Open Lower Limb Fractures-Management and Treatment Algorithm

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Abstract

An open fracture is defined as a fracture which associates a continuity solution that communicates with the fracture site or its hematoma. They are associated with great morbidity and motor dysfunction. Lower limb open leg fractures are more severe than upper limb fractures due to tissue damage and increased frequency of associated brain lesion. The femur is usually affected in the context of high energy trauma and hence it tends to occur in polytraumatized patients.

As these fractures present high severity, the treatment must be multidisciplinary with plastic surgery, orthopedics and vascular surgery since different tissues are involved in the trauma. The orientation of the patient and the different priorities to take non-therapeutic treatment over the last few years has developed. The transaction should be done in the centers of the diagnosis of vascular reconstruction, schematic stabilization, debridement and reconstruction of the soft tissue and bone.

The aim of this article is to review the criticism regarding the treatment of open fractures of the lower limb with respect to global assessment, vascular evaluation, debridement, antibiotic therapy, compartment syndrome, skeletal stabilization and reconstruction of soft tissues and bone.

Keywords: Open fractures; Lower limb; Femur; Tibia; Algorithm; Trauma

History

After centuries of stagnation, the treatment of open fractures has evolved rapidly in the last two hundred years, and developments in military trauma and musculoskeletal injuries have greatly influenced emergency medicine [1]. The use of amputation for medical purposes, still considered today as a way to approach an already unsalvageable limb, saving the patient's life, dates back to the time of Hippocrates (460-370 BCE) [2]. Only later, between the 16th and 18th centuries, the basic rules of amputation and the true concept of debridement were defined with Ambroise Paré (1509-1590) and Pierre-Joseph Desault (1744-1795) respectively [3,4]. Already in the 19th century, Ollier (1825-1900) presents the advantages of using plaster immobilization and the advent of the World Wars and Korea began to consider repairing bone and soft tissue injuries and keeping the limb at the expense of amputation [5].

Epidemiology and Etiology

In both civil and military contexts, and regardless of mechanism, extremities undertake most trauma blows. The lower limbs are much more injured than the upper limbs (75% vs. 25%) [6]. According to more current statistics, it is known that approximately 3% of all fractures are open and that the tibia is by far the most affected bone (48-50%), especially in high energy situations such as road accidents (58%) or after running over or falling from the height (22%) [7]. The fractures of the forearm (12.6%) and the ankle (9.7%) are followed with a lower incidence.

Algorithm and Initial Evaluation

The arrival of a patient with limb trauma and an open fracture imposes extensive evaluation based on criteria defined by ATLS® (ABCDE). After the evaluation of the airway's permeability (A) and respiratory function (B), the considerable blood loss and the existence of hemodynamic instability or large hemorrhages should be controlled (C), starting from a set of decisions that allow choosing between amputation or maintenance of the limb. In general, it may be said that if there is an extensive arterial defect the orientation will depend on the limb ischemia time [8,9]. If the ischemic time (IT) is

- 4 hours-there is some useful time to perform angiography to characterize the vascular defect
- 4-6 hours-IT still acceptable but no maneuver to perform invasive complementary exams. Patient must be referred to the operation room for vascular surgery
- 6 hours-long IT with a high probability of amputation (Figure 1)

Figure 1: Algorithm and initial evaluation.

As an aid in choosing to amputate or maintain the limb, there are still clinical signs (see "Vascular lesion evaluation" section) and Scores that together (and never in isolation) help the physician make a more justified and consensual decision.

- The initial evaluation of the patient is followed ideally following this order:
- Summary Neurological Examination (SNE)
- Painkillers
- Manual fracture alignment (repeating SNE)
- Removal of contamination, only if gross
- Photographic documentation of the wound/classification of the type of fracture/application of Scores
- Wound cover with wet and clean bandages
- Temporary fracture stabilization with splints (repeating the SNE again)
- Initiate antibiotic therapy (and do tetanus reinforcement if warranted)

Open Fracture Classification

The most known gradation systems include the Gustillo-Anderson system and the AO/OTA system. The first one becomes more practical in assessing fracture severity and the probability of infection [10-12], but the second one, due to its greater reproducibility and lower inter- and intraobserver variability, is more used in the academic context and in the publication of scientific work [13,14] (Figure 2).

