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REVIEW ARTICLE

Open fractures

J.M. Muñoz Vives[a,*], P. Caba Doussoux[b], and D. Martí i Garín[c]

[a] *Traumatology Department, "Dr. Josep Trueta" University Hospital, Girona, Spain*
[b] *Traumatology Unit, "12 de Octubre" University Hospital, Madrid, Spain*
[c] *Traumatology Unit, Sabadell Hospital, Parc Taulí Health Corporation, Sabadell, Barcelona, Spain*

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Abstract
A review is presented on the current status of open fracture treatments, and an attempt is made to clear up controversies and establish the basic principles of their current treatment.
The use of antibiotics in the initial treatment of open fractures is a well known concept, and the earlier they are given the greater is the reduction in the likelihood of infection. The more radical the debridement is, the lower the rate of infection. The fixation method of choice for open fractures of the diaphysis of the leg is the intramedullary nail. The use of external fixation should be limited to cases of multiple traumas. If the debridement has been exhaustive, a better result is obtained with the primary closure of the wound. The loss of soft tissue must be repaired as soon as possible and using the simplest but most efficient system on the orthoplastic ladder; secondary closure, free graft, rotational flap, free microvascularised flap.
Although some treatment guidelines are clear, each open fracture is different and must be adapted to each fracture and to each patient.

PALABRAS CLAVE
Fractura abierta;
Antibiótico;
Herida;
Tibia;
Clavo endomedular

Fracturas abiertas

Resumen
Se presenta una revisión del estado actual del tratamiento de las fracturas abiertas. Procurando despejar controversias y establecer los principios básicos de su tratamiento actual.
El empleo de antibióticos en el tratamiento inicial de las fracturas abiertas es un concepto bien establecido, cuanto más precoz es su administración mayor es la reducción de la posibilidad de infección. Cuanto más radical es el desbridamiento, menor es la tasa de

*Corresponding author.
E-mail: jmmuvi@gmail.com (J.M. Muñoz Vives).

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infección. El método de fijación de elección para las fracturas abiertas de las diáfisis de la extremidad inferior es el enclavado endomedular. El uso de fijadores externos debería limitarse a los casos de politraumatismos. Si el desbridamiento ha sido exhaustivo, se obtiene un mejor resultado con el cierre primario de la herida. Se debe reparar la pérdida de partes blandas tan pronto como sea posible y mediante el uso del sistema más simple pero eficaz en la escalera ortoplástica: cierre secundario, injerto libre, colgajo rotacional, colgajo libre microvascularizado.
Aunque algunas pautas de tratamiento son claras, cada fractura abierta es distinta por lo cual el tratamiento debe ajustarse a cada fractura y a cada paciente.

Introduction

The presence of a fracture with exposed bone has been synonymous with amputation, deep infection or death in the first month. Deep infection with osteomyelitis following an open fracture is still a feared and devastating complication of such fractures. The skin is the main mechanical barrier against infection and the wound caused by an open fracture is immediately contaminated by the flora on the skin or in the surroundings. Devitalized soft tissues are an ideal setting for the proliferation of bacteria and the risk of infection is very high[1] unless early treatment is implemented, including debridement, treatment with antibiotics and fixation.

Live tissue is the best defence against infection. Tissues with low levels of perfusion offer the best medium for bacterial proliferation. One of the cornerstones in the treatment of open fractures is to remove tissues that are not able to defend themselves against germs. The removal of dead tissue does not completely eliminate micro-organisms, but it does significantly reduce their number and the remaining microbes find it much more difficult to proliferate in the live tissue that is left.

Open fractures are frequently accompanied by the loss of soft tissue that may be extended by debridement, another fundamental step to achieve a functional limb is the coverage of this loss.

The aim of this review is to go over the advances in the treatment of open fractures, seeking the highest level of scientific evidence although we have not always found it. Despite being relatively frequent, their presentation is heterogeneous, preventing significant conclusions from being reached in all aspects, and although open fractures may occur in any bone, we have used open fractures of the tibia as our reference.

Antibiotic treatment

The treatment of open fractures with antibiotics has brought down the rate of post-surgical infection and is considered as the current standard of treatment, albeit not the main factor for preventing infection. Dellinger et al.,[2] in 204 exposed fractures, pointed out that factors related with the onset of infection are more related to the degree of the soft-tissue lesion and their treatment than with the duration or type of antibiotic treatment.

