CURRENT CONCEPTS

Surgical treatment of fracture-related infection
Part I: Bone and soft tissue debridement

Tratamiento quirúrgico de la infección relacionada con fracturas
Parte I: desbridamiento óseo y de tejidos blandos

Matheus Lemos Azi1, Carlos Oliver Valderrama-Molina2, Alejandro Vallejo-Diaz3, William Dias-Belangero4, Vincenzo Giordano6, Guido Carabelli8, Carlos Federico Sancineto8

1 Secretaría de Salud del Estado da Bahia and Sociedade Beneficente Israelita Albert Einstein, Hospital Ortopédico do Estado, Salvador, Brazil. E-mail: mlazi@hotmail.com.
2 Hospital Pablo Tobón Uribe, Orthopedics Service, Medellín, Colombia.
3 Hospital Alma Máter de Antioquia, Orthopedics and Trauma Department, Medellín, Colombia.
4 Universidad Pontificia Bolivariana, Orthopedics and Trauma Department, Medellín, Colombia.
5 Hospital Municipal Miguel Couto, Orthopedics and Traumatology Service Prof. Nova Monteiro, Rio de Janeiro, Brazil.
6 Hospital Municipal Miguel Couto, Orthopedics and Traumatology Service Prof. Nova Monteiro, Rio de Janeiro, Brazil.
7 Rede D’or São Luiz, Clínica São Vicente, Rio de Janeiro, Brazil.
8 Hospital Italiano de Buenos Aires, Instituto de Ortopedia y Traumatología Carlos E. Ottolenghi, Buenos Aires, Argentina.

Abstract

Fracture-related infection (FRI) is a severe complication of the surgical treatment of traumatic bone injuries and occurs more frequently in patients with such injuries than in those undergoing elective joint replacement surgery. The surgical treatment of FRI is based on meticulous bone and soft tissue debridement, dead space management, reconstruction of soft tissue defects, and restoration of bone stability in non-union fractures. Furthermore, the use of local antibiotic therapy is recommended in some cases. The objective of this article was to review the current concepts of available techniques for the surgical treatment of FRI, with emphasis on bone and soft tissue debridement.

Keywords: Surgical Wound Infection; Fracture Fixation; Osteomyelitis; Debridement (MeSH).

Resumen

La infección relacionada con fracturas (IRF) es una complicación grave en el tratamiento quirúrgico de lesiones óseas traumáticas y ocurre con mayor frecuencia en pacientes con este tipo de lesiones que en aquellos llevados a cirugía de reemplazo articular electiva. El tratamiento quirúrgico de la IRF se basa en el desbridamiento meticuloso del hueso y los tejidos blandos, el manejo del espacio muerto, la reconstrucción de los defectos de tejidos blandos y la restauración de la estabilidad ósea en los pacientes con fracturas no consolidadas. Además, en algunos casos, se recomienda el uso de terapia antibiótica local. En este sentido, el objetivo de este artículo fue revisar los conceptos actuales de las técnicas quirúrgicas disponibles para el tratamiento quirúrgico de la IRF, haciendo énfasis en el desbridamiento del hueso y los tejidos blandos.

Palabras clave: Infección de herida quirúrgica; Fijación de fractura; Osteomielitis; Desbridamiento (DeCS).
Introduction

Fracture-related infection (FRI) is a major complication in the treatment of traumatic bone injuries that occurs more frequently in patients with this type of injury than in those undergoing elective joint replacement surgery. The proportion of FRI ranges from 1% to 8.1% in closed fractures and can reach up to 30% in open fractures. It is worth mentioning that, according to our literature search, no specific data on FRI in Latin America were found.

The terms “osteomyelitis” and “osteitis” have been used to refer to bone infection; however, they are nonspecific and often confusing. Stemming from the joint work of several scientific societies, the concept of FRI was defined in 2018, encompassing the unique characteristics of this type of infection. In this expert consensus, clinical findings, as well as laboratory and imaging tests, were stratified as confirmatory or suggestive criteria for the presence of this type of infection (Figure 1). In 2022, these criteria were validated, showing that the presence of at least one confirmatory criterion has a sensitivity of 97.5%, a specificity of 100%, and an area under the receiver operating characteristic curve (AUC-ROC) of 0.99.

