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Literature Review on Assessment and Decision-Making in Complex Limb Fracture Management: A Critical Evaluation of Evidence-Based Approaches

Muhammed Monjur Ahmed

Trauma & Orthopaedic Surgery, Barts NHS Health Trust, London, England
Email: ahmed0898@hotmail.co.uk

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Abstract

Aim: This review aims to provide a comprehensive and up-to-date overview of the assessment and management of complex limb trauma, focusing on factors influencing the decision between limb salvage and primary amputation. Method: A structured literature review was conducted using current guidelines and peer-reviewed evidence. Emphasis was placed on initial assessment protocols, validated scoring systems, and multidisciplinary involvement. Clinical assessment tools, imaging modalities, classification systems, and advances in orthopaedic, vascular, and plastic surgical techniques were reviewed to inform best practice. Results: Complex limb trauma, including mangled extremities, presents significant challenges requiring rapid haemorrhage control, neurovascular evaluation, and prioritisation of life-threatening injuries. Imaging with MDCT and angiography supports surgical planning. Scoring systems such as MESS, PSI, and NISSA provide objective assessment but have limitations in predicting outcomes. Successful limb salvage depends on three key tenets: revascularisation, soft tissue coverage, and bone fixation. Techniques such as the Ilizarov method, free flap reconstruction, and endovascular interventions have improved salvage rates. However, primary amputation remains optimal when salvage criteria are unmet, particularly in cases of prolonged ischaemia, severe soft tissue loss, or poor bone stock. Long-term studies show comparable functional outcomes between limb salvage and amputation, with higher psychological benefits but increased complication and rehospitalisation rates associated with salvage. Conclusion: Optimal management of complex limb trauma requires early multidisciplinary involvement and adherence to evidence-based protocols. Scoring systems offer valuable guidance but should not replace clinical judgement. With modern advances in limb reconstruction, salvage is increasingly feasible, yet timely amputation remains appropriate in select cases. Future work should focus on refining decision-making tools and promoting patient-centred care to optimise functional recovery and quality of life.

Keywords

Trauma, Complex Limb Trauma, Limb Salvage, Primary Amputation, Mangled Extremity, Orthopaedics, Trauma, Orthoplastic, Surgery, Outcomes

1. Introduction & Background

Complex limb trauma presents a significant challenge for limb salvage and for achieving outcomes that return patients to their premorbid functional status [1]. A mangled extremity refers to a limb with severe anatomical disruption to bone, nerve, muscle, vasculature and/or soft tissues [2]. The clinical team must determine whether to proceed with amputation or attempt salvage and reconstruction, a decision supported by clinical assessment, classification systems, evidence-based medicine, and collaboration with multiple allied surgical specialties.

A structured A-E approach to evaluating these injuries is critical to optimising patient outcomes, with management guided by Advanced Trauma Life Support (ATLS) principles [3], including timely transfer to hospitals capable of providing orthoplastic care and the use of validated scoring tools, such as the Injury Severity Score (ISS) [4].

Although management procedures have been well described in earlier research, incorporating predictive analytics—such as AI-powered scoring systems—may be necessary for future advancements in clinical decision-making. This could enable patient-specific outcome forecasting and real-time risk classification, creating new research and application opportunities in the treatment of complex limb injuries.

This paper provides a comprehensive, up-to-date literature review on the assessment of complex limb injuries and the factors influencing the decision between salvage and amputation.

2. Assessment

2.1. Assessment

Complex limb fractures can be distracting during the initial assessment, potentially diverting attention from life-threatening conditions that must take precedence. However, during the primary survey, it is crucial to identify and control haemorrhage from musculoskeletal injuries, as these can contribute significantly to morbidity and mortality [3]. Clinicians must maintain a high index of suspicion for vascular injury, and the measured use of Doppler ultrasonography or computed tomography (CT) with angiography can help determine the viability of the limb [5] [6].

Extremity injuries with life-threatening potential include mangled extremities, major arterial haemorrhage, and crush syndrome. Severe soft tissue lacerations and complex long bone fractures may involve major vessels, leading to exsanguinating haemorrhage. Direct pressure, timely application of a tourniquet, and splinting play a critical role in haemorrhage control by minimising movement, promoting vessel tamponade, encouraging clot formation, and reducing ongoing blood loss [3] [7]-[9].

2.2. Key Assessment Factors

A thorough clinical evaluation is essential for assessing complex limb injuries, including documentation of perfusion (distal capillary refill time and distal pulses), sensation, and motor function (neurovascular status) both pre- and post-reduction of a fracture, if required [10]. Research by Hafez *et al.* demonstrated that patients with neurovascular deficits or signs of compartment syndrome on initial assessment had an increased risk of amputation [11].