A large part of the current concepts and therapeutic guidelines on prophylaxis are based on studies carried out more than twenty years ago using concepts for the treatment of open fractures very different from those in use today. The clinical trial by Patzakis et al.[3] was the first to show the beneficial effect of reducing infectious complications by following a regime of first generation cefalosporins compared with penicillin and placebo. Those results were subsequently confirmed by other studies such as that by Gustilo and Anderson,[4] which showed an infection rate of 2.4% in a series of 520 patients treated with cefazolin. The current bases for treatment have been established in accordance with two meta-analyses, one published by the Eastern Association of Surgery of Trauma[5] (EAST) which included in its review 50 articles published up to 1997, of which 10 were prospective randomized studies. The joint analysis showed a clear reduction in post-operative infections following antibiotic prophylaxis. The other systematic review was that published by Gosselin et al.[6] which found a reduction of 59% in the risk of infection through the use of current antibiotic regimes.

The treatment concepts in complex open fractures have progressed and are based on staged treatment strategies, practically non-invasive osteosynthesis techniques and early coverage of soft tissue to preserve the biology for bone consolidation and avoid a large proportion of subsequent nosocomial infections.

There have also been changes in the epidemiology of intra-hospital infections; the bacteria causing infections in open fractures come from the saprophyte flora on the skin or germs in the environment and hospital flora. Saprophyte or environment flora can contaminate the wound at the moment of the accident; but it is the intra-hospital flora that most frequently colonize the bone and the wound during subsequent surgical procedures or through colonization of the skin.

The first prophylaxis protocols were based on long-term antibiotic therapies and on the use of wound cultures before debridement. The initial studies showed a high correlation between the germs cultured initially and those causing the infection. Robinson et al.[7] concluded that a majority of open fractures are contaminated at the time of the first hospital assistance; the germs isolated were community pollutants sensitive to most antibiotics and did not recommend the routine performance of cultures as this has little clinical efficacy in the reduction of the infection. Lee et al.[8] found that only 8% of the germs that grew in the initial cultures were the cause of the definitive infection and the correlation with cultures performed after debridement was also low, less than 25%. In a subsequent study, Carsenti-Etesse et al.[9] proved that 92% of the infections that appeared after an open fracture were due to the infection acquired in the hospital.

Most of the infections in open fractures are due to strains of *Staphilococcus aureus, Streptococcus* sp., *Enterococcus* and gram-negative bacilli such as *Pseudomona aeruginosa, Enterobacter* or *Proteus*. In addition, cultures frequently show multi-resistant strains of germs such as methycillin-resistant *S. aureus* (MRSA), strains of vancomycin-resistant *Enterococcus* (VRE) and multi-resistant gram-negative bacteria. The fact that a majority of infections occur in the hospital has changed the concept of antibiotic treatment. However, the discussion about whether it is prophylaxis or treatment continues unabated and does not seem to have a lot of clinical relevance. Regardless of the initial antibiotic treatment, extensive debridement is advisable as well as effecting early covering of the wound to avoid infection.

There are no conclusive data to establish once and for all the best antibiotic treatment strategy, although the current trend is towards a clear reduction in the treatment duration. The main discussion points are the ideal moment to start antibiotic treatment, its total duration and the best combination of drugs. Other research fields are the efficacy of the devices for local release of antibiotics, using polymethyl methacrylate or impregnated osteosynthesis material.

The studies available suggest that antibiotic treatment should be begun as soon as possible after the fracture occurs. Patzakis and Wilkin[10] recorded an infection rate of 4.7% when treatment was begun during the first three hours versus 7.4% when the treatment was delayed.

Antibiotics

The results of the cultures taken from the wound show that the vast majority of the germs isolated are sensitive to drugs with a bactericidal effect on staphylococci. First generation cefalosporins have good penetrability in bone as well as good tolerance and low toxicity, making them the treatment of choice in grade I and II open fractures when there is no major contamination.

The wounds with major involvement of soft tissues, as happens in Gustilo grade III fractures or in those occurring in setting with abundant organic matter, such as earth or manure, are frequently contaminated from the outset by Gram-negative flora and require a more extensive antibiotic covering. The combination most often used consists in the administration of a first generation cephalosporin with an aminoglycoside. The administration of aminoglycosides in multiple split doses has a higher incidence of nephrotoxicity than when administered in a single dose and single-dose administration presents a better activity against *Pseudomonas* and other Gram-negatives.[11] Studies comparing classic combined therapies, with cefalosporins and aminoglycosides, against other combinations, such as single-dose third generation cefalosporins or ciprofloxacin, are favourable to the first combination.[12]

There is some controversy about the initial antibiotic treatment of open fractures in which there is contamination due to organic matter, such as in those arising in an agricultural setting, or lesions compromising major vessels. For an infection by *Clostridium* to occur, it is necessary to have an anaerobic setting such as that occurring in the presence of necrotic tissues or dead spaces. The role of early and extensive debridement is the key to avoid gaseous gangrene. On the other hand, both cephazolin and the combination of amoxicillin and clavulanic acid have shown an excellent bactericidal activity against *Clostridium*. Most of the regimes recommended include in these cases high doses of penicillin G, but there is no evidence for this.

