DOI: http://dx.doi.org/10.1590/1413-785220192704221240

SOFT-TISSUE INJURY TO THE FOOT AND ANKLE: LITERATURE REVIEW AND STAGED MANAGEMENT PROTOCOL

LESÃO DE TECIDOS MOLES NO TRAUMA DO TORNOZELO E PÉ: REVISÃO DA LITERATURA E TRATAMENTO ESTAGIADO

*ALEXANDRE LEME GODOY-SANTOS[1], TIM SCHEPERS[2], SOFT TISSUE FOOT & ANKLE GROUP**

1. Universidade de São Paulo, Faculdade de Medicina, Hospital das Clínicas, Instituto de Ortopedia e Traumatologia (IOT/FMUSP), São Paulo, Brazil.
2. Amsterdam UMC, Amsterdam, Netherlands.

ABSTRACT

Complex trauma of the foot and ankle is characterized by fractures with severe soft tissue damage associated with neurovascular injury and joint involvement. These injuries are frequently present in the polytraumatized patient and are a predictor of unfavorable clinical outcome. In the initial approach to a patient with complex foot and ankle trauma, the decision between amputation and reconstruction is crucial. The various existing classification systems are of limited effectiveness and should serve as tools to assist and support a clinical decision rather than as determinants of conduct. In the emergency department, one of two treatment options must be adopted: early complete treatment or staged treatment. The former consists of definitive fixation and immediate skin coverage, using either primary closure (suturing) or flaps, and is usually reserved for less complex cases. Staged treatment is divided into initial and definitive. The objectives in the first phase are: prevention of the progression of ischemia, necrosis and infection. The principles of definitive treatment are: proximal-to-distal bone reconstruction, anatomic foot alignment, fusions in severe cartilage lesions or gross instabilities, stable internal fixation and adequate skin coverage. ***Level of evidence III, Systematic review of level III studies.***

Keywords: Ankle. Foot. Soft-tissue. Trauma. Fracture, Bone.

RESUMO

O trauma complexo do pé e tornozelo, caracterizado por fraturas com dano grave aos tecidos moles, associado a lesões vasculares e nervosas e com acometimento articular, está presente com frequência no paciente politraumatizado e é preditor de desfecho clínico desfavorável. Na abordagem inicial de um paciente com trauma complexo do pé e tornozelo, a decisão entre amputação ou preservação do membro é crucial. Os diversos sistemas de classificação existentes são de eficácia limitada e devem servir como ferramentas que auxiliam e fortalecem uma decisão clínica, e não como determinantes de uma conduta. No atendimento de emergência, uma das duas opções de tratamento deve ser adotada: tratamento total precoce ou tratamento estagiado. O primeiro consiste na fixação definitiva e na cobertura cutânea imediata, seja por sutura primária ou por meio de retalhos, sendo geralmente reservado a casos menos complexos. O tratamento estagiado é dividido em inicial e definitivo, e o objetivo, na primeira fase, é a prevenção da progressão da isquemia, da necrose e da infecção. Os princípios do tratamento definitivo são: reconstrução óssea de proximal para distal, alinhamento anatômico do pé, fusões nas lesões graves da cartilagem ou nas instabilidades grosseiras, fixação interna estável e cobertura cutânea adequada. ***Nível de evidência III, Revisão sistemática de estudos de nível III.***

Descritores: *Tornozelo. Pé. Trauma. Fratura Óssea.*

Citation: Godoy-Santos AL, Schepers T, Soft Tissue Foot & Ankle Group. Soft-tissue injury to the foot and ankle: literature review and staged management protocol. Acta Ortop Bras. [online]. 2019;27(4):223-9. Available from URL: http://www.scielo.br/aob.

INTRODUCTION

The term 'complex trauma of the foot and ankle' is reserved for fractures that involve severe soft tissue damage associated with neurovascular lesions and joint involvement, which entail a high risk for complications.[1] These injuries can also be called: mutilating injuries to the lower extremity, mangled extremity injuries and high-energy lower extremity trauma.[2]

Court-Brown and Caesar observed fractures involving the foot and ankle of approximately 12% of a total group of approximately 6000 patients over the period of one year, of which toe and metatarsal

All authors declare no potential conflict of interest related to this article.

Work conducted at the Universidade de São Paulo, Faculdade de Medicina, Hospital das Clínicas, Department of Orthopedics and Traumatology (DOT/FMUSP), São Paulo, Brazil, and by the Soft Tissue Foot & Ankle Group.
Correspondence: Alexandre Leme Godoy-Santos. Department of Orthopedics and Traumatology - Universidade de São Paulo. Rua Dr. Ovídio Pires de Campos, 333, Cerqueira Cesar, São Paulo, SP, Brazil. 05403-010. alexandrelemegodoy@gmail.com

* Stefan Rammelt - Universitätsklinikum Carl Gustav Carus, Germany. Marcos Hideyo Sakaki - Universidade de São Paulo, Brazil. Cristián Ortiz Mateluna - University of Desarrollo, Chile. Rafael Barban Sposeto - Universidade de São Paulo, Brazil. Panagiotis Symeonidis - St. Luke's Hospital, Greece. Rogerio Bitar - Hospital for Special Surgery, USA. Husam Darwish - King Abdulaziz University Hospital, Saudi Arabia. Hans Zwipp - Universitätsklinikum Carl Gustav Carus, Germany.