Feature	Fracture Type				
	I	II	IIIA	IIIB	IIIC
Wound size, cm	<1	>1	>1	>1	>1
Energy	Low	Moderate	High	High	High
Contamination	Minimal	Moderate	Severe	Severe	Severe
Deep soft tissue damage	Minimal	Moderate	Severe	Severe	Severe
Fracture comminution	Minimal	Moderate	Severe/ segmental fractures	Severe/ segmental fractures	Severe/ segmental fractures
Periosteal stripping	No	No	Yes	Yes	Yes
Local coverage	Adequate	Adequate	Adequate	Inadequate	Adequate
Neurovascular injury	No	No	No	No	Yes
Infection rate	0%-2%	2%-7%	7%	10%-50%	25%-50%

Data from Gustilo et al,[3] Gustilo and Anderson,[10] and Gustilo et al.[11]

Figure 2: Expanded version of open fractures classification.

Scores

Intended to quantify energy transfer to limb, limb response to deforming forces (type and fracture pattern, the existence of neurovascular injury), and systemic response to trauma including, in some cases, the age of the patient [9,15].

The most commonly used Scores include the Mangled Extremity Severity Score (MESS), the Predictive Salvage Index (PSI), the LSI (Limb Salvage Index), NISSA (Nerve Injury, Ischemia, Soft Tissue Injury, Skeletal Injury, Shock, and Age of the Patient), HFS-97 (Hannover Fracture Scale-97) and GHOISS (Ganga Hospital Open Injury Severity Score) (Figure 3).

The MESS Score being simpler and the only one that derives from a study with a prospective validation trial is the most used for this purpose. It has been shown in some situations to have high specificity and a positive predictive value [16,17]. It should be noted that all these Scores have relatively low sensitivity and that although useful in limb salvage prediction, to the opposite (that is, in the decision to amputate) their utility becomes more limited. There are also studies that advise against using any of the Scores as decisive for amputating or saving the limb or to use them with extreme caution [10,18].
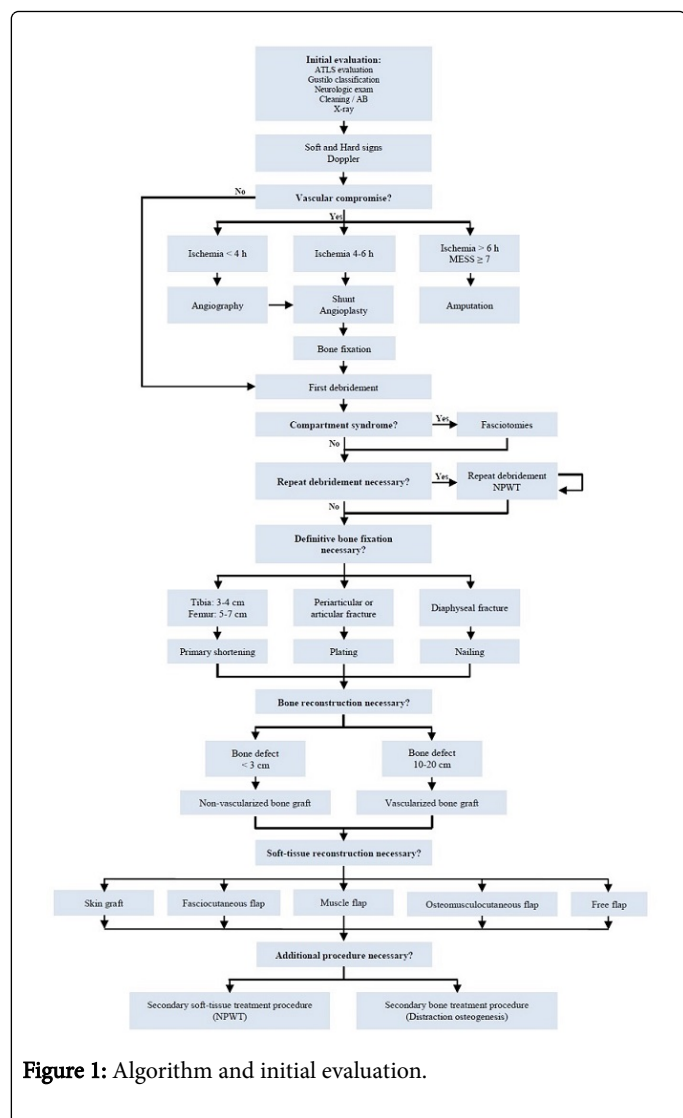
Figure 3: Mangled extremity severity score.