The recommended antibiotic treatments are established in accordance with the Gustilo classification (table 1) although it should be recalled that this classification suffers from low inter-observer reliability, 60%, so the treatment decision must be individualized depending on the soft-tissue lesion, the time elapsed and the contamination in the wound (table 2).

There is no evidence supporting the use of regimes lasting for more than three days or repeated regimes following subsequent surgeries.[5,13] Dellinger et al.[14] did not find any significant differences between treatments lasting 24 and 5 days. Most of the clinical guidelines still recommend treatment regimes lasting for 48 to 72 hours for type II and type III fractures.

Treatment with polymethyl methacrylate cement impregnated with antibiotic has been used as a co-adjuvant treatment with systemic antibiotic therapy for open fractures and it has been shown to reduce infection. Ostermann et al.[15] found that the infection rate was significantly lower in the group treated with local co-adjuvant treatment with polymethyl methacrylate impregnated with tobramycin with respect to the group treated with isolate antibiotic therapy.

Studies have also been published on the isolated use of local antibiotics: Moehring et al.[16], in a randomized prospective study, did not find significant differences in the infection rate between the group treated with systemic antibiotic therapy and another treated only with cement impregnated with tobramycin. The main advantages of this treatment method are the high local concentrations of antibiotic, between 10 and 30 times more than with endovenous administration, with a reduction in the systemic secondary effects. There are doubts about the possibility of creating resistances with local treatment and on the possible inhibiting effect on osteoblastic activity.[13] the antibiotics with the best profile for local treatment are the aminoglycosides, due to their thermal stability, wide spectrum of activity and low allergenic capacity. The habitual dose recommended is 3.6 g of tobramycin for every 40 g.

Other slow-release systems, such as intramedullary pins coated with antibiotic, or re-absorbable elements, such as calcium sulphate or polylactic acid impregnated with antibiotic, have been used in clinical practice, but

Table 1 Classification of open fractures

Type of fracture	Description Contamination mechanism	Fracture	Wound	Soft-tissue lesion
Type I	Clean Low energy Inside-out	Transverse or oblique, short	Less than 1 cm	Minimal soft-tissue lesion No crushing
Type II	Moderate contamination	Moderate comminution	Greater than 1 cm	Without any extensive lesion of soft tissues, avulsions or skin flaps
Type III	High energy trauma Contaminated wound	Large-scale comminution and instability of the fragments	Not assessable	Extensive lesion of soft tissues, including muscle, skin, and neurovascular structures
Type III A	High energy, crushing lesions	Comminute and segmentary fractures	Not assessable	Adequate coverage of soft tissues, direct closure with soft tissues
Type III B	Massive contamination	Periosteal detachment	Not assessable	Periosteal detachment and exposure of the fracture. Secondary reconstruction techniques required with local or free flap to cover the fracture
Type III C	Any	Any	Not assessable	Any open fracture with an associated vascular lesion requiring repair, regardless of the soft-tissue lesion

Gustilo et al[53].

experience is scant and there is no evidence of its true efficacy.

Amputation

The first decision to be taken in an open fracture is whether or not the limb can be saved, and this depends on many factors: age, prior condition, vascular lesion, presence of other lesions, among others. Amputation as an extreme measure is the most radical of debridements and it may save the lives of some patients.

The decision on an immediate amputation is taken by the health-care team, with little input by patients and their relatives. Secondary amputation is usually a decision taken jointly by the patient and the traumatologist, normally because both foresee a poor level of functionality in the limb.

Attempts have been made to establish prognostic factors or scales for secondary amputation, the application of which would avoid suffering on the part of patients from the accident to the moment of the secondary amputation. Lange et al.[17] established the absence of sensitivity in the sole of the foot as a prognostic factor and, in 1990, Johansen et al.[18] introduced the Mangled Extremity Severity Score (MESS) scale that includes such variables as age, time of ischaemia and degree of lesion in order to try and establish a prognosis for secondary amputation. Subsequently, other scales have emerged to help in taking the decision on amputation. Nonetheless, a prospective multi-centric study under the auspices of the LEAP Study Group,[19] on an initial cohort of about 600 patients, showed that none of the factors (arterial lesion, damage to the posterior tibial nerve, ...) nor any of the scales published to date predicted for the amputation of the limb.

A meta-analysis[20] did not find any significant differences in the functional results between amputees and non-amputees 7 years after their accidents. What is more, the prognostic factors for a poor functional outcome identified by the study were low educational level, poverty, non-white race, advanced age, female gender, lack of medical insurance, low social support, smoking, and suing for compensation; disappointingly, the study did not identify any variable under the control of the traumatologist.

