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Open fractures: evidence-based best practices

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Abstract Open fracture management is a common challenge to orthopaedic trauma surgeons and a burdensome condition to the patient, health care, and entire society. Fracture-related infection (FRI) is the leading morbid complication to avoid during open fracture management because it leads to sepsis, nonunion, limb loss, and overall very poor region-specific and general functional outcomes. This review, based on a symposium presented at the 2022 OTA International Trauma Care Forum, provides a practical and evidence-based summary on key strategies to prevent FRI in open fractures, which can be grouped as optimizing host factors, antimicrobial prophylaxis, surgical site management (skin preparation, debridement, and wound irrigation), provision of skeletal stability, and soft-tissue coverage. When it is applicable, strategies are differentiated between optimal resource and resource-limited settings.

Keywords: fracture, open fracture, tibia fracture, infection, fracture-related infection, antibiotic prophylaxis, irrigation and debridement, fracture fixation, soft-tissue defect, soft-tissue coverage

1. Prevention of Fracture-Related Infection

Prevention of fracture-related infection (FRI) is a crucial aspect of managing patients with musculoskeletal trauma. A multidisciplinary approach can provide a comprehensive care plan that includes several preventive measures to reduce the risk of infection. These measures include host optimization, appropriate antibiotic prophylaxis, surgical site preparation, provision of skeletal stability, and soft-tissue coverage.

Fracture-related infection is a severe complication that can occur after fracture fixation surgery with open reduction and internal fixation or intramedullary nail (IMN) fixation procedures.[1] The presence of metal implants such as screws, IMNs, and plates, along with other risk factors such as wound contamination from open fractures and medically compromised host status, can create a favorable environment for bacterial colonization, potentially leading to FRI. In this summary, we will discuss the prevention of FRI, including risk factors, prophylactic antibiotics, and surgical techniques.

Common host-related risk factors of FRI include diabetes, peripheral vascular disease, smoking, malnutrition, obesity, and immunosuppression.[2] Patients with these risk factors should be identified and given special attention during the preoperative and postoperative period to improve modifiable factors such as nutrition, smoking, and blood glucose concentration.[3] Nasal decolonization of staphylococcus aureus carriers (using intranasal mupirocin ointment, with or without chlorhexidine soap body wash) before orthopaedic procedures is recommended by the WHO to reduce infection in elective and traumatic surgical cases.[4]

tProphylactic antibiotics are an essential part of preventing FRI. A FRI consensus group recommends prophylactic antibiotics before surgery for patients undergoing open reduction and internal fixation of open or closed fractures.[1] Antibiotics should be given within 60 minutes before surgery and continued for up to 24 hours after surgery. The choice of antibiotics should be based on the type of bacterium most commonly associated with FRI. *Staphylococcus aureus* and coagulase-negative staphylococci are the most common pathogens found in FRI. Therefore, antibiotics with activity against these organisms, such as cefazolin, are recommended. Higher grade (Type 3) open fractures may benefit from expanding coverage to gram-negative organisms for a short time. Local antibiotics have also been successful in decreasing infection in high-energy fractures and open fractures.[5,6] In severe open fractures, definitive soft-tissue coverage should occur as close to the time of fracture fixation as possible and ideally within 48 hours of fixation.[7]

Surgical techniques also play a role in preventing FRI. The surgical field should be prepared with antiseptic solutions. Iodophor versus chlorhexidine solutions have similar infection rates.[8] Devitalized tissue should be removed during debridement, and vital tissue should not be traumatized.[9] Patient normothermia is important because hypothermia can impair immune

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function and delay wound healing. The United States Centers for Disease Control and Prevention recommends the use of aqueous iodophor solutions for intraoperative irrigation of deep or subcutaneous tissues.[10]