Article received in 03/14/2019, approved in 03/18/2019.

fractures represented 85%.[3] In a supplementary study, the authors noticed that foot fractures corresponded to 10.5% of all open fractures in almost 2400 open fractures over 15 years.[4]

The most common mechanism of injury involved in complex fractures of the foot and ankle is traffic accidents, which represent 49% of causes, followed by falls from heights and work-related trauma.[5]

The general distribution of foot and ankle fractures, observed by Shibuya et al., reveals 56% ankle, 17% hindfoot, 9% midfoot and 18% forefoot fractures.[6]

The World Health Organization reports that every year 1.2 million people die in traffic accidents and more than 50 million are injured.[7]

The literature shows a high rate of association between complex foot and ankle trauma and polytrauma or multiple injuries between 32% and 52% of the cases, making the treatment of these injuries an even greater challenge.[1,2,8-13] Complex trauma of the foot and ankle is a predictor of an unfavorable prognosis in polytraumatized patients and deserves attention and prioritized treatment like diaphyseal fractures of long bones.[14-23]

In traffic accidents, the upper part of the passenger's body is well protected, but the area of the distal third of the lower limb is vulnerable.[24,25]

Complex foot and ankle trauma is an event that affects the lives of patients, represents a high cost for healthcare systems, and has an impact on the productive activity of countries.[24-26] This form of trauma often results in some degree of disability, and is therefore a veritable treatment challenge. In this scenario, there is an area not yet adequately defined between injuries that cannot be reconstructed and those where the best outcome is amputation. In this article, we present a literature review and staged management protocol to help in decision making.

Classification Systems

Many classification systems have been reported in the literature and can be used in this scenario, such as the Gustilo-Anderson system for open (compound) fractures,[27] the Oestern and Tscherne classification for closed fractures,[28] the AO soft-tissue injury grading system – closed skin injuries (IC) / open skin injuries (IO).[29]

Zwipp et al.[1,13] designed a scoring system for ankle and foot injuries to define complex trauma (Figure 1). The foot and ankle are divided into 5 main areas. Each injured area is equal to 1 point, to which points are added based on the severity of the soft tissue injury according to the Oestern-Tscherne Classification, and a score of 5 points or more in the most affected area is considered complex trauma of the foot and ankle. In the hands of a team unused to this kind of trauma, it is more appropriate to regard the lesion as complex, even with a lower total score, and to consider referring the patient to a tertiary orthopedic trauma facility.

The MESS (Mangled Extremity Severity Score) system represents an option for deciding between reconstruction and amputation. It is based on four criteria (Table 1). When the score is 7 points or above, amputation should be considered.[30]

Other systems described in the literature are presented in Table 2. These limb-salvage scoring scales were designed to reduce subjectivity and provide guidance in the difficult therapeutic decision-making process in complex foot and ankle trauma cases. Ideally, a decision-making system in cases of severe lower limb trauma should be 100% specific and 100% sensitive; however, clinical practice and narrative findings regarding the different systems reveal specificity above 95%, yet sensitivity between 60% and 70%.[31-40]

These scoring systems are of limited use and should not be used as the sole criteria when deciding between amputation and reconstruction. They serve as a tool to facilitate and support a clinical decision.[41-43]

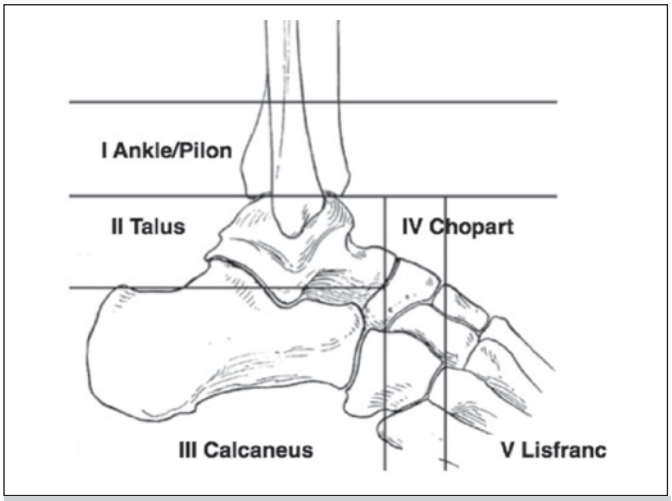

Figure 1. Scoring system for foot and ankle injuries to define complex foot and ankle trauma, according to Zwipp et al.,1,13 with division into 5 areas.

Table 1. Mangled Extremity Severity Score (MESS).

Skeletal / soft-tissue injury	score
Low energy (stab; simple fracture; pistol gunshot wound)	1
Medium energy (open or multiple fractures, dislocation)	2
High energy (high speed MVA or rifle GSW)	3
Very high energy (high speed trauma + gross contamination)	4
Limb ischemia	
Pulse reduced or absent but perfusion normal	1*
Pulseless; paresthesias, diminished capillary refill	2*
Cool, paralyzed, insensate, numb:	3*
Shock	
Systolic BP always > 90 mm Hg	0
Hypotensive transiently	1
Persistent hypotension	2
Age (years)	
< 30	0
30-50	1
> 50	2
* Double the score in cases of ischemia >6 hours	

MESS score: A score above 7 increases the chance of amputation.

