromised arteries. Following arterial repair, injured veins must be addressed. Injured veins should be trimmed to viable tissue and then sutured without tension. If no viable tissue remains, artificial, or autologous grafts may be indicated. The reversed saphenous vein graft is most commonly used, with the peroneal artery graft as an alternative for insufficient graft length.[52] Dorsal hand veins, superficial forearm veins, or excess trimmed vessels from the injured extremity may serve as smaller diameter grafts.

Following vascular repair, skeletal stabilization should be performed. Although definitive fixation should be completed in staged fashion, prompt initial fixation provides a framework for soft tissue, vascular, and nervous repair and improves outcomes in the following operative steps.[26,53] Most often, temporary external fixation is preferred. Although external fixation results in nonunion in up to 50% of cases and is inadequate for permanent fixation, it can promptly stabilize polytrauma patients. At this point, devitalized bone without soft tissue attachments should be removed. Detached fragments critical for reconstruction may be saved for future use.

Intra-articular fracture reduction and stabilization should quickly follow skeletal stabilization whenever possible to enable joint motion and provide adequate healing time for the joint capsule and ligaments. Additionally, covering the healing joints with well-vascularized soft tissue can decrease healing time and should be attempted when possible.[54] Extensive damage to large joints may necessitate arthroplasty. In ground-contacting joints such as the ankle or foot, stability is prioritized over mobility. In such fractures, primary joint arthrodesis is indicated and achieves a lower nonunion rate with comparable functional outcomes to open reduction and internal fixation.[55]

Tendon and tendomuscular junction repair should be attempted following fracture stabilization. Tendon integrity is important, as intact tendons stabilize healing bones.[56] Early tendon restoration and protection is necessary to preserve function and prevent scar formation. Direct repair should be attempted when possible, but tendon grafts may be indicated for extensive tendon defects or impaired tendon viability.[52] The most commonly used grafts include the palmaris longus, flexor hallucis longus tendons, and the gracilis or latissimus dorsi muscles for muscle transfers.[57]

Once debridement, irrigation, vascular repair, and adequate skeletal stabilization are complete, nerve and soft tissue wounds can be assessed. Successful nerve reconstruction is paramount in restoring function to mangled extremities. Generally, nerves should be repaired acutely to prevent scarring or neuropathy. Acute nerve fascicle lacerations should be aligned and directly sutured under a microscope. Tension can promote scar formation and limit nerve regeneration and must be avoided. Nerve gaps can be connected using bridging veins or synthetic nerve conduits. Large nerve gaps may require nerve transfer or grafting. Gaps over 15 cm in length may require end-to-end anastomosis with surrounding nerves, but this should be avoided unless necessary.[16] Crushed nerves with obliterated surrounding tissue may necessitate nerve transfers in a delayed fashion if the extremity is preserved. Any remaining soft tissue wounds should be dressed, taking special care to avoid exposing tendons, bone, blood vessels and nerves. Negative pressure therapy is preferred, but grossly contaminated wounds require wet-to-dry dressing and serial operating room debridements until clean granulation tissue is visualized. Following initial operative intervention, the injured limb should be splinted, brought to length, and aligned and to facilitate extremity reperfusion, relieve pain, and prevent further soft tissue injury. Externally fixated proximal extremity injuries do not require splinting. Distal injuries, however, may still require splinting after external fixation. The neurovascular examination should then be repeated to ensure nervous and vascular integrity.

In summary, successful mangled lower extremity care requires efficient triage and adherence to an evidence-based outline for emergent treatment. Prioritizing life over limb is critical, beginning with initial stabilization in the field using the ATLS protocol. First, the patient's airway and breathing must be secured. Next, circulation and hemorrhage must be assessed and controlled. Neurologic status and environmental exposure must then be addressed and managed. After primary stabilization, it is crucial to perform a secondary survey to examine nonemergent injuries and outline future care. In the absence indications necessitating amputation, limb salvage should be attempted. Initial operative treatment should entail wound irrigation and debridement, limb revascularization, initial skeletal injury stabilization, tendon, and joint repair, and lastly nerve and soft tissue repair. Antibiotics must be administered continuously as they have demonstrated significantly decreased infection risk and improved postoperative outcomes. Furthermore, adequate vascular shunting, temporization with external fixation, and wound management are paramount in optimizing postoperative outcomes.

SUMMARY

The mangled lower extremity is a severe injury that produces significant patient burden and difficulty for the surgeons treating them. Despite a growing body of literature studying the management of such injuries, streamlining multidisciplinary care for patients remains difficult. Recent literature has demonstrated success in following efficient treatment pathways for patients, including initial stabilization, treatment of life-threatening injuries, and subsequent operative management of lower extremity injuries. Previous studies show efficacy in mangled lower extremity injury treatment involving initial revascularization, skeletal stabilization, and tendon repair then followed by nerve and soft tissue injury treatment. This paper is the first part of a comprehensive narrative review on current management of the mangled lower extremity, describing current recommendations for determining patient prognosis, optimizing functional outcomes, and guiding treatment decisions based on proven prognostic factors for patients.

CLINICS CARE POINTS

- The patient's life must be prioritized over the salvage of limbs.
- The advance trauma life support protocol must be addressed first in its entirety to ensure patient stability.
- Irrigation and debridement of wounds, hemorrhage control, and initial lengthening

and stabilization of bones allows for improved operative planning and optimized outcomes.

DISCLOSURE

The Authors have nothing to disclose.

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