Prevention of Infection in Open Fractures

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KEYWORDS

- Open fracture • Infection • Antibiotics • Debridement • Soft tissue coverage
- Fracture fixation

KEY POINTS

- Open fractures are challenging injuries and are associated with increased risk for complications, such as infection.
- The goals of open fracture management are prevention of infection, fracture union, and restoration of function.
- Management principles include careful patient and injury assessment, early administration of antibiotics, thorough surgical debridement, wound management with soft tissue coverage, and stable fracture fixation.

INTRODUCTION

Open fractures are often the result of high-energy trauma and may be associated with life-threatening injuries.[1] Open fractures are characterized by definition by soft tissue injury that results in communication of the fracture site with the outside environment and contamination of the fracture site with microorganisms or even introduction of foreign bodies into the wound.[2] Moreover, depending on the severity of injury, there is damage to the surrounding soft tissue envelope and to bone vascularity, which compromises the healing potential, as well as the response of the host defense mechanisms to contaminating microorganisms. As a result, open fractures are associated with increased risk for complications, such as infection and nonunion, and present a challenging problem to the treating physician.

The goals of open fracture management are prevention of infection, fracture union, and restoration of function. These goals are best achieved by careful patient and injury evaluation, early administration of systemic antibiotics supplemented by local delivery of antibiotics in severe injuries, thorough surgical debridement, wound management

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with soft tissue coverage if needed, and stable fracture fixation. Key principles in prevention of infection following open fractures are summarized in **Box 1**.

EVALUATION AND CLASSIFICATION
Evaluation of Patient and Extremity

Open fractures are often caused by high-energy trauma, such as motor vehicle, motorcycle, and auto versus pedestrian injuries, and may be associated with potentially life-threatening injuries to the head, chest, and abdomen.[1,3] The injury severity score of patients with open diaphyseal fractures of the femur is 18.1 on average.[1] Thorough evaluation of every patient with an open fracture is necessary to diagnose and treat associated injuries, and appropriate resuscitation measures should be initiated on presentation of the patient.

The neurovascular status of the injured extremity should be carefully assessed and documented. The size, location, and degree of gross contamination of the open fracture wound should be evaluated. The wound should be irrigated, gross contamination should be removed, and a sterile dressing should be applied. The treating surgeon should not forget that the complication of compartment syndrome may still develop, despite the presence of the open fracture wound, especially in injuries with a severe crushing component.[4] The fractured extremity should be grossly realigned and immobilized with a splint. Intravenous antibiotic therapy should be started and tetanus prophylaxis should be given depending on the patient's immunization status. Fracture characteristics, such as location, articular involvement, and comminution, should be assessed by imaging studies to plan fixation of the fracture.

Classification of Open Fractures

Open fractures vary in severity depending on the mechanism and energy of injury. Therefore, classification systems of open fractures have been developed to describe the injury, guide treatment, determine prognosis, and compare various treatment methods for research purposes. The classification system of Gustilo and Anderson, subsequently modified by Gustilo, Mendoza, and Williams, has been extensively used (**Box 2**).[5,6] Newer classification systems have also been proposed.[7]

Box 1
Key principles in prevention of infection after open fractures

- Detailed evaluation of patient for associated and potentially life-threatening injuries.
- Systemic antibiotic therapy on patient presentation.
- Intraoperative assessment of severity of injury and classification of open fracture.
- Thorough surgical debridement with removal of all devitalized tissue and foreign bodies.
- Local antibiotic delivery with the bead-pouch technique in severe injuries.
- Primary wound closure is an option for less-severe injuries if only healthy, viable tissue is present in the wound after a meticulous debridement.
- Delayed closure with second-look debridement for more severe injuries.
- Local or free muscle flaps for extensive soft tissue damage.
- Fracture stabilization with appropriate technique based on fracture, soft tissue, and patient characteristics.