Table 2. Predictive scores for limb preservation.

Score	Author and year
Abbreviated Injury Score - AIS	AAAM. 1971
Gustilo classification	Gustilo Anderson 1976; Gustilo et al 1984
Hannover Fracture Scale-97/98 - HFS-97	Tcherne. 1983
Mangled Extremity Syndrome Index - MESI	Gregory et al. 1985
Predictive Salvage Index - PSI	Howe et al. 1987
Mangled Extremity Severity Score - MESS	Johansen et al. 1990
Limb Salvage Index - LSI	Russel et al. 1991
Nerve injury, Soft-Tissue injury, Skeletal injury, Age Score - NISSSA	McNamara et al. 1994
Foot and Ankle Severity Scale - FASS	Manoli et al. 1997
The Ganga Hospital Severity Score	Rajasekaran. 2005

Treatment Principles

The objective of complex foot and ankle trauma treatment is to restore lower limb function, producing a painless, stable and functional lower limb, while avoiding infections, complications, revision surgery and hospital readmission.

First hours after trauma

In the emergency unit, a patient with a severe foot and ankle injury should be assessed for all local and systemic parameters and have the treatment algorithm defined:

1. Early total care

This type of care should be adopted in selected cases with simple fractures, clean wounds and a team trained in the definitive procedures; when both the patient's systemic condition and the local conditions are adequate to support the duration of the procedures and surgical aggression.

Soft tissue management options are:

- Primary closure
- Vacuum assisted closure device
- Fixation in combination with local or microsurgical flap
- Amputation

2. Staged treatment

- Initial treatment
- Definitive treatment

Initial Treatment

The initial approach to a complex foot and ankle injury has clear objectives and can be divided into 3 parts:

- Prevent the progression of ischemia and necrosis
- Prevent infection
- Decide between amputation and reconstruction.

Part I: Prevent the progression of ischemia and necrosis

The first step should be screening for severe trauma and when necessary resuscitation according to the principles of Advanced Trauma Life Support, both during prehospital care and afterwards during in-hospital care.[44]

In this scenario, only dislocations and fractures with major deviations that cause impairment of perfusion should be briefly treated, preferably at the site of the accident.

If there are no other life-threatening injuries that require immediate attention, or when the patient has responded adequately to systemic stabilization maneuvers, then the injury to the foot and ankle is assessed and treated.[6]

The second step is diagnosis through physical examination – the clinician should assess vascular status (palpable pulses, capillary refill, temperature, and color), neurological impairment (sensitivity, deficient), soft tissue injury (closed or open) and the conditions of bones and joints. Conventional radiographs are sufficient to determine early treatment (e.g., external fixation). Supplementary tests and computed (angio) tomography will be necessary for definitive treatment planning (span-scan-plan principle).[45]

At this stage of the treatment, compartment syndrome (CS) should be diagnosed or ruled out.

Characteristic clinical signs include:

- Tense edema – has proven the most consistent physical examination finding
- Progressive pain despite immobilization.
- Progressive increase in the need for analgesics.
- Worsening of pain with passive finger mobilization.
- Diminished discrimination of two points on the plantar aspect of the foot and toes.

The numerical diagnosis of CS occurs when muscle perfusion pressure (difference between diastolic pressure and intramuscular pressure) is less than 30 mmHg.[46]

However, if there is strong clinical suspicion and risk factors involved - hypoxia, hypovolemia, vascular injury with peripheral ischemia, high-energy trauma, severe soft tissue injury and complex fractures of the tibia –fasciotomy should be performed. Early fasciotomy is associated with lower rates of morbidity and a better outcome.[2]

A medial approach combined with two dorsal approaches over the second and fourth metatarsals is effective in releasing all 9 foot compartments.[2]

A single dorsal incision was described and termed Hannover's approach, while a single extended medial incision is known as the Henry approach.[2]

Kakadia demonstrated that the use of a vessel loop and negative pressure therapy for fasciotomy wound closure results in a higher rate of primary closure and reduces overall healing time (Figures 2A and 2B).[47]

In addition to the diagnosis and treatment of CS, this sub-phase also includes:

- Aggressive debridement using saline lavage and removal of dead tissue and loose bone fragments.
- Temporary fixation of the fracture using an external fixator or Kirschner wires to allow:

- Inspection and healing of soft tissues
- Prevention of equinus deformity
- Prevention of infection