It may be generally stated that there are certain indications for limb amputation from the beginning [19-21]. These are subdivided into:

Absolute indications

- Incomplete amputations
- Extensive crushing injuries
- Time of "hot ischemia" exceeding 6 hours

Relative indications

- Ischemic limb with evident neurological dysfunction
- Segmental muscle loss in >2 compartments
- Bone loss >1/3 of the entire length of the bone
- Severe open foot injuries associated with tibial fractures

Antibiotherapy

The consensus on the choice of the best antibiotic to do and its timing depends on many of the authors and the country or even the institution where it is performed. The vast majority accept that the best option for antibiotic therapy upon arrival of the patient relies on the use of Amoxicillin/Clavulanic Acid or Cephalosporins of 1st Generation, administered in a maximum time limit of 3 hours. The need to add Gentamicin to Gustillo-Andersen type III fractures and a Penicillin or Metronidazole is discussed if there is "rural" or "standing water" contamination. The patient should maintain these associations until definitive closure of the wound and at each debridement should be added to Gentamicin (1.5 mg/kg) and at the time of skeletal stabilization and definitive closure of soft tissues, Gentamicin should be associated with Vancomycin or Teicoplanin [9,10,22,23].

Evaluation of Vascular Injury

The clinic is of extreme importance in assessing a limb's vascular compromise. The relevance of a vascular lesion and the need for complementary examinations such as EcoDoppler or Angiography are based on clinical signs that translate into a lower or greater severity of the vascular defect [9,10,24,25].

Soft signs

- History of bleeding on site or during transport
- The proximity of a penetrating lesion of an artery
- Small non-pulsatile hematoma on an artery
- The distal pulse decreased in relation to the contralateral
- The neurological deficit with origin near an identified artery
- The proximity of the artery to an open wound or fragmented exposed bone

Hard signs

- Classic signs of arterial occlusion (6P's)
- Massive/throbbing bleeding
- Rapidly expanding hematoma
- The palpable or audible murmur on a hematoma

It is believed that there is a need to perform the mentioned complementary exams (Doppler or Angiography) if:

- There are doubts about lack of pulse
- There is the inability to evaluate pulses
- There is a combination of several soft signs
- The Arm-Ankle Index <0.9

And still if:

- there is at least one hard sign
- it is necessary to know the location of the defect
- there are multiple defects obvious to the objective examination
- there is a posterior dislocation of the knee

In situations where major vascular defects can be repaired, the priority is to return irrigation to the limb. One hypothesis for temporary treatment is the use of arterial shunts [25,26]. Its indications, therefore, include Gustilo type IIIC exposed fractures, complex revascularization procedures and application of the Damage Control concept in patients with excessive blood loss [25,27,28].

These shunts allow re-establishing circulation in the limb, reduce morbidity and apply a skeletal stabilization (temporary or definitive) without additional vascular damage [25,29]. The viability of the limb should always be re-evaluated after any manipulation and surgical approaches should be planned to take into account the need for posterior "plastics".

The definitive arterial repair can then be carried out. It should be noted that the presence of a single intact artery is not a contraindication for the use of free vascularized flaps [29,30]. The definitive arterial reconstruction should be performed only 2 hours after limb revascularization, and the anesthesia team should be advised of possible hemodynamic instabilities during this period. The most commonly used method is autologous vein grafting, inverted (mainly cephalic vein), and whenever performed, local coverage of the repaired vessel with soft tissues should be attempted [25,31].

Bone and Soft Tissue Debridement

This procedure will probably be the most important for the reduction of infection and maintenance of tissue viability [9,10,23].

The first debridement is the most relevant of all. It should be noted that the immediate operation of the wound should only be performed in the ER room in very specific circumstances: 1) there is a very gross contamination of the wound, 2) there is a great suspicion of compartment syndrome, 3) the limb is severely devascularized 4) there are other lesions that justify/multiple lesions.

Soft tissue debridement

Contrary to what has been reported, recent studies have shown that a debridement performed after 6 hours does not contribute to a greater probability of wound infection unless it is done in the first 24 hours [8,32-35].