FDG-PET: fluorine-18 fluorodeoxyglucose positron emission tomography. HPF: high power field. FRI: fracture-related infection. CRP: C-reactive protein test. PMN: polymorphonuclear neutrophils. MRI: magnetic resonance imaging. CT: computed tomography. ESR: erythrocyte sedimentation rate.

Figure 1. Diagnostic criteria for fracture-related infection.
Source: Adapted from Obremskey et al. and Onsea et al.
A fundamental role in the pathophysiology of FRI is played by the mechanisms of bacterial persistence in the bone with bacterial invasion of the bone canaliculus and infection by intracellular bacteria; in the soft tissue with the formation of abscesses and microcolonies; and in the implant with the formation of biofilm.1,9 Considering that these mechanisms favor bacterial survival, successful treatment of FRI requires the use of systemic and local antibiotic therapy, as well as local reduction of the bacterial inoculum through surgical procedures.9,10 Moreover, microorganisms that manage to adopt these persistence mechanisms have lower metabolic activity, are less susceptible to certain antibiotics, and require higher minimum inhibitory concentrations than planktonic forms.9,10 Consequently, systemic antibiotics frequently fail to reach appropriate therapeutic levels in bone tissue, leading to therapeutic failures in these patients.9

Furthermore, the duration of infection is also of critical importance, as biofilm maturation leads to persistence of infection in the presence of internal fixation devices, and the outcome is often uncertain when the implant is retained.5 The maturation of the biofilm is a continuous process that varies depending on the species of bacteria that make it up and occurs between the third and tenth week. In general, after this period, debridement should be more aggressive and implant retention is neither possible nor recommended in most cases.9,10

The literature on FRI is limited and most of it is published in English. Therefore, the objective of this article is to review the current concepts on the surgical techniques available for the treatment of FRI, with emphasis on bone and soft-tissue debridement.

Surgical management options for fracture-related infection

Currently, there are no evidence-based clinical practice guidelines for the treatment of FRI.11,12 There are two approaches to the surgical management of this type of infection. The first prioritizes bone healing, and management is based on debridement, suppressive antibiotic therapy, and implant retention (DAIR). The second approach mainly aims to control the infection, and management is based on debridement and implant removal or replacement depending on the fracture healing, plus targeted antibiotic therapy.11,12 Choosing between these two therapeutic strategies for FRI will depend on multiple factors, including the classification of the infection.

Classification of fracture-related infection

Although several classification systems for osteomyelitis have been described,13,14 the most widespread is the one presented by Waldvogel et al.13 in which infections can be acute or chronic depending on the duration of symptoms.13 Unfortunately, differentiating between acute or chronic forms of FRI is difficult because, as noted by Hotchen et al.,14 determining the exact time of infection onset is difficult in most cases. However, it has been reported that the classification of FRI as acute or chronic does not have a strong influence on the diagnostic process nor on the selection of surgical treatment.14 Even so, one should always consider the changes brought about by the chronification of the infection, as some of them must be strictly dealt with during surgical debridement.9

Chronic infection is characterized by bone destruction and the formation of new bone structure.15 Typical histopathologic findings of chronic infection include the presence of bone necrosis and polymorphonuclear leukocytes, along with large
numbers of lymphocytes, histiocytes and, occasionally, plasma cells.\textsuperscript{16} In this regard, it has been described that bony sequestrum is a fragment of necrotic bone that becomes a potential reservoir of bacteria and biofilm, providing an ideal nutrient medium for the consequent proliferation and dissemination of bacteria.\textsuperscript{17} On the other hand, the involucrum is a reactive formation of new bone around the sequestrum;\textsuperscript{17} it is irregular and is often intersected by channels that communicate the sequestrum with the periphery, through which pus can reach the soft tissues and eventually drain into the skin, forming sinuses or fistulas (Figure 2). Also, the involucrum may gradually increase in density and thickness to form, in whole or in part, a new diaphysis. The new bone increases in size and density progressively over weeks or months depending on the size of the bone and the extent and duration of the infection.\textsuperscript{16} Following osteosynthesis, the distribution of bone necrosis depends on the energy of the trauma, the care applied in the surgical technique, and the implants used (e.g. intramedullary nails or osteosynthesis plates).\textsuperscript{18}