Box 2
Gustilo and Anderson classification of open fractures

- Type I: Wound of 1 cm or smaller, with minimal contamination or muscle crushing.
- Type II: Wound more than 1 cm long with moderate soft tissue damage and crushing. Bone coverage is adequate and comminution is minimal.
- Type IIIA: Extensive soft tissue damage, often due to a high-energy injury with a crushing component. Massively contaminated wounds and severely comminuted or segmental fractures are included in this subtype. Bone coverage is adequate.
- Type IIIB: Extensive soft tissue damage with periosteal stripping and bone exposure, usually with severe contamination and bone comminution. Flap coverage is required.
- Type IIIC: Arterial injury requiring repair.

The severity of the open fracture determines the risk of infection, which ranges from 0% to 2% for type I open fractures, 2% to 10% for Type II, and 10% to 50% for type III fractures.[6,8]

As with all classification systems, reliability of the classification and agreement among observers remains an issue. A study evaluating the responses of orthopedic surgeons who were asked to classify open fractures of the tibia on the basis of video-taped case presentations reported that the average agreement among observers was 60%.[9]

It is important to remember that the true extent and severity of the injury cannot be accurately assessed in the emergency department. The degree of contamination and soft tissue crushing are important factors for classifying an open fracture that may be mistakenly overlooked in a wound of small size. Therefore, classification of the fracture should be done in the operating room following wound exploration and debridement.

ANTIBIOTIC ADMINISTRATION

Early antibiotic administration is a key principle of open fracture management, because most patients with open fractures have wounds contaminated with microorganisms.[5,10] Systemic antibiotics should be administered in all patients with open fractures and local antibiotics in select cases.

Role of Antibiotics in Reducing Infection

The role of antibiotics in reducing the infection rate in patients with open fractures was demonstrated by Patzakis and colleagues[10] in a prospective randomized study. The infection rate when cephalothin was administered before debridement was 2.3% (2 of 84 fractures) compared with 13.9% (11 of 79 fractures) when no antibiotics were used.[10]

Timing of Antibiotics

Early antibiotic administration is very important. Patzakis and Wilkins[8] initially reported in 1989 that a delay longer than 3 hours from injury was associated with increased risk of infection. Subsequent animal and clinical studies have corroborated these findings. Penn-Barwell and colleagues[11] used a rat femur model with a defect contaminated with Staphylococcus aureus and found that delaying antibiotics to 6 or 24 hours had a detrimental effect on the infection rate regardless of the timing of surgery. Lack and colleagues[12] in a retrospective study of 137 type III open tibia factors

demonstrated that administration of antibiotics beyond 66 minutes from injury was an independent risk factor for infection with an odds ratio of almost 4.

Choice of Antibiotics

Although the necessity of antibiotics has been definitively established, there is no consensus on the optimal choice of agents and specifically on the necessity of gram-negative coverage, especially for less-severe injuries.

In severe (type III) open fractures there is wide agreement that gram-positive and gram-negative coverage is needed and this is usually provided by a first-generation cephalosporin, such as cefazolin, and by an aminoglycoside, such as gentamicin.[8,13–16] However, others have advocated against aminoglycoside use and gram-negative coverage.[17]

In less-severe (type I and II) open fractures some investigators have recommended coverage only for gram-positive organisms with administration of a cephalosporin.[13–15] In contrast, combined gram-positive and gram-negative coverage for these less-severe open fractures has been proposed by other investigators to provide coverage against contaminating gram-negative organisms.[8,16]

Patzakis and Wilkins[8] reported that combination therapy in open tibia fractures reduced the infection rate (4.5%, 5 of 109) compared with cephalosporin only (13%, 25 of 192). This study did not analyze type I and II open fractures separately but the distribution of fracture types was comparable between the 2 groups that received combination therapy versus cephalosporin only.