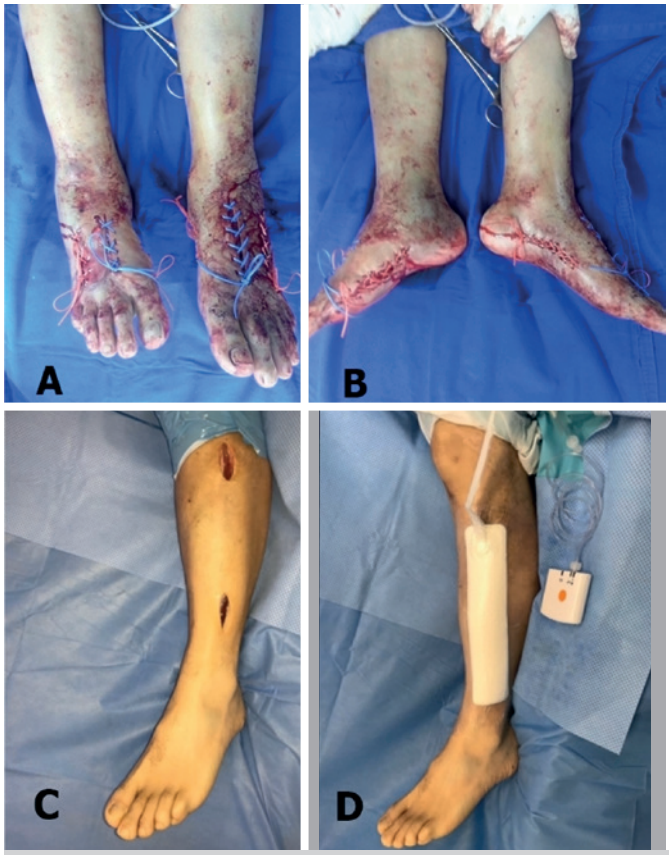

Figure 2. Adjunct soft tissue therapy in the treatment of Compartment Syndrome of the feet (A and B) and left leg (C and D). 2A. Immediate postoperative clinical presentation, dorsal view of dermofascietomies combined with the use of Vessel Loop, 2B. Immediate postoperative clinical presentation, medial view of the dermofascietomies combined with the use of the Vessel Loop. 2C. Immediate postoperative clinical presentation, lateral view of dermofascietomies, 2D. Incisional negative pressure dressing, lateral side of the dermofascietomies.

The method should permit the inspection of wounds and the application of dressings. The external fixator should be positioned on the most severely injured side in order to preserve the opposite side for the definitive surgical approach.
Indications for temporary stabilization are as follows:

- Fracture-dislocation with compromised neurovascular structures or skin at risk
- Unstable open fracture
- Fracture associated with compartment syndrome
- Gross instability of the focal point of fracture or of the joint.

Part II: Prevent infection

Open fractures should be quickly covered with sterile dressings in pre-hospital care. Less than 20% of infections in open fractures are caused by microorganisms present at the time of the trauma, and more than 90% of infections are hospital-acquired infections.[48]
Photographs must be taken to facilitate communication and patient records.
Antibiotic therapy should be initiated as soon as possible. First-generation cephalosporin is usually the first choice. Gentamicin is used in cases of gross contamination or type III open fractures. Consideration should be given to initiating tetanus prophylaxis, and definitive antibiotic therapy or a combination of antibiotics is based on the results of cultures and sensitivity tests.[10]
After debridement and initial irrigation, a new surgical approach should be adopted after 24 to 48 hours, depending on the initial contamination and the biological response of the remaining tissues.
When there are bone defects secondary to acute bone loss or removal due to infection, necrosis, or gross contamination, these may be used to fill the dead space: gentamicin-impregnated beads, antibiotic-impregnated polymethyl methacrylate or bioactive glass spacer.[49]
The use of negative pressure therapy in open fractures produces fewer infection-related complications while reducing hospital readmission and revision procedure rates.
In cases where open fracture wounds can be closed primarily following initial debridement, incisional negative pressure therapy aids the healing process (Figures 2C and 2D).
On the other hand, early soft tissue coverage has yielded lower rates of infection following complex trauma of the foot and ankle.[50]

Part III: Decide between amputation and reconstruction.

The combined rate of primary and secondary amputation is around 15% to 30%, depending on the severity of the injury. Primary amputation should be performed in extremely severe limb injuries or in life-threatening injuries, such as in multi-trauma patients with severe comorbidities[11] (Figure 3).
Whenever possible, the patient's opinion should be considered in light of the shared decision-making process. However, the final decision is based on the surgeon's experience combined with the judgment of the multidisciplinary team, who should be presenting the family and patient to sign the consent form.
The initial absence of plantar sensation is not a reliable predictor, since sensitivity returns in half of the cases. Psychological and social factors have showed themselves to be more important than scoring systems in predicting outcome. Scoring systems should not be the sole criteria on which the amputation decision is based. Everyone must keep in mind that defining reconstruction or amputation is not a prediction of outcome or of function.[43]

Amputation

The type of lower limb amputation is widely affected by the level of arterial damage, the level of viable soft tissues, and the quality and contamination of the remaining bone; amputations can be performed at different levels:

Figure 3. Decision making in amputation. 3A. Dorsal view of the soft tissue and bone injury to the left foot. 3B. Lateral view of the soft tissue injury and bone involvement of the left foot. 3C. Radiograph showing severity of the bone tissue injury. 3D. Anteroposterior radiograph of Chopart amputation, combined with primary arthrodesis. 3E. Lateral radiograph of Chopart amputation, combined with primary arthrodesis. 3F. Clinical presentation of the patient in upright position, with Chopart's disarticulation, combined with tibiotalocalcaneal arthrodesis.