![Image of sequestra and involucrum.](image)

White arrow: necrotic bone or sequestrum. Black arrow: viable reactive bone involvement. Dotted arrow: pus between the sequestrum and the involucrum.  
**Figure 2.** Sequestra and involucrum. A. Tibial plafond. B. Femoral diaphysis.  
Source: Image obtained by the authors while conducting the study.

On the other hand, Wilenegger & Roth\textsuperscript{19} classified post-osteosynthesis infection based on the time of symptom onset after internal fixation of fractures, differentiating the following three groups: early infection (≤2 weeks), delayed infection (3-10 weeks), and late infection (>10 weeks).\textsuperscript{19} The time interval between the onset of symptoms and the initial surgery, together with the patient's signs and symptoms, help to establish the route of infection transmission (inoculation during surgery vs. hematogenous route), identify the possible microorganisms involved, and guide treatment.\textsuperscript{9,20} In the case of delayed or late infection, maturation of the biofilm requires more aggressive debridement and there is a lower probability of success with implant retention.\textsuperscript{9}

This classification by Wilenegger & Roth\textsuperscript{19} also highlights other relevant factors such as implant stability or fracture healing status, which is not expected to occur in patients with early infection or delayed infection.\textsuperscript{9} One example of the use of this classification is found in the study by Morgenstern et al.,\textsuperscript{21} who reported that the success rate of DAIR was higher in
patients with early FRI (86%) than in patients with late infection (67%). However, it should be noted that, although the Willenegger & Roth classification is widely accepted, there is insufficient evidence to claim that it is superior to other classification systems.12

Overview of the surgical treatment of fracture-related infection

Surgical treatment of FRI is based on four pillars, namely meticulous debridement of bone and soft tissues, dead space management, soft tissue reconstruction, and restoration of bone stability along with management of bone defects in non-union fractures.22 In addition, the use of local antibiotics is recommended in some instances, mainly for dead space management and local control in highly suppurative infections.

Debridement is the cornerstone of FRI treatment and involves excision of all infected and necrotic tissue.15,23 However, this procedure must be performed with reconstructive surgical techniques in mind. In this sense, the surgical management of this type of infection requires a multidisciplinary approach involving at least professionals in orthopedics, plastic surgery, and infectious diseases.9,22,23

When making the decision to perform surgical debridement, it is important to take into account patient-related factors, as well as the availability of surgical instruments, medical supplies, and personnel. Regarding the patient, it is necessary to consider soft tissue conditions, mobility of the skin adjacent to the fistulous tracts, presence of flaps and location of blood vessels, proximal or distal joint mobility, and presence of comorbidities, especially those related to the possibility of performing reconstructive procedures after debridement (peripheral arterial disease, alterations in sensation, or functional status prior to FRI).23 Furthermore, imaging tests can identify the location of abscesses that need to be drained, the presence of sequestra and involucrum, the healing status of fractures, and the presence of fixation material or foreign bodies that require additional explorations.24

Although it is possible to perform debridement using basic surgical instruments, it is necessary to verify their availability in advance. Consequently, chisels, curettes, rongeurs, intramedullary reaming systems, irrigation systems to wash the detritus generated by the debridement, elements to remove implants and broken materials, flasks and vials to store the extracted samples to perform cultures and histopathology studies, and any necessary element to carry out the temporary covering of the wound in case there are coverage defects after debridement, should be available.25 Finally, it should be emphasized that proper surgical debridement must be performed by trained medical personnel with experience in identifying necrotic bone, the ability to perform extensive soft-tissue examinations, and knowledge of reconstructive surgical techniques.11