It is important to remember that the severity of injury will be better appreciated in the operating room following wound exploration and debridement and an open fracture may be misclassified in the emergency department. As a result, a type IIIA open fracture with a wound of small size may be misclassified as type I or II open fracture and treated with cephalosporin only. Interestingly, a study of 189 patients with 202 open fractures, most of which were treated without gram-negative coverage, reported that gram-negative organisms were isolated in in 55% of the infections that developed during follow-up.[18]

The potential nephrotoxicity of aminoglycosides is a concern that may explain the reluctance to administer aminoglycosides in the setting of open fractures. A recent study evaluated patients with open fractures who were treated either with cefazolin (n = 41) or with cefazolin and gentamicin (n = 113).[19] Baseline characteristics and risk factors for renal dysfunction did not vary between groups. There was no difference in the development of acute kidney injury (4.8% in patients receiving cefazolin vs 4% patients receiving cefazolin and gentamicin).[19] This may be, in part, due to the short duration of aminoglycosides used.

Quinolones have been proposed as an oral alternative to intravenous antibiotics, based on their broad-spectrum antimicrobial coverage, bactericidal properties, oral administration, and good tolerance. A randomized prospective study showed that ciprofloxacin as a single agent in type I and II open fractures resulted in a similar infection rate (6%) compared with combination therapy with cefamandole and gentamicin.[20] However, in type III open fractures, ciprofloxacin was associated with a higher infection rate of 31% compared with 7.7% in the combination therapy group. Moreover, quinolones have been associated with inhibition of osteoblasts.[21] Quinolones are excellent agents against gram-negative pathogens and are considered an alternative when aminoglycosides cannot be used.

A recent study compared use of piperacillin/tazobactam versus cefazolin plus gentamicin for antibiotic prophylaxis in patients with type 3 open fractures and found similar rates of surgical site infections at 1 year (31.4% vs 32.4%, respectively).[22]

Piperacillin/tazobactam has a spectrum of activity similar to that of a cephalosporin plus an aminoglycoside, but its advantages include administration of a single agent and coverage against anaerobes in cases of fecal or clostridial contamination that may occur with farm-related injuries.

Anaerobic coverage (eg, penicillin, clindamycin, or metronidazole) should be added in injuries with potential contamination with clostridial organisms (eg, farm injuries) and in vascular injuries that can create conditions of ischemia and low oxygen tension. The goal is to prevent clostridial myonecrosis (gas gangrene). However, prevention of this catastrophic and life-threatening complication is primarily based on thorough surgical debridement. Antibiotic therapy is not a substitute for inadequate debridement.

Antimicrobial resistance in bacteria has been emerging and infections due to methicillin-resistant *S aureus* (MRSA), multidrug-resistant gram-negative bacilli, and vancomycin-resistant *Enterococci* are progressively increasing. This creates concerns about the adequacy of current antibiotic protocols, especially against MRSA. On the other hand, expanded prophylactic coverage with vancomycin may facilitate the emergence of glycopeptide-resistant organisms. A randomized controlled trial compared administration of a combination of vancomycin and cefazolin to administration of only cefazolin in 101 patients with open fractures and found no difference in the infection rates between the group receiving vancomycin and cefazolin (19%) versus the group receiving only cefazolin (15%).[23] As a result, the routine use of vancomycin in open fractures cannot be recommended based on available data. Antibiotic choices are summarized in **Table 1**.

The Role of Wound Cultures

Wound cultures obtained at patient presentation or intraoperatively do not help select the optimal antibiotic regimen, because they fail to identify the organism causing a subsequent infection in most cases.[24,25] Only 18% (3 of 17) of infections that developed in a series of 171 open fractures were caused by an organism identified by perioperative cultures.[20] Another study reported that predebridement cultures identified the infecting organism only 22% of the time and postdebridement cultures 42% of