In the light of the results, decisions on the immediate amputation of a limb must take many factors into account, but none is an absolute discriminant as to which patient is going to have a poor outcome. Decisions on secondary amputation must be taken collectively with the patient whenever possible.

Debridement and care of the wound

It has been established that open fractures must be debrided within 6 h and it seems logical that the sooner the bacterial load is eliminated and the less time the microbes have to colonize neighbouring areas, the better the infection rate will be.[21,22] Nevertheless, Spencer et al.[23] did not find this relationship and justify a delay in debridement if this can be performed by an expert team.

Table 2 Antibiotic treatment according to the Gustilo classification

Gustilo-Anderson classification	First-choice treatment	Optional treatment	Allergy to penicillin	Notes
*Types I and II**	*Cephazolin* 1 g IV on admission followed by cephazolin 1 g/8 h IV (3 doses) Surgery*: 1 g IV on induction. Repeat dose of cephazolin 1 g if surgery duration ≤ 3 h Cephazolin 1 g/8 h IV in the post-operative period (3 doses).	*Amoxicillin-clavulanic acid* 2 g IV on admission followed by amoxicillin-clavulanic acid 2 g IV every 8 h (3 doses)	*Vancomycin* 1 g IV one hour prior to surgery. Repeat vancomycin 1 g dose if surgery duration ≥ 6 h.	
Types II, III A and III B*	*Cephazolin* 2g IV on admission 1g/8h IV for 48 h after admission	*Cephazolin* 2g IV on admission 1g/8h IV for 48 h after admission	*Vancomycin* 1 g/12 h IV administering the first dose on admission and maintaining the regime for 48 h after admission	Consider co-adjuvant treatment with antibiotic-impregnated cement (3.6 g of tobramycin to 40 g of cement) in fractures with loss of bone mass or major exposure
	Gentamycin 240 mg/24 h IV administering the first dose on admission and maintaining the regime for 48 h after admission	*Levofloxacin* 500 mg IV every 12 h in slow IV perfusion	*Gentamycin* 240 mg/24 h IV administering the first dose on admission and maintaining the regime for 48 h after admission	
Wounds contaminated by organic matter *Crushing wounds* *Type III C*	Add *penicillin G* 4,000,000 IU/4 h on admission	Replace cephazolin by *amoxicillin-clavulanic acid* 2 g IV on admission followed by amoxicillin-clavulanic acid 2 g IV every 8 h for no more than 72 h	Add *clindamycin*, 2.4-2.7 g/day IV, split into 2-4 identical doses	

*: administration of cephazolin during surgery; IV: intravenous administration.

On many occasions the initial debridement does not achieve its goal of eliminating all non-viable tissue and subsequent debridements become necessary. The ultimate goal is to obtain a limb in which all tissues are correctly vascularized.

This is a fundamental step in the debridement process. The wound must be extended to eliminate the necrotic tissue that may be found quite far from the initial skin wound. The lesional mechanism, a protruding bone fragment reduced at the scene of the accident, the examination of the limb (bruising and ecchymosis, instability in neighbouring joints), X-rays, paying attention to the presence of air at a distance from the initial wound ..., all these and other findings must be taken into account when deciding to extend the wound.

The entire limb must be prepared in open fractures and a tourniquet must be placed ready for use in the event of massive bleeding. The use of a tourniquet may end up causing necrosis of tissues that are already compromised and the absence of bleeding may prevent the distinction between healthy and necrotic tissue.

Washing is intended to reduce the microbial inoculants, eliminate extraneous material and clots but not to replace debridement. Between five and twelve litres must be used to wash a wound, although there is some discussion about whether this should be done with high or low pressure washing using a syringe[24] and the use of saline solution or else with the addition of soap or antiseptics.[25] The use of high pressure reduces contamination, particularly if the bacterial inoculant was not produced within the three hours prior to washing or there is marked contamination due to extraneous bodies. However, it also produces tissue damage that delays the wound's healing. A similar effect is produced by the addition of soap, antiseptics or antibiotics: these bring about a greater reduction in the initial bacterial load, but they also damage the cells of the body with a rebound effect, increasing the number of micro-organisms at the end of a few hours.

Most authors are conservative with regard to skin. Resection must only be applied if the skin presents a clearly necrotic appearance. Small wounds in type I and II fractures may be widened elliptically.

The fascias may be resected with the certainty that this will not produce any significant functional alteration, but it must be recalled that the perforating arteries nourishing the skin pass through the subcutaneous fascias. The paratendon constitutes the vital contribution for the tendon it contains and, if resected, the underlying tendon must be covered as soon as possible.