Pre-surgical preparation

In patients with local infection without sepsis, it is advisable not to administer antibiotics at least two weeks before debridement, in order to increase the diagnostic yield of microbiological cultures.26 In this regard, intravenous antibiotic therapy can be initiated after deep tissue sampling for culture.26 Debridement can be performed with a tourniquet, emptying the blood by gravity and not through compression to avoid the spread of bacteria in the bloodstream.26,27 To this end, the limb should be elevated for three to five minutes to allow the blood to drain out.26 One of the advantages of gravity blood emptying is that the remaining blood in the limb may help identify tissue vascularity, which is especially useful when assessing bone viability (Paprika sign).26
Soft tissue debridement

The objective of surgical debridement is to remove as much necrotic tissue as possible in order to minimize the local bacterial load, allowing the restoration of local vascularization to promote healing and access of antibiotics to the infected wound bed.\textsuperscript{28} Moreover, proper debridement requires a surgical approach that takes into consideration previous incisions and scars.

Initially, dead skin is pale, then it becomes purplish, and finally black. On some occasions, it is difficult to differentiate skin with poor perfusion from necrotic skin, so debridement should be performed progressively until there is bleeding from the edges of the surgical wound, indicating that the tissue is alive and has good perfusion.\textsuperscript{28} In early FRI, the area with erythema may mistakenly lead to exaggerated debridement. Therefore, in these cases it is recommended to be conservative and debride the wound edges and extend the wound as much as necessary to visualize the fracture site and/or the implants without creating large soft tissue defects that may generate greater morbidity, and to plan soft tissue reconstruction, as it is an essential part of the definitive treatment for FRI.\textsuperscript{25}

Poor quality scars should be removed, always trying to leave wound edges with well perfused tissues.\textsuperscript{26} In addition, scar tissue should be removed, as it can cause tension on wound closure, slow the healing rate, and act as a persistent site of infection.\textsuperscript{27} Finally, the cold steel scalpel should be chosen above the electrosurgical scalpel.\textsuperscript{27}

Fistula and sinus management

The incision made during surgery should include the cutaneous fistula (Figure 3).\textsuperscript{26} In patients with chronic FRI, a pathology study of the debrided sinuses and fistulas should be performed due to the risk of malignancy.\textsuperscript{26} In addition, the fistulous tract communicates with the central site of infection, so it is necessary to follow it and debride it along with the surrounding tissue.\textsuperscript{26} When the fistula is not located at the incision site, it can be temporarily ignored and curetted at the end of the procedure.\textsuperscript{26,29} The fistula should close spontaneously with adequate control of the main site of infection.\textsuperscript{26,29}

In some cases, pre-surgical injection of methylene blue is useful to guide debridement, as this cationic dye has been reported to bind to and stain dead eukaryotic cells and bacterial biofilms.\textsuperscript{29} In this regard, Shaw \textit{et al.}\textsuperscript{29} demonstrated in 2017 the in vitro ability of methylene blue to stain \textit{Staphylococcus epidermidis} biofilms on orthopedic implants. Due to its penetration capacity, methylene blue allows staining from the wound surface to the deep tissues, where most of the infected tissue is located and is therefore not viable for preservation.\textsuperscript{29} Although the exact interaction mechanism of methylene blue with
biological substrates is not known, its use is safe and effective, and no adverse effects have been reported in the literature.29

Methylene blue should be injected into the fistulous opening using the thickest needle or cannula available, and exerting as much pressure as possible to allow the dye to penetrate into the deep tissues.26 Moreover, performing this procedure the day before debridement allows the excess dye to flow out through the fistula, staining only the infected tissues.26 If the injection is made on the same day as the surgery, methylene blue will also stain healthy tissues and bacteria that make up the biofilm (Figure 4).26,29

![Figure 4](image)

**Figure 4.** Tissue staining with methylene blue allowed for increased staining in areas of biofilm deposition and necrotic tissue. A. Necrotic tissue on the plaque before debridement. B. Tissue after debridement and before implant removal.

Source: Image obtained by the authors while conducting the study.