Table 1		
Choice of antibiotics in open fractures		
Severity of Open Fracture	**Proposed Coverage**	**Antibiotic Options**
Type I, II	• Gram-positive organisms (some investigators) OR • Gram-positive and gram-negative organisms (some investigators)	• Cephalosporin (1st generation) OR • Cephalosporin (1st generation) and aminoglycoside (quinolone as alternative for gram-negative coverage)
Type III	• Gram-positive and gram-negative organisms (some investigators)	• Cephalosporin (1st generation) and aminoglycoside (quinolone as alternative for gram-negative coverage) OR • Piperacillin/tazobactam
Potential contamination with clostridial organisms OR vascular injuries	• Additional coverage for anaerobic organisms	• Penicillin OR clindamycin OR metronidazole

the time.[25] Postdebridement cultures would be preferable to predebridement cultures to select the best agents in the case of an early infection, but their accuracy is still suboptimal. In most cases, infections are not caused by the organisms initially present in the wound but by nosocomial organisms that subsequently contaminate the wound.

Duration of Systemic Antibiotic Therapy

The optimal length of antibiotic therapy remains controversial. The recommended duration of antibiotic therapy is 3 days,[8,15] although a study comparing 1 day to 5 days of antibiotics reported similar infection rates and suggested that 1 day of antibiotics may be an option.[26] An additional 3-day administration of antibiotics is recommended for subsequent surgical procedures, such as repeat debridement and wound coverage.[8,15]

Local Antibiotic Therapy

Local delivery of antibiotic therapy used as an adjunct to systemic antibiotic therapy in the treatment of open fractures.[27] A commonly used delivery vehicle is polymethylmethacrylate (PMMA) cement, which can be manually molded by the surgeon to bead-resembling spheres with a diameter ranging from 5 to 10 mm or to spacer blocks of larger size. Bioabsorbable delivery vehicles, such as calcium sulfate, appear to be a promising alternative in clinical studies.[28] In a rat model of a contaminated bone defect, a bioabsorbable phospholipid gel resulted in lower infection rate compared with PMMA beads.[29]

An antibiotic appropriate for local delivery must be available in powder form because antibiotics in aqueous solution inhibit the polymerization process, must be heat stable to withstand the temperatures generated during the exothermic polymerization reaction, and should be active against the targeted microorganisms. Several antibiotics, including aminoglycosides, vancomycin, and cephalosporins, can be successfully incorporated into PMMA cement for local delivery. In open fractures, aminoglycosides are commonly used due to their broad spectrum of activity, heat stability, and low allergenicity.

The process of release of antibiotic from the delivery vehicle to the surrounding tissues is called elution. The difference in concentration of antibiotics between the delivery system and its environment is the key factor determining elution. Elution is facilitated by an increased surface-area–to-volume ratio of the delivery vehicle,[30] and by a high concentration of antibiotic in the beads or spacer.[31] The type of antibiotic plays a role and tobramycin has superior elution properties when compared with vancomycin.[32] A fluid medium is necessary for elution of antibiotics and the rate of fluid turnover influences the local antibiotic concentration. Elution of antibiotics from PMMA beads follows a biphasic pattern, with an initial rapid phase and a secondary slow phase.[33]

Antibiotic-impregnated PMMA beads are commercially available in Europe, but no similar product has been approved by the Food and Drug Administration for use in the United States. The delivery system has to be prepared in the operating room by the surgeon immediately before use. The PMMA powder is mixed with the antibiotic in powder form, is polymerized, and then formed into beads, which are incorporated on a 24-gauge wire. Usually 3.6 g of tobramycin are mixed with 40 g of PMMA cement. Antibiotic-impregnated PMMA beads are inserted in the open fracture wound, which is subsequently sealed by a semipermeable barrier so that the eluted antibiotic remains at the involved area to achieve a high local concentration.

The bead-pouch technique has unique advantages. First, it maintains antibiotics within the wound and achieves a high local concentration of antibiotics.[34] Second,

the systemic concentration remains low, thus minimizing the adverse effects of amino-glycosides. The sealing of the wound from the external environment by the semiper-meable barrier prevents secondary contamination by nosocomial pathogens and may safely extend the period for soft tissue transfers. At the same time, the semiper-meable barrier establishes an aerobic wound environment, which is important for avoiding catastrophic anaerobic infections. Finally, it promotes patient comfort by avoiding painful dressing changes.