Transtibial (below-knee), Syme, Pirogoff, Chopart with tibiotalocalcaneal fusion (Figures 3D, 3E and 3F), Chopart combined with transfer of the tibialis anterior tendon to the neck of the talus neck and with percutaneous calcaneus tendon lengthening, and finally, transmetatarsal amputation preserving all the principal tendon insertions around the foot and ankle.
The main objective is survival while the secondary objective is to provide the best quality of life possible.
The principles of an amputation are:

- Identification and adequate treatment of nerves and vessels.
- Stable myodesis, guaranteeing robust soft tissue coverage.
- Preserve the balance of muscles and tendons.
- Preserve the length of the limb when feasible
- Multidisciplinary team approach throughout the treatment period

Reconstruction

The timing of definitive treatment with reconstruction depends on the systemic state of the patient and the soft tissues.

The principles of the reconstruction procedure are:
- First bone tissue

- From proximal to distal
- When the patient has a fracture of the talus and distal tibia – first talus before the tibial pilon or ankle.

- Anatomical reconstruction of axial alignment and functional columns of the foot.
- Primary fusions for severe cartilage injury or gross instability
- Stable internal fixation
- Early and stable soft tissue coverage

Early flaps for soft tissue reconstruction allow lower rates of infection following open fractures and functional rehabilitation.

The selection of the flap should take into account: minimal morbidity in the donor area, needs of the recipient area and familiarity of the surgeon (Figure 4).

The most commonly used flaps for the treatment of complex foot and ankle are:

1. anterolateral thigh flap
2. dorsalis major
3. rectus abdominus
4. gracilis

The outcome expectation consists of 6 aspects:

- final function of the locomotor system
- local aesthetics and remaining volume
- pain and loss of sensitivity
- total treatment time
- costs of hospitalization
- emotional factors

Functional results - locomotor system

A prospective multicenter study investigated the functional outcomes of 569 patients with severe lower limb injuries, resulting in reconstruction or amputation. In two years of follow-up, there was no significant difference between the amputation and reconstruction groups for the scores and time to return to work. The patients who underwent reconstruction had a higher rate of hospital readmission.[34]

Quality of life in post-traumatic amputees in comparison to limb reconstruction was evaluated in a meta-analysis. The authors demonstrated that lower limb reconstruction is more psychologically acceptable for patients with severe trauma as compared to amputation, although the physical outcome for both treatment options is the same.[51]

A prospective longitudinal study determined the outcome of complex foot and ankle injuries undergoing limb reconstruction surgery requiring free flaps compared to a similar group of patients who underwent early amputation at the level of the proximal tibia. The authors concluded that the patients requiring free flap transfer had significantly worse scores than the amputees.[52]

An amputation usually involves a shorter hospital stay, fewer surgical procedures, and faster total rehabilitation. The costs of the prosthesis are higher and the rehabilitation process more lengthy, depending on the patient's age at the time of the injury.[53]

In the US, the prevalence is 80,000 new amputees/year, with a treatment cost per amputee in the first two years of US$ 91,106, vs US$ 81,316 per patient treated with reconstruction. The cost of lifetime medical care per amputee is US$ 509,275 vs US$ 163,282 per patient treated with reconstruction.[53]

Two comparative cohort studies, one made up of civilian patients and the other of military patients, evaluated severe isolated injuries of the foot and showed inferior functional results in the groups undergoing reconstruction in both studies. The groups of authors observed higher rates of complications and need for revision surgery, as well as longer hospitalization and rehabilitation times in the groups undergoing reconstruction.[54,55]

Consideration must be given to an important bias in this area of knowledge. While the amputation technique has been performed and improved over the last 300 years, reconstructive surgery for complex foot and ankle injuries has been under development for the past 3 decades.