This procedure includes a set of steps that must be chronologically respected:

- Wash with soap solution/H_2O_2
- Placing a club
- Application of chlorhexidine (avoid open wound region)
- Fabrics should be approached from the shallower to the deeper and from the periphery to the center (definition of non-viable muscle tissue -4C's)
- Definitive classification of the lesion
- Washing of the wound (only after debriding)-High-pressure serum damages tissues and disseminates bacteriological material
- If there is no definitive reconstruction of soft or skeletal tissues, consideration should be given to the placement of a vacuum dressing

The concept of a "zone of injury" is important since tissue surrounding the wound apparently viable in an initial assessment may not be with the evolution of time and this has implications mainly in the planning of defect reconstruction and graft/flap application [23]. This involves re-evaluating the surgical wound 48 to 72 hours after the first debridement, avoiding multiple or serial debridements at all costs [32].

Bone tissue debridement

If it is necessary to evaluate the bone structures extending the wound, this should be done through the fasciotomy incisions. Bone viability is only really evaluated when the club is opened and there are small cortical hemorrhagic outbreaks ("paprica" sign). Detached and non-vascularized bone fragments are removed (they are not grafts) unless they are large joint fragments that can be reduced and fixed with absolute stability [8-10]. It should be noted that a good wash never replaces a good debridement [36]. The lavage should not be carried out with the pulsatile application of serum at high pressure since this devitalizes the tissues and spreads the bacterial load by them. It is advisable to use large amounts of warm saline solution at low pressure (ideally 3 liters in grade I fractures, 6 liters in grade II and 9 liters in grade III) [9,10].

Acute Compartment Syndrome

After the revascularization, skeletal stabilization and debridement procedures, it is necessary to consider the presence of acute compartment syndrome. This is a serious complication in the context of trauma by crushing or associated fractures. It occurs in about 0.7-7.3/100,000 people [37]. It occurs predominantly in the leg because the compartment volume ratio and muscle tissue are lower. The tibial shaft fracture is present in 36-50% of cases [37,38]. Men are 10 times more affected than women [37]. There are different theories about pathogenesis. Trauma from a pathophysiological point of view damages the tissues causes edema and causes an increase in intracompartmental pressure, ischemia, muscular and nervous necrosis. As necrosis is established the clinical picture is perpetuated with new tissue lesion and increased pressure. Venous compression follows arterial ischemia. In the context of exposed fractures, although the occurrence is less likely, it is not impossible. The presence of unexposed or partially exposed compartments may develop compartment syndrome. In the context of vascular lesions requiring revascularization, the ischemia-reperfusion injury may give rise to this pathological condition. The end result is nerve and muscle ischemia.

The diagnosis can be made from the clinical point of view, intracompartmental pressure assessment or both [39]. This will depend on whether we are dealing with a conscious and cooperating patient or with a patient with an altered state of consciousness. Pain that is disproportionate to the clinical context in need of frequent analgesic therapy is the earliest symptom [40]. The presence of aggravated pain with passive movements of the muscles is the finding at the most consistent physical examination. However, paraesthesia, motor deficits, increased palpation, paleness and increased capillary perfusion time are other clinical findings [41].

The presence of arterial pulses is a constant since its absence is a late manifestation and it means disastrous repercussions. The presence of pulse does not exclude the diagnosis. The clinic may vary depending on the affected compartments. It is accepted from the clinical point of view that if the specialist thinks about the possibility of a syndrome of compartment probably will be in this case. Waiting for a well-defined clinical picture increases the risk of irreversible nerve and muscle damage. Monitoring intracompartmental pressure may be a useful diagnostic tool in patients with altered consciousness who cannot collaborate in anamnesis. Normal intracompartmental pressure in the adult is about 8 mmHg [39]. The most recommended evaluation method is the transducer arterial monitoring system [42]. The measurement should be performed up to 5 cm from the fracture site [39]. A $\Delta p < 30$ mmGg (diastolic pressure-intracompartment pressure) is suggestive of compartment syndrome [38,40]. However, in sedated or induced coma patients, a decrease in diastolic pressure may lead to a false positive result. Serial or continuous evaluation presents better sensitivity and specificity at diagnosis [43]. Treatment should be based on fasciotomies of the four leg compartments through the two incisions of Mubarak [42], preserving the medial and lateral perforations of the leg to allow subsequent reconstruction of soft tissues if necessary.