**Foreign bodies and osteosynthesis material**

All foreign bodies, including broken or loose screws and cerclage wires, should be removed, as they act as biofilm carriers.30 If the DAIR strategy is chosen for the management of early and delayed infections, all unnecessary foreign bodies should be removed and only the osteosynthesis material essential to maintain fracture stability should be preserved.31 Once the fracture has healed, the implant should be removed to reduce the risk of relapse.31

**Bone debridement**

Bone debridement should be precise and have sufficient coverage to remove all compromised tissue; however, excessive removal of viable bone should be avoided, as this increases the difficulty of reconstruction.26 When approaching the infected area, it is advisable to perform a surgical exploration above the periosteum, avoiding devascularization of the viable bone adjacent to the necrotic bone.32 Necrotic bone usually has no periosteum and is easily exposed by elevating the adjacent tissue. On the other hand, it has been pointed out that the assessment of bone tissue viability is a gradual and non-categorical process.26,33

As in the case of tumors of the musculoskeletal system, it has been reported that the only way to eradicate bone infection is to perform radical debridement without being concerned about creating bone and/or soft tissue defects, mainly for the purpose of removing as much infected tissue as possible and thus reduce the risk of infection relapse.11,23,30 There is no simple method for making the decision to preserve the continuity of bone tissue or to perform a segmental resection of the bone.33 Thus, during debridement, it is necessary to find a balance between removing necrotic tissues where the systemic antibiotic will not be able to penetrate and preserving a continuity of bone tissue that allows maintaining the stability of the bone.26
Analyzing bone tissue viability involves intraoperative assessment of its color, texture and sound to percussion, as well as the quality of the cancellous bone and soft tissues around the bone, in order to differentiate between viable bone, infected but viable bone, and necrotic bone (Figure 5). Viable bone is usually surrounded by non-infected, viable soft tissues; in fact, viable infected bone may retain this healthy soft tissue environment. Finally, it is recommended to irrigate the surgical wound with abundant saline solution in combination with some abrasive method such as gauze cleaning of the bone surface and the implant surface.

Using tangential osteotomy may allow distinguishing between viable and nonviable cortical bone. Viable bone can be identified by creating thin layers of cortical bone, which will generate a punctate bleeding known as Paprika sign; on the contrary, necrotic bone is fragile and tends to fracture. Furthermore, striking viable bone with a solid surgical instrument produces a dull, muffled sound, while necrotic bone generates a dry, clear sound, which is similar to that produced when hitting a porcelain object. Also, infected cancellous bone feels softer than healthy cancellous bone and detailed observation makes it possible to identify granulation tissue and small dead bone lamellae.

Cortical bone infection

Necrotic bone should be removed with a chisel or high-speed burs, and, in order to ensure the successful consolidation or reception of bone grafts, it is crucial to observe that the resected bone’s margins are actively bleeding and viable. Likewise, if the patient’s implant was an osteosynthesis plate, it is common to see a layer of necrotic bone after its removal, which should also be removed with the help of a chisel. Screw holes should also be drilled with larger drill bits. On the other hand, the surgeon must carefully observe the edges of the resection and constantly reevaluate them, as the transition between living and necrotic bone tissue may not be evident, and this is not always related to previous imaging findings.

If possible, bone stability should be preserved; however, infection control and eradication should be the priority in the surgical management of FRI. When segmental bone defects involving more than 50% of the circumference of a load-bearing bone are
present, reconstructive techniques will be necessary. Moreover, there is always a risk of developing sclerotic lesions of the bone; however, fracture healing is possible if the depth of these lesions does not prevent the penetration of the antibiotics or the incorporation of bone grafts.

**Infection of the medullary canal**

After removing an infected intramedullary nail, the diaphysis should always be reamed with drills 2mm or 3mm larger than the diameter of the removed nail, and the locking hole trajectories should be cleaned with larger drills. The medullary canal can be reamed with conventional drills, in which case it will be necessary to make a distal bone window that, together with canal irrigation, allows the exit of the reaming residue; irrigation and aspiration devices such as the reamer irrigator aspirator (RIA; DepuySynthes; Johnson & Johnson Co. Inc., New Brunswick, NJ, USA) can also be used. It is important to irrigate the medullary canal with intramedullary probes and, also, a Foley catheter can be used to remove as much residue as possible from the reaming of this canal.