Realignment of displaced fractures using evidence-based methods, with the measured use of sedation, muscle relaxants, and analgesia, is required—particularly realignment of a deformed, pale, and pulseless limb—as this can often restore circulation [12] [13]. In scenarios where revascularisation does not occur, urgent surgical placement of a temporary intravascular shunt and skeletal stabilisation (also known as Damage Control Orthopaedics (DCO)) with an external fixation device is recommended [7] [12] [14] [15].

If the fracture is open, medical photography is vital prior to the application of temporary fixation, such as a back slab, to assist in discussions with the plastic surgery team regarding reconstruction following fracture fixation. Initial wound management involves the removal of gross contamination, followed by the application of saline-soaked gauze and an occlusive film, in accordance with British Orthopaedic Association Standards for Trauma (BOAST) guidelines. Intravenous antibiotics should be administered by the prehospital team, ideally within one hour, alongside tetanus prophylaxis where appropriate, provided there is no history of neurological complications or hypersensitivity to the vaccine [3]. These steps are crucial and have therefore been standardised in both the BOAST and National Institute for Health and Care Excellence (NICE) guidelines for the initial assessment of complex limb trauma [16] [17].

2.3. Red Flags

In patients with complex limb injuries, the trauma team should maintain a high index of suspicion for compartment syndrome [16]. Patients may present with pain out of proportion to the injury, pain on passive extension, and changes in the neurology of the extremity. Immediate removal of any circumferential dressings and elevation of the limb are key. Definitive treatment may be required with fasciotomy to relieve pressure within the muscular compartments [17].

In patients with a crush mechanism or difficult extrication involving prolonged immobilisation, rhabdomyolysis must be ruled out, indicated by the presence of "cola-coloured" urine and/or an elevated creatine kinase (CK) level. Empirical fluid resuscitation to prevent acute kidney injury (AKI) is recommended during the initial assessment [18].

In addition, assessment for associated systemic injuries is essential, including the identification of life-threatening injuries through multiple serial examinations, if required.

2.4. Primary Adjuncts & Imaging Modalities

Radiological evaluation is essential for surgical treatment planning. X-ray remains the first-line imaging modality for fracture assessment; however, it is limited to a single two-dimensional view and does not provide information on soft tissue status or viability. Therefore, multi-detector computed tomography (MDCT) is now the first-line modality for surgical planning, as it offers a detailed assessment of fracture delineation. When combined with angiography, MDCT enables comprehensive evaluation of vascular integrity, aiding in the identification of compromised blood flow and determining the need for revascularisation [16] [19].

Moreover, MDCT is readily available in all trauma centres across the United Kingdom, compared to magnetic resonance imaging (MRI), which is less frequently available and seldom used for soft tissue assessment in the acute stage of complex limb fractures. CT angiography is also utilised to assess vessel perforators and to determine the viability of potential free flap reconstruction in limb salvage cases [16].

2.5. Classification Systems

Complex limb injuries typically result from high-energy trauma, such as motor vehicle accidents, falls from height or blunt injury. These injuries often involve multiple surrounding structures, including bone, soft tissues, nerves and blood vessels. Thus, BOAST should be adhered to; these include guidelines on the management of open fractures, peripheral nerve injuries and arterial injuries associated with fractures and dislocations [12] [15] [20].

Predictive scoring systems have been developed to reduce unnecessary amputations and improve decision-making.

The Gustilo-Anderson (GA) open fracture classification categorises injury, based on soft tissue damage post-debridement, contamination and underlying vascular injury [21] [22], but has poor sensitivity and specificity in predicting outcomes [23]. The Predictive Salvage Index (PSI) assess vascular injury severity and the viability of muscle, bone and skin injury, providing additional guidance on salvageability [22]-[24]. The Mangled Extremity Severity Score (MESS), which evaluates ischemia, shock, patient characteristics, bone and soft tissue damage for complex limb fractures [6], remains widely used, with scores ≥7 strongly predicting the need for amputation [25]-[30]. Further refinements by McNamara *et al.*, such as Nerve Injury, Ischemia, Soft-tissue injury, Skeletal Injury, Shock and Age of Patient score (NISSA) incorporate neurological assessment, particularly plantar sensation [31]. However, subsequent research challenges its prognostic value [10] [32].

Factors included in the different scoring systems is shown in **Table 1** and should all be considered in decision making for limb salvage vs amputation. While scoring systems offer valuable insights, the National Institute for Health and Care Excellence (NICE) guidelines [7] emphasise they should not be the sole determinant in treatment decisions. Instead, a multidisciplinary approach ensures optimal outcomes, while minimising complications [7] [32]-[34].