The use of negative-pressure wound therapy (NPWT) is also an effective technique for managing open wounds. NPWT creates a closed system that removes exudate from the wound and can decrease bacterial counts, promoting a more sterile wound environment.[11] Local antibacterial substances and antibiotics further decrease bacterial counts with NPWT.[11] Wound closure with staples or suture does not affect infection rate, but the WHO does recommend use of triclosan-impregnated suture.[12,13] Drains do not seem to affect infection risk.[14] Wounds epithelialized in approximately 48 hours and dressing removal at 48 hours or longer were also not associated with infection risk.[15] Similarly, early or delayed showering also did not affect infection risk.[16]

2. Irrigation Fluids in Open Fracture Management

Irrigation and debridement of open fracture wounds represents another important modifiable variable that can affect outcomes in these injuries. There is little debate over the need to irrigate open fractures to remove gross contamination and debris from the zone of injury, but until recently, controversy remained regarding the choice of fluid and potential additives to be used for irrigation. Furthermore, there has been a lack of consensus regarding the optimal timing of debridement and irrigation. The FLOW study contributed significantly to our understanding of open fracture management by offering insights into the choice of open fracture irrigation fluids to minimize complications.[17]

Traditionally, normal saline solution has been the gold standard for irrigation. However, controversy persisted regarding the need for additional additives such as soaps/detergents, antibiotics, and metal ions. In addition, there was no consensus regarding the optimal pressure for effectively removing debris. The FLOW study contributed to this gap in the literature by comparing castile soap and saline solutions at 3 different irrigation pressures (high, low, and very low) in a large-scale randomized controlled trial with a 2 × 3 factorial design.[17] The trial was conducted across 41 centers worldwide, enrolling patients with open extremity fractures who were randomly assigned to irrigation pressures and solutions. The primary end point was reoperation within 12 months after the initial surgery, for either wound or bone healing complications or wound infections. There were 2447 patients included in the final analysis, with reoperation rates remaining consistent across the 3 irrigation pressure groups (high, low, and very low). However, with respect to the choice of irrigation solution, there were significantly higher reoperation rates in the castile soap group relative to the normal saline group, which challenged conventional wisdom and was contrary to previous experimental studies. Given the study's rigorous methodology, broad inclusion criteria, and focus on clinically relevant outcomes, the FLOW trial represented a major contribution toward identifying the most optimal irrigation fluid for open fracture treatment. Further large-scale studies investigating other irrigation additives such as silver ions are underway.

The FLOW trial also served to explore the relationship between the timing of surgical irrigation and debridement and subsequent deep infections or healing complications in open extremity fracture treatment.[18] Historically, early debridement and irrigation within 6 hours of injury had been the standard of care, although the evidence for that recommendation was limited. A secondary analysis of data from the FLOW trial used a propensity score-matching algorithm to adjust for patient and injury characteristics when analyzing the relationship between timing to surgical debridement and outcomes. This adjustment was necessary to account for the fact that, although more severe open fractures tend to be taken to surgery earlier than lower energy fractures, severe open fractures are also associated with increased reoperation risk and other adverse outcomes. The results of the propensity score-matched algorithm demonstrated no significant difference in reoperation rates between the early and late debridement groups. This study added meaningfully to a growing body of evidence that has served to disprove the so-called six-hour rule that suggested more urgent debridement of open fractures. As a result, rather than being held to a strict and arbitrary time frame, clinicians can make decisions regarding timing to open fracture debridement based on a comprehensive assessment of the patient, including resuscitation status, associated injuries, and operating room availability.