In muscles, the rule of the 4°C is still valid:[26] colour, consistency, contractility and the capacity to bleed. Live muscles are deep pink or red, with a firm elastic consistency, and contract when touched or stimulated with an electric scalpel and they bleed. All muscle tissue not meeting these conditions must be excised.

Experimentally,[27] Doppler laser flow meters have been used to determine whether a bone fragment maintains the circulation but we do not know of its application in open fractures. Cortical bone that has lost its insertions must always be removed and those cortical fragments presenting insertions with the ability to survive may be retained once they are clean. The conservation of fragments containing joint cartilage is advisable. Uncontaminated spongy bone may be retained after fragmentation to that it can act as a graft.

Finally, for nerves and arteries, the maximum effort must be made to preserve the nerve stems and arteries retaining their functionality.

Stabilization of open fractures

The stabilization of open fractures is fundamental and must be effected as the initial treatment along with debridement. Stabilization of the fracture limits movement at the focus, lowering the risk of dissemination of the bacteria[28] and restoring the limb's alignment. It also improves vascular flow and venous return and reduces oedema, pain and post-traumatic rigidities.[29]

In order to stabilize an open fracture, recourse has been had to external fixators, plates and intramedullary nails, with and without milling. The use of intramedullary nails in open fractures has been a source of some controversy, particularly because of the risk of producing an intramedullary infection or the possible iatrogenia by harming endosteal circulation in long bones. In an extensive review of the literature and in accordance with the authors' experience, these secondary iatrogenic effects are not significantly manifested and are more and more used in the treatment of open fractures.

External fixation in open fractures[30-32] presents good consolidation rates, close to 95%, with a long consolidation time and a high index of consolidation delays close to 25% after 6 months[30,33-35] often requiring additional surgery to achieve consolidation.

The rate of implant failures is low, but almost 70% of fractures required at least one extra reintervention to achieve consolidation. The defective consolidation index is approximately 20%, deep infections reach 16%, nail infections, 32% and chronic osteomyelitis has been established at 4%.[33,35]

In addition, with external fixation, the calluses are endosteal and not very bulky thus maintaining a risk of re-fracture when the fixator is removed. In many cases, this forces the fixator to be kept in place for a long time. Therefore, the use of external fixators as the definitive treatment in open fractures is a stabilization method entailing multiple reinterventions and complications, as well as a series of check-ups to verify progress and a prolonged treatment time.

The use of sequential intramedullary nail treatment after external fixation is a method more and more commonly used for the treatment of open fractures (fig. 1). This method is indicated in polytraumatized patients at risk of general complications[36] and in cases initially treated with an external fixator definitively transferred to other centres.[36-38]

The results in the literature[35-39] show a high consolidation index, in excess of 90%. At least one additional surgery is required in 23% of cases. The index of infections in the nails of the fixator is 15%. The time for conversion to intramedullary nails is 26 days on average and it must not be used unless

Figure 1 Grade IIIA open fracture of the tibia in the context of a polytraumatized patient. Initial direct closure and external fixation. Intramedullary nailing deferred.

the infections of the fixator pins have been resolved. The chronic osteomyelitis index is 2.5%, the lack of consolidation index was 14% and unsuccessful consolidations was 11%.

This kind of treatment was for some time proscribed due to the high complications index, especially for deep infections. There was subsequently evidence of a strong association between the infections in pins and the index of deep infections.[39] It is difficult to define the time that must elapse between the placement of the external fixator and the use of nailing, although the switch from one method to another has to be as short as possible. Where the pins present signs of infection, they must be removed, an external immobilization put in place and nailing should proceed once the signs of infection have withdrawn.

Unreamed nailing[39,40] has a consolidation index of 95%, deep infection is 7% and 33% required further reinterventions to achieve consolidation. The provision of a graft was required in 15% of cases. The chronic osteomyelitis index is low, 0.7%, with 22% of consolidation delays and 10% of unsuccessful consolidations. The use of small diameter nails is associated with a high index of implant breakages or of blocking screws (12%). Most papers comparing unreamed and reamed nails show slight advantages for reamed nails.

The milling of the intramedullary cavity has for some time been considered as a risk procedure in the treatment of open fractures due to the possibility of dissemination of germs and due to the destruction of already endangered circulation. Clinical revisions have not corroborated these risks and experimental studies have shown an increase in periosteal blood flow when milling is effected in the spinal canal.[41] In addition, the use of intramedullary nailing significantly reduces the possibility of reinterventions.[42]

The result of the treatment of open fractures using reamed nailing in the tibia,[35,43] shows a consolidations index of 97%, of which 15% required the provision of a graft. Deep infection was 6% and only 0.75% developed chronic osteomyelitis. Defective consolidations amounted to 6% and 36% required at least one reintervention to achieve consolidation. The implant failure index, 3%, was much lower than that for unreamed nails. Some authors accepting the use of reamed nailing for type II and IIIA open fractures question its use in grade IIIB-C fractures.