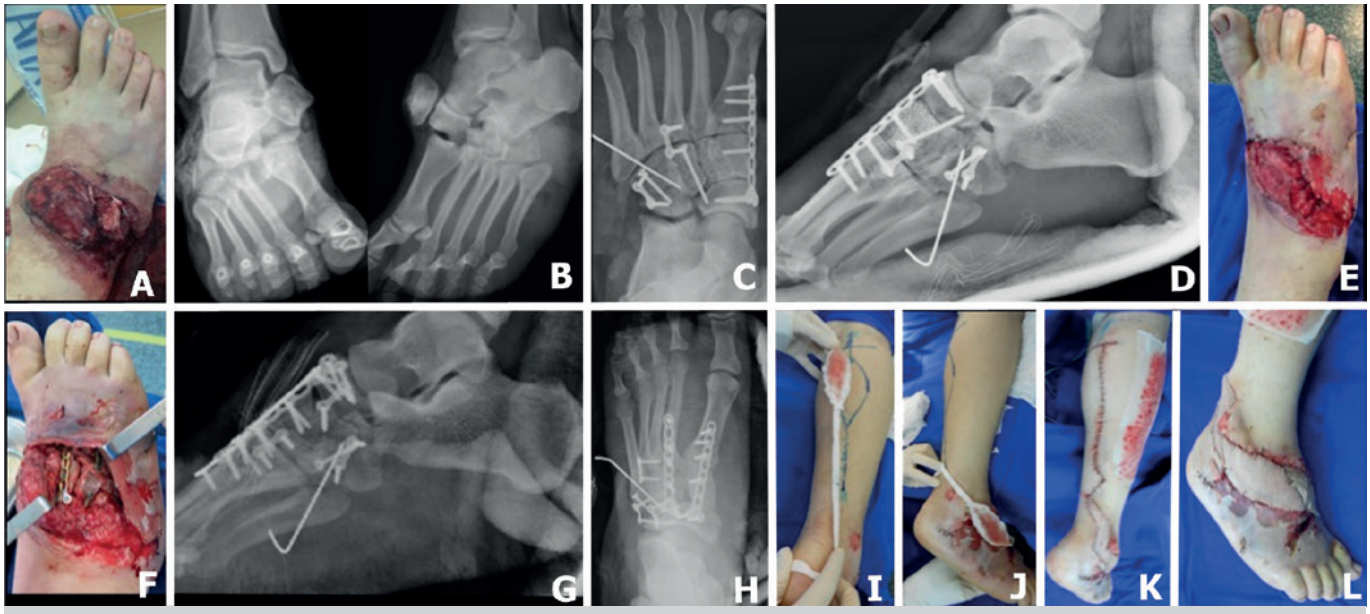

Figure 4. Example of foot reconstruction in complex injuries. 4A. Initial clinical image of the soft tissue injury, 4B. Initial AP radiograph of the ankle and oblique x-ray of the foot, showing tarsometatarsal dislocation-fracture with extrusion of the intermediate cuneiform, 4C. Anteroposterior radiograph after debridement, stabilization of the first, third and fifth radial bones, disimpactation of the cuboid and bone fragment interposition using an antibiotic-impregnated cement spacer in the intermediate cuneiform topography, 4D. Lateral radiograph after debridement, stabilization and bone fragment interposition using an antibiotic-impregnated cement spacer in the intermediate cuneiform topography, 4E. Immediate postoperative clinical presentation following debridement, stabilization and approximation of soft tissues for application of negative pressure dressing, 4F. Intraoperative clinical presentation - 72 hours after the first procedure – filling of bone fragment with autologous bone graft (iliac crest) and definitive fixation of the second radial bone, 4G. Lateral radiograph after definitive treatment 4H. Anteroposterior radiograph after definitive treatment, 4I. Planning of sural rotation flap posterior view, 4J. Planning of rotation flap lateral view, 4K. Final clinical presentation of skin coverage with rotation flap posterior view, 4L. Final clinical presentation of skin coverage with rotation flap lateral view.

FINAL CONSIDERATIONS

There have been considerable developments in the treatment of complex foot and ankle injuries over the last three decades. The final functional outcome needs to be projected right from the start of the treatment. Although saving the limb may be psychologically better in principle, a stiff, painful and/or insensitive, nonfunctional foot may represent a much worse outcome with the need for secondary interventions and prolonged hospitalization and rehabilitation.

Treatment should be individualized based on patient characteristics and local conditions. If the necessary tools are not available, referral to a specialized service should be considered. If the surgeon opts for ankle and foot reconstruction, stable internal fixation and early soft tissue coverage followed by an aggressive rehabilitation protocol and appropriate footwear modifications should be implemented to achieve maximum functional recovery. Complex foot injuries are hard to treat and may require an extended follow-up period with specialist care.

AUTHORS' CONTRIBUTIONS: Each author contributed individually and significantly to this paper. RBI (0000-0002-8965-5147)*: redação do artigo, estatística,revisão,conceito intelectual do artigo, realização das cirurgias e confecção de todo projeto de pesquisa; MAM (0000-0002-8165-115X)*: Captação de dados e revisão; GBS (0000-0002-8684-4479)*: realização da cirurgias e revisão; ABC (0000-0002-3099-4750)*: realização da cirurgias e revisão FCI (0000-0001-9616-4381)*: realização das cirurgias e revisão; THW (0000-0001-6219-0047)*: revisão e conceito intelectual do artigo; MRR (0000-0003-3441-8117)*: revisão e conceito intelectual do artigo; RMJ (0000-0003-4202-4652)*: revisão e conceito intelectual do artigo. *ORCID (Open Researcher and Contributor ID).