3. Fixation Strategies in Open Fractures

The optimal fixation strategy for open fractures remains controversial. This is in part due to a paradox whereby implants may be both beneficial and harmful in the prevention of fracture-related infection. The argument against internal implants is that hardware may provide a substrate for bacterial colonization and development of biofilm that may be detrimental in the context of an open fracture.[19] By contrast, the argument for internal hardware is that the stability provided by rigid implants is beneficial in reducing the risk of infection in fracture treatment. Worlock et al[20] demonstrated a 50% reduction in the risk of infection comparing stable and unstable fixation in a rabbit model of open tibial fracture. The benefit of fracture stability, coupled with other benefits of internal fixation such as earlier mobilization, better maintenance of reduction, and higher union rates, has led to a gradual transition toward early definitive internal fixation for most open fractures, particularly in high-income settings.[21] Nonetheless, there are several potential advantages to external fixation as a temporary or definitive construct. First, external fixation is a relatively simple procedure that can be effectively used quickly, particularly in polytrauma or damage control settings. In high-energy injuries, avoiding placement of hardware in the zone of injury may be beneficial in reducing the risk of infection. Second, external fixators may have cost advantages, particularly in lower resource contexts where the same implant is frequently reused for multiple patients.[22]

Broadly, there are 3 primary fixation strategies in the management of open fractures:

1. Definitive external fixation, which can be uniplanar or multiplanar.
2. Temporary external fixation followed by staged internal fixation.
3. Definitive internal fixation in a single stage.

The decision between these 3 options depends on both injury factors and resource availability. In high-income countries, there is consensus that most Gustilo type 1, 2, and 3A open fractures can be managed with definitive internal fixation in a single stage. There does remain controversy, however, in low and middle-income countries, where delays in presentation are common and resources required for internal fixation are less available. In addition, staging treatment with external followed by internal fixation is cost-prohibitive in many cases, forcing surgeons to choose definitive treatment as the index procedure. Haonga et al[23] published a randomized controlled trial comparing locked intramedullary nailing and uniplanar external fixation that enrolled 240 patients in Tanzania with Gustilo type 1 to 3A open tibial fractures presenting within 24 hours. The authors found no statistically significant difference in the primary outcome of reoperation for infection or nonunion, but secondary outcomes favored intramedullary nailing. Specifically, quality of life was higher at early time points, radiographic healing was faster, and the rate of severe malunion was lower. Comminuted fractures treated with external fixation were at particularly high risk of loss of alignment and nonunion. In addition, because return to work was faster, the direct costs of intramedullary nailing were outweighed by the greater societal costs from lost work among patients treated with definitive external fixation.[22]

In high-income countries, definitive treatment with internal fixation is well accepted for most open fractures and the use of uniplanar external fixators as definitive treatment has fallen out of favor.[21] However, ring external fixation may still have a role in more severe type 3A and 3B open injuries. The METRC group recently published the FIXIT trial, a multicenter study of 260 patients from 20 US trauma centers with "severe" type 3A and 3B open tibial fractures randomized to either ring fixation or intramedullary nailing as definitive treatment.[24] The study found no difference in deep infection or nonunion between groups, but there was a significantly higher rate of complications including pin track infection and loss of reduction in the ring fixator group. Notably, most of the patients in the FIXIT trial were treated initially with a temporary uniplanar external fixator before transitioning to the assigned definitive treatment strategy. The indications for staged treatment before definitive fixation include severe soft-tissue injury (eg, Gustilo type 3B), vascular injury (Gustilo Type 3C), damage control, and periarticular injuries. In Type 3B open injuries, staging is important to reduce the time between definitive fixation and flap coverage, which is a key factor in reducing the risk of infection.[25]

4. Soft-Tissue Coverage for Orthopaedic Surgeons

Open fractures that require flap coverage are a major challenge faced by orthopaedic surgeons. Most orthopaedic surgeons are facile with temporizing procedures such as external fixation, antibiotic bead pouches, and use of negative-pressure wound therapy.[26–29] Since the seminal article by Godina, most literature confirms that early definitive coverage, preferably with 3 to 5 days of injury, reduces the risk of deep infection and nonunion.[30–35] The concept of orthoplastic team has evolved from these studies.[34,36] Unfortunately, an orthoplastic team is not available in many hospitals. This can lead to delayed coverage, even when the patient is transferred to a center with these resources, and increases the risk of infection.

The importance of debridement cannot be overestimated.[37] All necrotic tissue and foreign bodies must be removed, regardless of how the wound may be covered later. The surgeon should perform repeated debridement until all nonviable tissues have been removed. The remaining viable tissue will serve to support any coverage, which is applied to the residual wound.