Table 1. Source akgun demir and karsidag, 2020 [35].

	MESI	MESS	PSI	LSI	NISSSA	GHOISS
Age	+	+			+	+
Shock	+	+			+	+
Warm Ischaemia Time	+	+	+	+	+	+
Bone Injury	+		+	+		+
Muscle Injury			+	+		+
Skin Injury	+			+		+
Nerve Injury	+			+	+	
Deep Vein Injury				+		
Skeletal/Soft Tissue		+			+	
Contamination					+	+
Time to treatment	+			+		
Co-morbidity	+					+

In general, these systems provide broad risk stratification but fail to capture patient-specific variables (e.g., comorbidities, social circumstances) that significantly impact outcomes. Therefore, clinical judgment must always supplement scoring system guidance [32]-[34].

Classification System	Advantages	Limitations
Gustilo-Anderson Classification	• Simple to use • Widely adopted internationally • Assists in guiding antibiotic therapy and timing of surgery • Provides a framework for team communication	• High interobserver variability • Classification occurs only post-debridement • Limited prognostic accuracy for functional outcomes • Does not dynamically assess soft tissue viability
Mangled Extremity Severity Score (MESS)	• Good sensitivity for predicting the need for amputation when scores ≥7 • Rapid and simple calculation • Helpful in initial triage • Correlates with overall injury severity	• Poor specificity • May overpredict the need for amputation in younger or healthier patients • Subjective ischemia assessment • Does not incorporate advances in modern revascularisation techniques
Nerve Injury, Ischaemia, Soft-tissue injury, Skeletal Injury, Shock, Age of Patient (NISSA) Score	• Includes neurological evaluation (plantar sensation) • Offers a detailed assessment of limb viability • Highlights the multifactorial nature of complex injuries	• Subjective neurological assessments • Sensitivity to patient consciousness and swelling • Limited external validation • Early scoring may be unreliable as injuries evolve
Predictive Salvage Index (PSI)	• Provides detailed anatomical evaluation • Specifically assesses vascular, bone, muscle, and skin damage • Useful in multidisciplinary discussions and planning	• Limited validation • Primarily designed for arterial injuries • Reduced predictive value in mixed-mechanism trauma • Variable performance across injury patterns
Limb Salvage Index (LSI)	• Focuses on arterial injury severity and ischaemia time • Integrates vascular injury assessment with overall limb viability • Beneficial in military and high-energy trauma settings	• Poorly validated in civilian trauma • Underestimated revascularisation times • Less applicable to polytrauma patients with significant systemic factors
Ganga Hospital Open Injury Severity Score (GHOISS)	• Specialised for grading open lower limb fractures • Correlates well with salvage versus amputation decisions • Considers wound contamination, size, and soft tissue loss	• Complex to apply • Specific to lower limb injuries • Requires significant training for consistent use • Less familiar outside orthoplastic trauma centres.
MESS-Modified Scores (e.g., MESS-2012 updates)	• Attempts to modernise original MESS criteria • Includes advances in fasciotomy and vascular repair techniques • More nuanced evaluation of ischaemia	• Retains elements of subjectivity • Limited validation in large cohorts • May not fully overcome the original limitations of the MESS system

3. Management

3.1. Limb Salvage: Perspective from Specialties

Limb salvage is favoured when three key tenets are present: successful revascularisation, adequate soft tissue coverage, and the possibility of bone fixation [36]. Advancements and increased knowledge across all allied specialties have significantly improved the likelihood of achieving these objectives [37].

The Ilizarov method of external fixation is commonly employed to treat complex limb fractures by facilitating bone lengthening, promoting soft tissue reconstruction, and enabling osteosynthesis [38]. Ilizarov [39] outlined the basic principles of this technique: the external fixation device allows for early limb function and loading, continuous control of callus formation, gradual lengthening, correction of complex fractures, and the application of tension stress, which stimulates biosynthetic activity within tissues. Additionally, this method minimises blood loss and is less aggressive towards soft tissues [40]-[43]. Furthermore, advances in other areas of orthopaedics, such as bone transport, bone grafting, plating, intramedullary nailing, and joint replacement, have improved the ability to achieve stable fixation of complex fractures [43] [44].