REFERENCES

1. Zwipp H, Dahlen C, Randt T, Gavlik JM. Complex trauma of the foot. Orthopade [in German]. 1997;26(12):1046–56.
2. Schepers T, Rammelt S. Complex Foot Injury: Early and Definite Management. Foot Ankle Clin. 2017;22(1):193-213.
3. Court-Brown CM, Caesar B. Epidemiology of adult fractures: a review. Injury. 2006;37(8):691–7.
4. Court-Brown CM, Bugler KE, Clement ND, Duckworth AD, McQueen MM. The epidemiology of open fractures in adults. A 15-year review. Injury. 2012;43(6):891–7.
5. Eberl R, Ruttenstock EM, Singer G, Brader P, Hoellwarth ME. Treatment algorithm for complex injuries of the foot in paediatric patients. Injury. 2011;42(10):1171-8.
6. Shibuya N, Davis ML, Jupiter DC. Epidemiology of foot and ankle fractures in the United States: an analysis of the National Trauma Data Bank (2007 to 2011). J Foot Ankle Surg. 2014;53(5):606-8.
7. World Health Organization. Public health round-up. Bull World Health Organ. 2013;97(3):240–1.
8. Ahrberg AB, Leimcke B, Tiemann AH, Josten C, Fakler JK. Missed foot fractures in polytrauma patients: a retrospective cohort study. Patient Saf Surg. 2014;8:10.
9. Tadros AM, Eid HO, Abu-Zidan FM. Epidemiology of foot injury in a high--income developing country. Injury. 2010;41(2):137-40.
10. Kinner B, Tietz S, Muller F, Prantl L, Nerlich M, Roll C. Outcome after complex trauma of the foot. J Trauma. 2011;70(1):159–68.
11. Rammelt S, Biewener A, Grass R, et al. Foot injuries in the polytraumatized patient [in German]. Unfallchirurg. 2005;108(10):858–65.
12. Ferreira RC, Sakata MA, Costa MT, Frizzo GG, Santin RA. Long-term results of salvage surgery in severely injured feet. Foot Ankle Int. 2010;31(2):113–23.
13. Zwipp H. Severe foot trauma in combination with talar injuries. In: Tscherne H, Schatzker J, editors. Major fractures of the pilon, the talus and the calcaneus. Berlin: Springer Verlag; 1993. p.123–35.
14. Holbrook TL, Anderson JP, Sieber WJ, Browner D, Hoyt DB. Outcome after major trauma: discharge and 6-month follow-up results from the Trauma Recovery Project. J Trauma. 1998;45(2):315–23.
15. Holbrook TL, Anderson JP, Sieber WJ, Browner D, Hoyt DB. Outcome after major trauma: 12- month and 18-month follow-up results from the Trauma Recovery Project. J Trauma. 1999;46(5):765–71.
16. Probst C, Richter M, Lefering R, Frink M, Gaulke R, Krettek C, Hildebrand F. Incidence and significance of injuries to the foot and ankle in polytrauma patients–an analysis of the Trauma Registry of DGU. Injury. 2010;41(2):210–5.
17. Stalp M, Koch C, Ruchholtz S, et al. Standardized outcome evaluation after blunt multiple injuries by scoring systems: a clinical follow-up investigation 2 years after injury. J Trauma. 2002;52(6):1160–8.
18. Tran T, Thordarson D. Functional outcome of multiply injured patients with associated foot injury. Foot Ankle Int. 2002;23(4):340–3.
19. Turchin DC, Schemitsch EH, McKee MD, Waddell JP. Do foot injuries significantly affect the functional outcome of multiply injured patients? J Orthop Trauma. 1999;13(1):1-4.
20. von Ruden C, Woltmann A, Rose M, Wurm S, Ruger M, Hierholzer C, et al. Outcome after severe multiple trauma: a retrospective analysis. J Trauma Manag Outcomes. 2013;7:4.
21. Weninger P, Aldrian S, Koenig F, Vécsei V, Nau T. Functional recovery at a minimum of 2 years after multiple injury-development of an outcome score. J Trauma. 2008;65(4):799-808.
22. Zelle BA, Brown SR, Panzica M, Lohse R, Sittaro NA, Krettek C, et al. The impact of injuries below the knee joint on the long-term functional outcome following polytrauma. Injury. 2005;36(1):169-77.
23. Heckman JD, Champine MJ. New techniques in the management of foot trauma. Clin Orthop Relat Res. 1989;(240):105-14.
24. Weninger P, Nau T, Aldrian S, Vései V. Long-term results in the treatment of foot injuries in polytraumatized patients [in German]. Zentralbl Chir. 2005;130(5):485–91.
25. Myerson MS, McGarvey WC, Henderson MR, Hakim J. Morbidity after crush injuries to the foot. J Orthop Trauma. 1994;8(4):343–9.
26. Westphal T, Piatek S, Schubert S, Schuschke T, Wincker S. Quality of life after foot injuries [in German]. Zentralbl Chir. 2002;127(3):238–42.
27. Gustilo RB, Anderson JT. Prevention of infection in the treatment of one thousand and twenty-five open fractures of longbones: retrospective and prospective analyses. J Bone Joint Surg Am. 1976;58(4):453-8.
28. Tscherne H, Oestern HJ. A new classification of soft-tissue damage in open and closed fractures (author's transl) [in German]. Unfallheilkunde. 1982;85(3):111-5.
29. Ruedi TP, Buckley R, Moran CG. AO Principles of Fracture Management. New York, NY, USA: Thieme Medical Publishers; 2007.
30. Johansen K, Daines M, Howey T, Helfet D, Hansen ST Jr. Objective criteria accurately predict amputation following lower extremity trauma. J Trauma. 1990;30(5):568-72.
31. Ahmed N, Sahito B, Baig N. Evaluation and reliability of Mangled Extremity Severity Scoring in traumatic amputation versus limb salvage. J Pakistan Orthop Assoc. 2013;25(2):35–40.
32. Bonanni F, Rhodes M, Lucke JF. The futility of predictive scoring of mangled lower extremities. J Trauma. 1993;34(1):99–104.
33. Bosse MJ, MacKenzie EJ, Kellam JF, Burgess AR, Webb LX, Swiontkowski MF, et al. A prospective evaluation of the clinical utility of the lower-extremity injury-severity scores. J Bone Joint Surg Am. 2001;83-A(1):3–14.
34. Bosse MJ, MacKenzie EJ, Kellam JF, Burgess AR, Webb LX, Swiontkowski MF, et al. An analysis of outcomes of reconstruction or amputation after leg-threatening injuries. N Engl J Med. 2002;347(24):1924-31.
35. Bosse MJ, McCarthy ML, Jones AL, Webb LX, Sims SH, Sanders RW, et al. The insensate foot following severe lower extremity trauma: an indication for amputation? J Bone Joint Surg Am. 2005;87(12):2601–8.
36. Durham RM, Mistry BM, Mazuski JE, Shapiro M, Jacobs D. Outcome and utility of scoring sys- tems in the management of the mangled extremity. Am J Surg. 1996;172(5):569-73.
37. Fodor L, Sobec R, Sita-Alb L, Fodor M, Ciuce C. Mangled lower extremity: can we trust the amputation scores? Int J Burns Trauma. 2012;2(1):51-8.
38. Helfet DL, Howey T, Sanders R, Johansen K. Limb salvage versus amputation. Prelim- inary results of the Mangled Extremity Severity Score. Clin Orthop Relat Res. 1990;(256):80-6.
39. Hoogendoorn JM, Van der Werken C. The mangled leg, decision-making based on scoring systems and outcome. Eur J Trauma. 2002;1(1):1-10.
40. Johansen K, Daines M, Howey T, Helfet D, Hansen ST Jr. Objective criteria accurately predict amputation following lower extremity trauma. J Trauma. 1990;30(5):568-72.