Occasionally, infection of the medullary canal may be limited to the metaphysis, without affecting the diaphysis. In these cases, it is possible to make an oval bone window and ream the metaphyseal cavity with high-speed burs or angled curettes, removing all the necrotic cancellous bone, preserving the vascularized cortical bone, and aiming to preserve the joint as long as its viability is demonstrated.

**Diffuse infection and segmental resection of the bone**

In patients with diffuse infections, it may be necessary to resect entire intercalary segments during debridement, which in turn will require the use of some type of reconstructive technique. In these cases, the proximal and distal edges must be defined, and a precise resection must be performed. Similarly, an osteotomy can be performed with drills and rasps (low-energy osteotomy) or with a Gigli or oscillating saw, using saline solution for cooling during the procedure to reduce necrosis at the edges of the resection. Finally, if burn necrosis is encountered, it is recommended that the edges of the osteotomy be smoothed using a rongeur until the cortex of the bone bleeds.

**Tissue samples for culture and histopathology**

Samples for microbiological cultures and histopathological studies should be obtained from areas of suspected infection and preferably from the bone-implant interface. If there are open wounds or active fistulas, it is recommended to take the samples after debridement. At least five deep tissue samples (bone, muscle, joint capsule, etc.) should be obtained, each with a different sterile instrument and stored individually in a dry tube or flask. In addition, it is recommended to perform aerobic and anaerobic bacterial cultures and, in immunosuppressed patients, fungal culture test and mycobacterial culture. Samples should be transferred to the microbiology laboratory as soon as possible.

It is not recommended to take samples of discharge or fistulous tracts, nor to obtain samples with swabs, due to their low performance in microbiological identification and the possibility of obtaining false positives that may inadequately guide the treatment. If possible, sonication can be performed on the implants. Histopathological studies are recommended to obtain complementary information for the diagnosis of infection or rule out the presence of malignancy.
Wound closure

Whenever possible, the surgical wound should be closed in layers with monofilament sutures. Likewise, tension of the wound edges should be avoided, and separate stitches should be used with the technique selected by the surgeon. If there is dead space and no local antibiotic has been used, deep surgical drains may be left in place to avoid hematomas or fluid collections that may promote infection. Moreover, when the wound cannot be closed and it is observed that the debridement has eradicated the infection at macroscopic level, it is possible to use transitional closure techniques such as beads and coverage with semi-permeable barriers or negative pressure devices, considering the eventual performance of a late primary closure or soft tissue reconstruction with flaps.

Serial debridement

In some cases, multiple debridements may be required for infection control, as well as other reconstructive surgical procedures, depending on the extent of infection, the patient’s comorbidities, and the degrees of fracture stability and bone or soft tissue loss. Since the presence of severe infections, hyperemia and blood loss hinder the process of establishing tissue viability, in these cases the initial surgery should focus on the drainage of deep collections, removal of necrotic tissue, and identification of the microorganisms causing the infection. After a brief period of antibiotic administration and once the local inflammation has subsided, it will be possible to perform a more exhaustive and precise debridement, in addition to the removal of implants and necrotic bone segments. When multiple surgical stages are necessary, bone defects should be temporarily filled with antibiotic-impregnated cement spacers. Finally, a systematic literature review, which included 93 studies (3701 patients) published between 1990 and 2017 on the surgical management of FRI, reported that two-stage procedures were the most frequent (54%), followed by one-stage procedures (19%).

Conclusion

Debridement is the cornerstone of surgical treatment for FRI and its objectives are to reduce the bacterial inoculum, provide an optimal vascularized bed to facilitate systemic antibiotic penetration, and promote a favorable local bacterial environment for subsequent bone and/or soft tissue reconstruction. Furthermore, debridement should be performed in three stages: first, planning the procedure; second, performing the debridement, where three structures (soft tissues [skin, tendons and muscle], osteosynthesis material, and bone), irrigation, and sampling for culture and histopathology should be considered; and third, dead space and soft tissue management before definitive reconstructive surgery is performed.

Conflicts of interest

None stated by the authors.

Funding

None stated by the authors.
Acknowledgments

The authors would like to express their gratitude to the research support group at AOTruma Latin America for their help in the development of research on fracture-related infections.

References