Keating et al.[44] found slight advantages in favour of treatment using reamed nailing. Similar results have since been found elsewhere. There are no differences in the consolidation or infection rates, but the patients treated with unreamed nailing have a higher index of breakage for the blocking screws and a slightly higher consolidation delay rate. There is no evidence allowing a recommendation of unreamed over reamed in open fractures, as the series published are short and retrospective.

In tibia and fibula fractures, the stabilization of the fibula diminishes the mobility of the fracture focus in the tibia, particularly in those cases where an external fixator is used as the stabilization method. An occasional clinical paper[45] has recommended osteosynthesis of the fibula in those fractures where the distal tibial-fibular syndesmosis is affected, even though no differences were found in terms of deviations in consolidation between the cases in which osteosynthesis of the fibula was effected and those cases in which it was not.

The authors recommend osteosynthesis of the fibula whenever the syndesmosis is affected, in cases where the synthesis of the tibia is precarious, and in definitive treatment with an external fixator, as biomechanical studies have shown that this is the stabilization method that can best benefit this kind of added synthesis.

Immobilization with a plaster cast following medullary nailing has poor results.[37] In a prospective randomized study of grade II and III open fractures, treatment with plaster of Paris following nailing presented worse results than treatment with nailing followed by an external fixator. In this sense, open fractures of the tibia treated with plaster of Paris following nailing took longer to consolidate, presented more defective consolidations, required more medical check-ups and do not have a significantly greater index of septic complications. The authors do not recommend treatment with plaster after removal of the external fixation.

The use of plates for the stabilization of open diaphyseal fractures of the tibia has been practically abandoned, although some authors have encouraged this if it is followed by good coverage of soft tissues.

Nonetheless, its use is widely accepted in fractures of the upper limb, joint fractures, proximal and distal epiphyseal-metaphyseal fractures of the tibia and distal femur fractures, especially since the emergence of blocked plate systems using less invasive techniques through smaller incisions, thus limiting the cutaneous and septic complications caused by more extensive incisions. This kind of plates present the disadvantage of a difficulty in reducing the fracture prior to the placement of the plate.

Open fractures of the femoral diaphysis

The treatment of choice for this kind of fracture is intramedullary nailing (fig. 2). The infection index is 3% and the consolidation delay index is 98%. Consolidation problems amount to 6.5%. Secondary reoperations come to 13.5% and implant failure is 1%. Reoperations are described in 17% of cases.[35]

The use of an external fixator in the treatment of open fractures of the femur has poor results, with high indices of consolidation delays and defective consolidations.

Figure 2 Grade II open fracture of the femur. Direct initial closure and intramedullary nailing.

Limitations on mobility in the knee have also been described. There are no papers demonstrating differences in results when comparing reamed nailing with undreamed.[8]

The use of an external fixator in femur fractures should be reserved for severely polytraumatized patients and vascular lesions requiring surgical treatment. When an external fixator is used, consideration should be given to the next step of intramedullary nailing as soon as the patient's general condition, the status of the wound and any vascular repairs so allow. Although there are few articles in the literature, sequential treatment in open fractures of the femur seems safer than in tibia fractures, due to the greater muscle coverage on the bone.

Coverage of soft tissues

Open fractures generally occur due to high-energy mechanisms and the harm produced is directly related to the energy dissipated in the bone and the soft tissue at the moment of the body's impact.

Lesions to soft tissues are very frequently under-estimated in the first evaluation of patients with the subsequent problems that this may produce, such as infection of the wound, defects in soft tissues, bone defects, compartmental syndrome, chronic osteomyelitis, pseudoarthrosis and even amputation.[46,47] In order to achieve acceptable results, a comprehensive clearly regulated treatment of both the bone lesions and the soft tissue is essential. Various studies have highlighted that lesions to soft tissues and their correct treatment are decisive for the consolidation of fractures and the ultimate functional outcome.[2,48,49]

Treatment of wounds and coverage of exposed bone are the cornerstones of fracture treatment, although there are no definitive criteria for treatment and many of the treatment ideas and concepts are based on studies published some time ago with low methodological quality. The recent literature reflects studies on two controversial aspects: the appropriate moment for closure or coverage of the wound and the indications for amputation of severely damaged limbs.