41. Robertson PA. Prediction of amputation after severe lower limb trauma. J Bone Joint Surg Br. 1991;73(5):816-8.
42. Busse JW, Jacobs CL, Swiontkowski MF, Bosse MJ, Bhandari M, Evidence-Based Orthopaedic Trauma Working Group. Complex limb salvage or early amputation for severe lower-limb injury: a meta-analysis of observational studies. J Orthop Trauma. 2007;21(1):70-6.
43. Brown KV, Ramasamy A, McLeod J, Stapley S, Clasper JC. Predicting the need for early amputation in ballistic mangled extremity injuries. J Trauma. 2009;66(4 Suppl):S93–7.
44. Hammerberg EM, Whitesides TE Jr, Seiler JG 3rd. The reliability of measurement of tissue pressure in compartment syndrome. J Orthop Trauma. 2012;26(1):24-31.
45. Roberts CS, Pape HC, Jones AL, Malkani AL, Rodriguez JL, Giannoudis PV. Damage control orthopaedics: evolving concepts in the treatment of patients who have sustained orthopaedic trauma. Instr Course Lect. 2005;54:447–62.
46. Dodd A, Le I. Foot compartment syndrome: diagnosis and management. J Am Acad Orthop Surg. 2013;21(11):657-64.
47. Kakagia D. How to Close a Limb Fasciotomy Wound: An Overview of Current Techniques. Int J Low Extrem Wounds. 2015;14(3):268-76.
48. Patzakis MJ, Bains RS, Lee J, Shepherd L, Singer G, Ressler R, et al. Prospective, randomized, double-blind study comparing single-agent antibiotic therapy, ciprofloxacin, to combination antibiotic therapy in open fracture wound. J Orthop Trauma. 2000;14(8):529-33.
49. Gergely I, Zazgyva A, Man A, Zuh SG, Pop TS. The in vitro antibacterial effect of S53P4 bioactive glass and gentamicin impregnated polymethylmethacrylate beads. Acta Microbiol Immunol Hung. 2014;61(2):145-60.
50. Brenner P, Rammelt S, Gavlik JM, Zwipp H. Early soft tissue coverage after complex foot trauma. World J Surg. 2001;25(5):603-9.
51. Ellington JK, Bosse MJ, Castillo RC, MacKenzie EJ; LEAP Study Group. The mangled foot and ankle: results from a 2-year prospective study. J Orthop Trauma. 2013;27(1):43-8.
52. Akula M, Gella S, Shaw CJ, McShane P, Mohsen AM. A meta-analysis of amputation versus limb salvage in mangled lower limb injuries--the patient perspective. Injury. 2011;42(11):1194-7.
53. MacKenzie EJ, Jones AS, Bosse MJ, Castillo RC, Pollak AN, Webb LX, et al. Health-care costs associated with amputation or reconstruction of a limb--threatening injury. J Bone Joint Surg Am. 2007;89(8):1685-92.
54. Demiralp B, Ege T, Kose O, Yurttas Y, Basbozkurt M. Amputation versus functional reconstruction in the management of complex hind foot injuries caused by land-mine explosions: a long-term retrospective comparison. Eur J Orthop Surg Traumatol. 2014;24(4):621-6.
55. Shawen SB, Keeling JJ, Branstetter J, Kirk KL, Ficke JR. The mangled foot and leg: salvage versus amputation. Foot Ankle Clin. 2010;15(1):63-75.