The use of negative-pressure wound therapy in open fractures is common. However, it has not been shown to dramatically change the requirement for definitive coverage.[38–40] It may decrease the complexity of the procedure required to cover a wound and may reduce the incidence of infection when coverage is delayed until 7 days, but this should not be viewed as an alternative to coverage.

There are many soft-tissue techniques which can be easily learned and do not require microsurgical skill availability. These techniques include skin grafting with or without skin graft substitute, rotational muscle flaps, local flaps, and fasciocutaneous flaps. There is currently an abundance of literature and instructional videos which can be used to learn these techniques. There appears to be no difference between these simpler flaps and free flaps when indications are met.[41,42]

4.1. Split-Thickness Skin Graft

Split-thickness skin grafts (STSGs) are indicated when a wound has a vascular bed. In general, STSG should not be placed over bone without periosteum or hardware. In the case of exposed tendon without peritenon or exposed bone without periosteum, artery, or nerve, STSG may be applied after an intermediate treatment with a skin scaffold. These scaffolds, often made of denatured collagen, may be left in place for 3 weeks to allow adequate vascularization before definitive skin graft.

4.2. Rotational Muscle Flaps

Rotational muscle flaps are commonly used to cover soft-tissue wounds from the knee to the mid-distal tibia. The gastrocnemius and soleus flaps are the most commonly used in the lower extremity. For both the gastrocnemius and soleus flaps, the lateral head of the muscle is more difficult to rotate because the muscle must be rotated around the fibula. However, either head or both heads may be used. Likewise, both a gastrocnemius and soleus flap may be combined as long as the other head remains intact. When planning for coverage using either of these muscles, the surgeon should carefully evaluate the muscle whenever possible during the first debridement to assess damage to the muscle or its blood supply.

The gastrocnemius flap can cover wounds from the superior margin of the patella to the proximal-mid tibia. Blood supply to the gastrocnemius is from a single vascular pedicle to each head arising proximal to the knee joint from the medial and lateral sural arteries or direct branches from the popliteal artery.

The soleus flap can reliably cover from the inferior portion of the tibial tubercle to the junction of the mid-distal tibia. Blood supply to the soleus is from 2 major vascular pedicles and multiple accessory arteries. The proximal branch arises from the popliteal artery, and the distal branch may arise from the peroneal artery or from the posterior tibial artery.

4.3. Axial/Random Pattern Flaps

Many types of flaps that are based on skin perforating arteries have been described.[43] These may be simply rotated into the defect or may be elevated on a vascular pedicle and rotated into position. Axial pattern flaps are based on angiosomes, with the skin perforator supplying blood to the flap. Random pattern flaps are based on the subdermal plexus rather than on a specific perforator. When the flap is separated completely from the underlying tissue and rotated on a vascular perforator, it is known as a pedicled perforator flap. These flaps can cover small, longitudinal defects over the distal leg and upper extremity.

4.4. Fasciocutaneous Flaps

The reverse sural artery flap is used to cover wounds of the lower third of the leg.[44,45] The flap is based on the most distal perforator from the sural artery, which is located 4 cm above the tip of the lateral malleolus and 2 cm posterior to the fibula. Easily performed, once learned, it can cover wounds as large as 15 × 7 cm. It is ideal for coverage of transverse wounds.

5. Conclusion

Timely administration of prophylactic antibiotics is one of the few pragmatic, evidence-based strategies to minimize the prevalence of FRI in open fractures. Other treatment factors are more difficult to standardize in such an objective fashion but timely thorough debridement and restoration of skeletal stability with expeditious soft-tissue coverage are essential steps, all completed preferably within 72 hours of injury. Local antibiotic administration with different delivery techniques, specifics of wound irrigation, and use of negative-pressure wound therapy are likely to have an important but less well-defined evidence-based role in open fracture management.

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