The various studies published within the Lower Extremity Assessment Project (LEAP) working group have shown that some of the deepest-rooted concepts about the treatment of open fractures might not be correct with the most modern treatment techniques.[19,50,51]

The different rate at which energy is dissipated through the soft tissues with respect to bone implies that the extension of a lesion in soft tissue is always much greater than the bone lesion. This phenomenon has been described as the lesion area. The anatomic region injured includes areas of tissue destruction and inflamed tissue decreasing from the point of contact, so that, during the first assessment, it is difficult to establish the true scope of the lesion. The main error in the initial phase of the treatment consists in an inadequate evaluation of the extent of the lesion and the coverage needs.[46,52,53]

The first step in the evaluation of soft tissues consists in establishing an adequate classification. The system devised by Gustilo and Anderson (table 1), despite presenting a few problems with inter-observer reliability, is simple and takes into account the most important aspects for decision-taking, the extension of soft tissue lesion and, secondarily, the degree of bone involvement and contamination. In addition, it presents an excellent correlation with infection rates.[4,54]

The most important factor for sub-dividing serious type III fractures is based on the surgeon's estimation of the need for subsequent coverage of the wound with local or free flaps.

The data published in the LEAP multi-centric prospective study after analysis of the evolution of 527 patients indicate that the state of soft tissues is the most important indicator to determine the need for amputation above the neurological or vascular lesion.[49,51] There is a special sub-group of fractures that deserve separate consideration, lesions caused by agricultural machinery and those occurring in major catastrophes, which present the added problem of direct lesions due to the crushing of soft tissues in a high contaminated setting, meaning that septic complications are more frequent in this group.[47]

Other elements to be considered in the initial evaluation are the production mechanism, co-morbidities and the patient's age. Bowen et al.[55] showed that co-morbidities such as tobacco consumption, age in excess of 80 years, diabetes or immunodeficiency multiplied the risk of complications following an open fracture by a factor of eight.

The first step for definitive coverage is to achieve a clean bed. There are multiple options for treating wounds after debridement: the placement of polymethyl methacrylate balls impregnated with antibiotic, semi-permeable sheets or vacuum aspiration systems.

Aspiration systems using negative pressure have brought about a revolution in the treatment of the wounds associated with exposed fractures. VAC-type systems seal the wound from its surroundings and produce a negative pressure to prevent the accumulation of fluids, improves micro-circulation, favours granulation and reduces bacterial proliferation, so it is an excellent co-adjuvant in the preparation of the wound for definitive coverage.[56] The use of this technique as a definitive treatment is disputed. Aspiration therapy may facilitate definitive closure in small well-vascularized areas with exposure of osteosynthesis material or bone through stimulation of abundant granulation tissue that subsequently epithelializes.

Dedmont et al.[57] found that treatment with VAC in grade IIIB fractures has similar rates for infections and consolidation compared to historic control subjects. However, it diminished the ratio of rotational flaps needed to cover the wound.

Coverage modes. The orthoplastic reconstruction ladder

There is a limited number of reconstructive procedures for covering soft tissues and these can be structured using the analogy of the "orthoplastic reconstructive surgery ladder".[47,58]

Most open fractures can be covered using simple procedures such as direct closure of the wound or free skin graft (first and second step of orthoplastic treatment). Small lesions without loss of soft tissues can be closed directly following debridement. In those lesions where there is loss of skin and fascia but the underlying soft tissue is well vascularized, the joint's function is not compromised and there are no major elements exposed such as nerves or tendons, then coverage is indicated with partial or complete free skin grafts. Most open fractures of the femur are good examples of this group.

In more complex wounds, it is necessary to consider the use of free or pediculate muscle grafts. Rotational pediculate flaps constitute the third rung of treatment (fig. 3). These flaps present greater morbidity. The use of tissues close to the fracture and the "lesion area" implies on occasions that the tissue to be used for the flap may present vascularization problems, particularly in high-energy fractures.

The last rung in orthoplastic treatment comprises vascularized free flaps, which are the treatment of choice in cases of severely injured limbs and in complex open fractures of the distal tibia and foot.

Taking decisions on the coverage of open fractures

In the conventional treatment strategy, the immediate closure of an open fracture was delayed to prevent retention of non-viable material and so prevent the onset of serous infections such as gangrene. Direct closure of the primary wound is not currently recommended as a routine measure[52,58] because better results are obtained in selected fractures at centres with sufficient experience.[17]

Figure 3 Grade IIIB open fracture of the tibia. External fixation and application of an aspiration system with negative pressure for the skin deficit. Intramedullary nailing and rotational flap for coverage.

The main advantage of primary closure is that it allows the fracture focus to be isolated from the external environment and it avoids further surgery, although there is a clear conflict with the serial debridement technique. Several studies have been published on immediate or early closure; in a study of 119 patients, DeLong et al.[59] did not find any significant difference with regard to infection rates or lack of knitting when immediate closure was applied after debridement or when the closure was deferred, providing the debridement is done aggressively. Primary closure must only be performed in type II or IIIA fractures with little contamination and moderate lesions to soft tissues.