The antibiotic bead-pouch technique has been shown to reduce the infection rate when used in addition to systemic antibiotics for management of open fractures. Ostermann and colleagues[35] compared systemic antibiotics alone with combined treatment with both systemic antibiotics and the bead-pouch technique in a series of 1085 open fractures. The infection rate was considerably lower in the antibiotic bead-pouch group (3.7% [31 of 845 fractures] vs 12% [29 of 240 fractures]) but the reduction of infection was statistically significant in type III fractures only (6.5% for the antibiotic bead pouch vs 20.6% for systemic antibiotics alone).[35] A systematic re-view reported that the absolute rate of infection was lower for all types of open tibia fractures treated with intramedullary nailing when local antibiotics were administered in addition to systemic antibiotics.[36]

DEBRIDEMENT AND IRRIGATION
Debridement

Thorough surgical debridement plays a critical role in the management of open frac-tures.[37,38] Devitalized tissue and foreign material promote the growth of microorgan-isms, constitute a barrier for the host's defense mechanisms, and should be removed. Debridement should be performed in the operating room. Surgical extension of the wound allows assessment of the degree of soft tissue damage and contamination. Skin and subcutaneous tissue are sharply debrided back to bleeding edges. Muscle is debrided until bleeding is visualized. Viable muscle can be identified by its bleeding, color, and contractility. Bone fragments without soft tissue attachments are avascular and should be discarded. Articular fragments, however, should be preserved even if they have no attached blood supply, provided they are large enough and the surgeon believes reconstruction of the involved joint is possible. A repeat debridement can be performed after 24 to 48 hours based on the degree of contamination and soft tissue damage. The goal is a clean wound with viable tissues and no infection. In injuries requiring flap coverage, debridement should be also repeated at the time of the soft tissue procedure.

Timing of Debridement

Traditional concerns that delays in surgical management beyond 6 hours would lead to increased infection rates have not been substantiated in the literature.[8,39–43] Patza-kis and Wilkins[8] reported in 1989 that the infection rate was similar in open fracture wounds debrided within 12 hours from injury (6.8%, 27 of 396) and in those debrided after 12 hours from injury (7.1%, 50 of 708) and concluded that elapsed time from injury to debridement is not a critical factor for development of infection in patients receiving antibiotic therapy.

Pollak and colleagues[40] and the LEAP study group found no relationship between time to surgical debridement and infection in 307 patients with severe open lower ex-tremity fractures. The infection rate was 28%, 29%, and 26% in patients who under-went debridement earlier than 5 hours, 5 to 10 hours, and more than 10 hours from injury, respectively. Weber and colleagues,[43] in a prospective cohort study of 736

patients with open fractures, found no association between development of deep infection and time to debridement. In multivariate analysis, the only factors associated with infection were the severity (type III vs type I) and anatomic location (tibia vs upper extremity) of the fracture.

Although bacterial populations in an untreated contaminated wound increase over time, it appears that early antibiotic administration and thorough surgical debridement can effectively reduce the contamination present. As a result, small delays in surgical management do not appear to translate in increased infection rates and may allow for stabilization and resuscitation of the patient, as well as for treatment of the patient by experienced surgical teams with all necessary equipment available.

Irrigation

Irrigation mechanically removes foreign bodies and reduces the bacterial concentration.

Antiseptic solutions may be toxic to host cells and are better avoided.[44] A study comparing bacitracin solution to nonsterile castile soap solution for irrigation of open fractures found no difference in infection and nonunion rates, but an increased rate of wound-healing problems with bacitracin.[45] Irrigation with normal saline was not evaluated in this study.