The simultaneous exposure of tissue and bone presents specific management challenges. Consequently, the armamentarium of the plastic surgeon has expanded to include a wide range of techniques, from primary wound closure to free tissue transfer, guided by the principles of the reconstructive ladder [45]-[48], wound anatomy, wound physiology, prognostic biomarkers, and the phases of wound healing [49]. As the complexity of fractures targeted for salvage has increased, more sophisticated plastic surgical techniques have been developed to optimise outcomes [50]. Crucially, achieving soft tissue coverage is vital to prevent deep infection, including infection of orthopaedic implants. Even in extensive soft tissue defects, the introduction of vacuum-assisted closure (VAC) has supported wound management, prepared wounds for further reconstructive surgery, and reduced infection risk, making it a valuable tool in the treatment of Gustilo-Anderson type IIIb fractures with major soft tissue loss, thus aiding limb salvage [51]-[57].

Early primary vessel repair using microsurgical techniques, vein grafts, arteriovenous (AV) loop formations, and endovascular interventions are key to vascular salvage and to reducing ischaemia-related complications that can lead to secondary amputation [58]-[60].

Overall, the resources and skills now available to major trauma teams have greatly expanded, resulting in an increased number of successful limb salvage attempts that historically would have necessitated amputation. Furthermore, the accumulated experience of specialist clinicians in assessing complex limb fractures supports more measured and informed decision-making [6] [61] [62].

3.2. Primary Amputation

In certain cases, primary amputation is the preferred course of action if the three tenets of limb salvage are not achieved [60]-[63]. Prolonged ischaemia leads to irreversible tissue necrosis; significantly large wounds increase the risk of infection; and complex or extensive limb fractures result in poor outcomes due to the inability to achieve adequate fixation, often owing to reduced bone stock.

A retrospective study by Wenhao *et al.* involving thirty-five patients with Grade IIIc lower limb injuries found that limb salvage was initially successful in twentythree patients (66%); however, twelve patients (34%) ultimately underwent secondary amputation. Their findings indicated that a MESS of seven or greater, prolonged limb ischaemia, complex limb fractures, and the presence of compartment syndrome were associated with an increased risk of secondary amputation. Consequently, the MESS serves as a highly prognostic tool, and clinical decision-making should be carefully reconsidered in patients with a MESS of seven or above to ensure optimal management outcomes [64].

Additionally, factors associated with poor outcomes—such as non-union, wound infection, and osteomyelitis—as well as those increasing the risk of rehospitalisation, including limited patient education, low socio-economic status, inadequate social support, low self-efficacy, and smoking, should be carefully considered during the decision-making process [65].

Importantly, amputation should not be regarded as a failure of treatment, and this information must be clearly communicated to the patient, particularly when adjuncts to delay surgery are available [66] [67].

3.3. Longterm Functional Outcomes and Rehabilitation

Numerous studies [62] [63] [65] [68] [69] investigating the outcomes of reconstruction versus amputation have shown that, at two years, there is no significant difference in self-reported health status. However, patients who undergo limb salvage tend to experience better psychological outcomes [70].

A study by Michael *et al.* [66] demonstrated that, after a period of adjustment, patients who underwent amputation achieved functional outcomes comparable to those who successfully salvaged their limbs. Nonetheless, predictors of poorer outcomes included rehospitalisation for major complications, such as secondary amputation. Additionally, patients who underwent limb salvage, compared to those who had a primary amputation, were more likely to be rehospitalised (47.6% vs 33.9%, $p = 0.002$] and had a slightly greater proportion returning to work by two years (53.0% vs 49.4%).

The journey towards complete limb salvage and a return to pre-injury status can be arduous, with significant complications and increased morbidity across physical, financial, psychological, and social domains [55] [71]-[73]. Therefore, it is crucial to 'Get It Right the First Time' (GIRFT) through a thorough, multidisciplinary assessment of complex limb fractures.

4. Conclusions

The assessment and management of complex limb fractures require a multidisciplinary [74], evidence-based approach that balances the potential for limb salvage against the risks of prolonged recovery, complications, and functional impairment. Scoring systems such as MESS, PSI, and NISSA offer objective guidance but have limitations and must be complemented by experienced clinical judgement [59].

Advancements in orthopaedic fixation, vascular repair, and reconstructive surgery have improved salvage rates. However, early amputation remains appropriate when salvage attempts risk worsening morbidity or delaying rehabilitation. Long-term functional outcomes between limb salvage and primary amputation are often comparable, particularly when rehabilitation is optimised early.

Future research should prioritise:

- The creation of dynamic, real-time predictive models employing machine learning to better stratify salvage versus amputation outcomes.
- The establishment of national trauma registries to collect large datasets on limb salvage attempts and outcomes
- Investigation into patient-centred rehabilitation protocols that address both physical and psychological healing
- Enhanced collaboration between orthoplastic units to develop standardised care pathways, based on patient demographics and the severity of injuries

A patient-centred, data-driven decision-making framework could fundamentally reshape the management of complex limb injuries, ensuring individualised and equitable care.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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