The main goal of the treatment of open fractures consists in early closure and coverage of the wound, when necessary, in the first 10 days after admission.[52] The current paradigm for treatment in exposed fractures is the strategy of "fix and cover", implying radical debridement of the whole lesion area, bone stabilization and early coverage, which generally implies, in high-energy fractures of lower limbs, a muscle flap or a vascularized free flap.[60,61] The initial studies by Cierny and Byrd using this technique in a short series of patients achieved encouraging results.[62,63]

The most importance classic study was published by Godina et al.[64] on 534 patients, revealing that the treatment of high-energy tibia fractures using radical debridement and early coverage with vascularized free flaps within the first 72 hours had better results in terms of infection rates and pseudoarthrosis than patients in whom coverage was deferred. This treatment technique implies the need for very extensive debridement. The data have been corroborated by other studies that have shown very low infection rates with an approach based on early fixation and early coverage.

In IIIB and IIIC fractures of the tibia, Gopal et al.[61] found that the both infection and amputation rates were lower when definitive coverage was implemented in the first 72 h than when it was delayed.

The treatment strategy most often recommended at the present time is definitive coverage and bone stabilization during the first week.

The decision to use rotational muscle flaps or free flaps depends on the anatomic location of the wound, the severity of the soft-tissue lesion or the expertise of the surgical team. The LEAP group compared two coverage techniques, rotational or free flap, and found that the degree of comminution was indicative for the failure de rotational flaps, possibly reflecting the fact that more comminute fractures (AO/OTA type C) present greater damage to soft tissues and are probably not candidates for coverage with regional flaps.[65]

There is some controversy over the sequence for skeletal fixation and coverage of soft tissues. External fixation is almost always the first step in the initial bone stabilization, and there are doubts about whether definitive stabilization with an intramedullary nail in tibia fractures should be performed simultaneously with coverage or following a safe period.[66] For this reason, several treatment strategies have been established, fixation of the fracture and coverage in the same surgical act, removal of the fixator during the coverage procedure followed by posterior internal fixation when there are no signs of infection in the trajectories of the fixator's nails, or definitive treatment with external fixation.

The "fix and cover" technique would be indicated in all cases where the circumstances of the patient or of the team allow coverage to be performed during the first 72 h.

Many high-energy fractures arise in the context of polytraumatic injuries and the treatment priority in these cases is not the open fracture, which would force surgery to be delayed. In such cases, the treatment strategy involves covering the wound as soon as possible and deferring internal fixation when there are no signs of infection in the trajectories of the pins or on the edges of the wound.

The fractures with major loss of bone tissue represent an added problem. Circular external fixation associated with early coverage is a good treatment option if there is considerable diaphyseal defect. When the bone loss is less than three centimetres, consideration may be given to a shortening of the limb and internal fixation in selected cases.

Conclusions

The use of antibiotics in the initial treatment of open fractures is a well established concept; the earlier the administration of antibiotics, the greater the reduction of the possibility of infection. It is a good idea to use a cephalosporin in little-exposed fractures and to add an aminoglycoside when comminution or significant contamination is present. Adding penicillin has not been proven to reduce anaerobic infections. The prolongation of antibiotic therapy for more than 3 days provides no benefit.

The more radical the debridement, the lower the infection rate. We have no reliable method available to decide whether a devitalized bone fragment, even with insertions, can be retained and which ones must be excised.

The addition of soap, antiseptics and antibiotics initially reduces the bacterial load but it may cause a rebound effect on bacterial growth after a few hours. Washing at high pressure produces an effect similar to that of the additives, i.e. it diminishes the inoculum but, by also injuring the patient's tissues, it produces a rebound effect, so its use should be limited to highly contaminated fractures.

The fixation method of choice for open fractures of the diaphysis in lower limbs is intramedullary nailing. Where the characteristics of the fracture do not allow its placement, consideration will be given to osteosynthesis, using a plate or external fixator. If osteosynthesis with a plate is used, efforts should be made to cover it entirely with soft tissues.

The use of external fixators must be limited to cases of polytraumatic injury in which the patient's general state makes them necessary (damage-control surgery), and those where the existence of an arterial lesion requires speedy stabilization of the fracture focus. In such cases, proceeding to intramedullary nailing must take place as soon as possible.

If the debridement has been exhaustive, a better result is obtained with primary closure of the wound. The loss of soft tissue must be repaired as soon as possible, using the simplest effective system on the orthoplastic ladder: secondary closure, free graft, rotational flap, microvascularized free flap.

It is a good idea to use negative pressure aspiration systems between debridement and coverage, which can in some cases spare patients the application of a flap.

Prospective randomized studies are few in number and their conclusions are occasionally contradictory. Although some treatment regimes are clear, every open fracture is different and their treatment must therefore be adapted to each kind of fracture and to each patient.

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