High-pressure pulsatile lavage is more effective than low-pressure lavage in removing adherent bacteria if more than 6 hours have elapsed since the injury,[46] but it has been associated in experimental studies with bacterial seeding into the intra-medullary canal,[46] with increased wound bacterial counts at 48 hours after irrigation,[47] and with adverse effects on early new bone formation.[48]

A recent randomized controlled trial of 2447 patients with open fractures compared the effects of different irrigation solutions (castile soap vs normal saline) and irrigation pressures (high pressure vs low pressure vs very low pressure) on the reoperation rate within 12 months from after the index surgery.[49] Irrigation with saline was associated with a significantly higher reoperation rate compared with castile soap (14.8% vs 11.6%). The reoperation rates were similar regardless of irrigation pressure, indicating that very low pressure (gravity) is an acceptable low-cost alternative method of irrigation.[49]

The author of the current article recommends irrigating the wound with 9 L of saline by gravity tubing.

WOUND MANAGEMENT
Wound Closure

The optimal time for wound closure remains controversial.[50] Primary wound closure generates concerns for potential development of the catastrophic complication of gas gangrene (clostridial myonecrosis) that may lead to loss of the limb or even death of the patient.[51] However, gas gangrene has mostly complicated military wounds with severe tissue injury, gross contamination, and inadequate antibiotic therapy or debridement.

Clinical studies of civilian injuries have not shown an increased infection rate following primary closure,[8,52–54] and suggested that primary closure may prevent secondary contamination and reduce surgical morbidity, hospital stay, and cost.[52,53] Patzakis and Wilkins[8] reported in 1989 that primary closure did not result in increased infection rate. Specifically, infection complicated 10.6% of wounds closed primarily compared with 13.4% of wounds closed with a delay.[8]

Primary closure of open fracture wounds is a viable option in carefully selected cases, provided there is no severe tissue damage and contamination, especially

with soil or fecal matter, early administration of antibiotics has taken place, a meticulous debridement has been executed by an experienced surgeon, and the wound edges can be approximated without tension.

Partial wound closure is another option for less-severe injuries.[55] The surgical extension of the wound, created to assess the bone and soft tissues and facilitate debridement, can be closed primarily in type I and II open fractures, leaving only the injury wound open, to be closed in delayed fashion.

Delayed wound closure prevents anaerobic conditions in the wound, permits drainage, allows for repeat debridement at 24 to 48 hours, gives time to tissues of questionable viability to declare themselves, and facilitates use of the antibiotic bead-pouch technique. Delayed wound closure is recommended in injuries with extensive soft tissue damage and gross contamination, in patients presenting with a considerable delay, in wounds with tissues of questionable viability at the end of the debridement, and in wounds that cannot be approximated without tension.

If there is any doubt about the viability of the tissues and/or the adequacy of the debridement, the wound should not be closed primarily and a second-look debridement should be undertaken with the plan to perform delayed wound closure or a soft tissue coverage procedure, depending on the status of the soft tissue envelope.

In cases of delayed wound coverage, the wound should not be left exposed to the outside environment to prevent contamination with nosocomial pathogens. Instead, the antibiotic bead-pouch technique,[35] or negative-pressure wound therapy,[56] should be used.

Soft Tissue Reconstruction

When extensive damage to the soft tissues is present, as in type IIIB open fractures, adequate coverage may not be possible and soft tissue reconstruction is required. A well-vascularized soft tissue envelope promotes fracture healing, delivery of antibiotics, and action of the host defense mechanisms. It provides durable coverage, which prevents secondary contamination of the wound and desiccation of exposed anatomic structures, such as bone, cartilage, and tendons. The selection of coverage depends on the location and magnitude of the soft tissue defect.[57,58]

Soft tissue reconstruction is achieved with local or free tissue transfers. A microvascular surgeon should evaluate an open fracture with extensive soft tissue damage and participate in its management. Local pedicle muscle flaps include the gastrocnemius for proximal third tibia fractures and the soleus for middle third fractures. In distal third tibia fractures, free muscle flaps, such as the latissimus dorsi, the rectus abdominis, and the gracilis muscle, are necessary.[57,58] Free muscle flaps may be considered even in more proximally located fractures. Local muscles usually participate in the zone of injury; thus, their viability may be compromised. Pollak and colleagues[58] concluded that use of a free flap in limbs with a severe osseous injury was associated with fewer wound complications necessitating operative treatment compared with a rotational flap.