Temporary Skeletal Stabilization

Temporary skeletal stabilization can be performed soon after vascular reconstruction or if this is not necessary after the debridement and fasciotomy procedures. Being a fast, non-aggressive procedure associated with low infective risk is indicated when primary stabilization or soft tissue coverage is not performed after debridement procedures [42].

The type of external fixation and the form of construction should be planned according to bone stability permitting soft tissue reconstruction approaches. A monolateral construction with the placement of a tibial bar, a breech bar and two bars in interconnection allow a stable construction and possibility of adjustment during future

procedures [42]. The placement of the Schanz pins should take into account the neurovascular bundles of the leg and its entry point should be about 2 cm medial to the tibial crest [44]. It is recommended to place two tibial pins below and two tibial pins above the fracture focus. The use of femoral pins to cause fixation of the knee is recommended in proximal fractures of the tibia. Placement of pins in the calcaneus, talus or metatarsus depends on the need for stabilization of the ankle in the context of distal tibial fractures.

The use of circular constructions is indicated when there is a significant bone loss or in just-articular fractures with loss of soft tissues [38]. In case of significant bone loss, it is possible to perform osteogenesis through distraction as a bone reconstruction procedure. Accessibility to the leg is very compromised.

The use of external fixators as a definitive treatment method may be a consequence after multiple debridement procedures. In this context, internal fixation is contraindicated.

Internal Fixation

Internal fixation may be performed primarily after debridement procedures, or in sequence after temporary skeletal stabilization. Primary internal fixation can be performed ab initio if the wound is not highly contaminated, there is no great bone loss and immediate soft tissue reconstruction. There are few studies that show that the treatment with plates and screws can obtain results similar to external fixation or endomedullary nailing [45-47]. Regarding endomedullary nailing, there is evidence that it can be performed up to the Gustilo-Anderson class IIIB class either in diaphyseal fractures of the tibia or in the femur and without an increased risk of infection [38,48]. It is recommended to use a technique without endomedullary milling in order not to destroy the endosteal vascularization and to promote bone consolidation. Conversion to definitive stabilization should be early, up to 72 hours [42], planning soft tissue reconstruction at the same operative time, reducing the risk of infection. It is not acceptable to allow the internal stabilizing material to be exposed. The plaques are recommended in periarticular, articular fractures and with associated vascular involvement [38]. Endomedullary nails are the treatment of choice in diaphyseal fractures. However, the presence of endomedullary pins is a point of endomedullary contamination with the possibility of infective diaphysitis after pinching [42]. It is recommended that endomedullary nailing is performed until the 28th day of temporary stabilization with external fixator [38].

Wound Coverage

The concept of the reconstructive ladder has been replaced by the concept of the reconstructive elevator. The latter concept is based on the fact that more complex techniques, such as free flaps, can be used as initio because they present better results [10]. However, different forms of reconstruction can be identified: primary closure, secondary closure, skin grafts, fasciocutaneous flaps, muscle flaps, osteomusculocutaneous flaps, and free flaps. Primary closure of wounds can be performed on Gustilo-Anderson type I, II and IIIA fractures provided there is no frank contamination, a latency time after 12 hours, an ISS>25, peripheral arterial disease, diabetes mellitus or disease of connective tissue [38]. It is recommended, in the presence of these variables, to give priority to second intention healing. Soft tissue reconstruction occurs in the context of Gustilo-Anderson type IIIB and Gustilo-Anderson type IIIC fractures with the impossibility of approaching the traumatic flaps. Fasciocutaneous flaps are a simple,

versatile and available method, providing reconstruction with tissue similar to native and avoiding muscle injury. However, by not carrying muscle they do not promote local vascular delivery as effectively. This type of flap is recommended in fractures of the distal metaphysis of the tibia around the ankle because of the difficulty of reconstruction with muscle tissue [42]. In other cases, local muscle flaps should be performed in an emergency, if antibiotic therapy, debridement, and adequate stabilization are used [42]. The use of a Fix and Flap protocol considers a reconstruction with local muscle flap within the first 72 hr [38,49,50]. The advantages of muscle flaps are the prevention of dehydration and infection, a source of undifferentiated cells and osteoprogenitor cells, a source of growth factors (TGF-β, IGF-1, IL6, BNNF, FGF-2), promotion of local vascularization and antimicrobial activity [51]. During this period the infectious and bankruptcy risk of the flap is greatly reduced.