Soft tissue reconstruction should be performed early, within the first week from injury, because delays have been associated with increased flap and infectious complications.[12,24,59,60] Godina[60] advocated flap coverage within 72 hours. Gopal and colleagues[57] also used an early aggressive protocol in type IIIB and IIIC open fractures and observed deep infection in 6% (4/63) of fractures that were covered within 72 hours, compared with 29% (6/21) in fractures covered beyond 72 hours. It should be noted that in these studies the antibiotic bead pouch was not used, and therefore secondary contamination may have been an important confounding factor contributing to infectious complications.

FRACTURE FIXATION

Stabilization of the open fracture is an important part of management. Stability at the fracture site prevents further injury to the soft tissues, and enhances the host response to contaminating organisms.[61] In addition, fracture stability facilitates wound and patient care, and allows early motion and functional rehabilitation of the extremity. Fracture stabilization can be definitive or provisional and can be accomplished with intramedullary nailing, plate and screw fixation, or external fixation. Selection among these options depends on careful evaluation of fracture, soft tissue, and patient characteristics.[16] More than one method may be applicable to a specific injury and the surgeon's expertise and availability of implants should also be taken into account.

Intramedullary nailing is an effective method of stabilization of diaphyseal fractures of the lower extremity.[62,63] Statically interlocked intramedullary nailing maintains length and alignment of the fracture bone, is biomechanically superior to other methods, and does not interfere with soft tissue management. However, cortical circulation is disrupted to a variable degree, especially when reaming of the medullary canal takes place.[64] An animal study showed that, despite the adverse effect of reaming on endosteal perfusion, perfusion of callus and early strength of union were similar following intramedullary nailing with or without reaming.[65]

Plate and screw fixation is useful in intra-articular and metaphyseal fractures because it allows anatomic reduction and restoration of joint congruency.[66,67] Plate and screw fixation is recommended for open diaphyseal fractures of the forearm and humerus unless there is severe muscle damage and contamination.[68]

External fixation can be applied in a technically easy, safe, and expedient way, with minimal blood loss. For this reason, it can be beneficial in damage-control situations, such as type IIIC open fractures and unstable polytrauma patients.[69] External fixation preserves the vascularity of the fracture site and avoids implant insertion at the zone of injury. Therefore, it may be useful in wounds with severe soft tissue damage and gross contamination, as in type IIIB open fractures.[70,71] External fixation also can be useful as provisional joint-spanning fixation in open periarticular fractures followed by definitive fixation at a second stage.[72]

SUMMARY

Open fractures are challenging, often high-energy injuries that require a principle-based approach that starts with detailed evaluation of the patient for associated and potentially life-threatening injuries. The severity of the open fracture is best assessed intraoperatively and is an important factor in determining the rate of complications, such as infection and nonunion.

Systemic antibiotic therapy should be initiated on patient presentation. Local antibiotic delivery with the bead-pouch technique is beneficial in severe injuries.

Thorough surgical debridement with removal of all devitalized tissue and foreign bodies is critical for prevention of infection.

Primary wound closure is an option for less-severe injuries if only healthy, viable tissue is present in the wound after a meticulous debridement performed by an experienced surgeon. Delayed closure with a second-look debridement is recommended for more severe injuries. In the presence of extensive soft tissue damage, local or free muscle flaps should be transferred to achieve coverage. The open fracture should be stabilized using one of the available options based on fracture, soft tissue, and patient characteristics, and on surgeon's expertise. A management plan guided by the previously discussed principles will help prevent infection in these challenging injuries.

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