Several options exist in the type of local flaps to use. These depend on the anatomical region involved, local vascularization and local soft tissue integrity (Table 1).

Region	Graft/Flap
Inguinal	V-Y
	Bipediculated
	Keystone
	Rectus abdominalis
	Rectus femuralis
	Abdominus transversus
	Fascia latta tensor
Thigh	V-Y
	Bipediculated
	Keystone
	Rectus abdominalis
	Rectus femuralis
	Fascia latta tensor
	Vastus lateralis
	Gracilis
	Sartorius
Knee and proximal leg	Gastrocnemius
	Hemi-solearis
	Reverse anterolateral thigh
	Anterior tibial perforator
Leg-middle	Hemi-solearis
	Gastrocnemius
	Propeller
Leg-distal	Peroneal osteocutaneus
	Sural

	Safenus
	Anterior tibial perforator
	Tibialis posterior
	Reverse solear
Heel	Sural
	Safenus
Ankle and dorsal foot	lateral supramaleolar adipofascial
	Sural artery
Foot	Lateral calcanear artery
	Finger short extensor muscle rotation
	Hallux abductor muscle rotation
	Pedis dorsalis artery

Table 1: Local flaps according to the anatomical region.

The free flaps allow great versatility in rebuilding large exposed areas. Angiography, discussed in the initial approach as a vascular assessment method, is recommended to plan the surgery, particularly the site of vascular anastomoses. It is recommended to perform this type of flaps in a program and with a differentiated and experienced team in microsurgery [42]. The most frequently described free flaps in the treatment of exposed fractures of the lower limb are the dorsal, rectus, anterior, radial, forearm, lateral, and para-scapular muscles [38,52].

Bone Reconstruction

Bone reconstruction is indicated when there is bone discontinuity with loss of bone tissue and probable development of pseudoarthrosis. This may include primary bone shortening, autologous bone grafting, distraction osteogenesis, and vascularized bone flap. Indications, poorly defined, vary between authors.

Primary shortening may be one of the techniques associated with temporary stabilization if the defect is between 3-4 cm in the tibia or 5-7 cm in the femur [53]. It allows acquiring a stable fixation, early ambulation, and less associated costs.

In this context, distraction osteogenesis allows, in the second time, to reconstitute limb length and correct deformities. This technique involves external fixation, corticotomy, and bone distraction. It is recommended for defects between 2-10 cm [53]. Bone growth is done at a rate of 1 mm/day [38]. It has a success rate of over 75% [53].

Non-vascularized bone graft is a treatment option for defects between 0.5-3 cm [54]. The most frequent place of harvest is the iliac crest. It is recommended in the treatment of pseudarthroses in the context of segmental bone loss.

The vascularized bone flap has the advantage of own blood supply that gives it a higher rate of consolidation, less risk of stress fractures, reconstruction of major defects, bone necrosis or in the context of osteomyelitis. The peroneal flap is the most frequently used [38]. Up to 25 cm can be harvested, maintaining the 7 cm proximal and 4 cm distal to preserve the stability of the knee and ankle, respectively [54].

The flap should be 4 cm longer than the defect to allow the bone to overlap. The time to consolidation is between 3-6 months.

Conclusion

You should always star a polytraumatized and open fracture patient with the ATLS protocol. In the presence of an arterial injury if the ischemia time (IT) is:

- <4hours-angiography
- 4-6 hours-vascular surgery
- >6 hours-amputation

If there is at least 1 hard sign+need to know the defect's location OR multiple obvious defects in the exam OR posterior dislocation of the knee and still if there is incapability of pulse evaluation OR combination of several soft signs and if IPA OR IBT<0,9 ? arteriography

The most accepted algorithm in present days for IIIC grade fractures without amputation indication has the following structure: vascular shunt application-fracture external fixation-definitive vessel repair after other systemic imbalances are corrected-debridement-definitive correction of osseous defects.

The usage of scores like MESS, PSI, MESI have been much more applied to lower limbs and their utility for the upper limbs is still very controversial.

The most important factors in infection rate reduction are the antibiotic administration and the quality of the debridement.

It is also important to retain that the vascular lesion acquires priority in treatment, we should consider definitive fixation of the limb initio, the soft tissue reconstruction should be done in the first 7 days and also muscular flaps seem to present the best results considering all flaps/grafts for soft tissue reconstruction.

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