Acute Management of Open Fractures: Proposal of a New Multidisciplinary Algorithm

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Abstract: Despite the frequency of open fractures, their management remains one of the greatest and most debated orthopedic challenges. The current challenges that health care faces financially and clinically offer an opportunity to develop a universal reliable, reproducible, evidence-based protocol. The authors review the current evidence concerning the acute management of open fractures and suggest a modern treatment algorithm.

The acute management of open fractures has long been a topic of debate and controversy among orthopedic surgeons. Complications associated with incomplete or inappropriate treatment carry significant consequences for the patient and treating surgeon. The acute treatment of these injuries has been based on the Gustilo and Anderson classification and on classic articles that are several decades old. Since then, the epidemiology of bacteria has changed, and little has been done to adapt our practice. The Orthopedic Trauma Association has been working on a new classification scheme for open fractures that is currently being validated. This scheme aims to classify open fractures during the debridement process based on muscle, bone, soft tissue, and vascular injury and has been designed to aid in predicting the outcome and treatment based on the complexity of the injury. In this article, the authors review the current evidence concerning the acute management of open fractures and propose a modern algorithm for treatment from the emergency department to the operating room.

Management in the Emergency Department

When seeing the patient in the emergency department, physicians and other health care providers should follow the Advanced Trauma Life Support guidelines established by the American College of Surgeons and its Committee on Trauma. These principles are:

- Assess the patient’s condition rapidly and accurately.
- Resuscitate and stabilize the patient according to priority.
- Determine whether the patient’s needs exceed a facility’s capacity.
- Arrange appropriately for the patient’s interhospital transfer (who, what, when, and how).
- Assure that optimum care is provided and that the level of care does not deteriorate at any point during the evaluation, resuscitation, or transfer process.

The decision about whether to keep or transfer the patient must be made at this time. The receiving center should have experience in dealing with these complex injuries and have a microvascular or plastic surgeon available for early care planning. The receiving center should also have a dedicated operating room time where orthopedic and plastic surgeons can collaborate early. Radiographs or photographs of the injury should be taken, and the wounds should be dressed appropriately, using a normal saline-soaked dressing. The patient’s tetanus immunization...
tion status should be checked and, if necessary, a tetanus vaccine administered. Antibiotics should be administered as soon as possible after injury.

**Antibiotic Prophylaxis Versus Placebo**

The occurrence of infection in an open fracture is a dramatic complication leading to significant morbidity, to include delayed union, non-union, multiple additional surgeries, or amputation. The risk of infection is multifactorial and often host, injury, and surgeon or management dependent. Antibiotic prophylaxis is an aspect of open-fracture management where the gold standard remains unclear. In fact, the ideal antibiotics for infection prophylaxis, as well as their timing and duration, are still debated.

The difficulty lies in the fact that decisions are based on level I articles that are now several decades old, and the epidemiology of bacterial contamination of open fractures has since changed. A landmark article by Gustilo and Anderson revealed that in more than two-thirds of 158 open fracture wounds, a positive bacterial culture was identified. Stratification of infection rates per open fracture types was 2% for type I fractures, 2% to 15% for type II fractures, and 5% to 50% for type III fractures. Most clinicians agree that patients should begin intravenous antibiotics within 3 hours after injury. This has been shown to reduce the rate of infection from 7.4% to 4.7% when compared with prophylaxis started more than 3 hours after the injury.\(^5\)

Prophylactic antibiotic therapy should be considered an adjunct to, and not a substitute for, a systematic open fracture management protocol that includes early and aggressive debridement and irrigation, fracture stabilization, and wound coverage. Nonetheless, prophylactic antibiotics are essential because, in their absence, infection can be expected to occur in 20% of open fractures.\(^2\)

This was investigated by several authors. A randomized trial by Patzakis et al\(^3\) revealed that a first-generation cephalosporine, such as cephalotin, reduced the infection rate more efficiently than a placebo or a combination of streptomycin and penicillin. More comparative studies, such as those by Bergman\(^6\) or Braun et al.,\(^7\) reached similar conclusions when comparing penicillin, dicloxacillin, or cloxacillin use for 2 days with use of a placebo. A metaanalysis on this specific topic was executed by the Cochrane group, confirming the efficiency of prophylactic antibiotics vs a placebo in open fractures.\(^8\) The result was a reduction of infection rate from 13.4% to 5.5%, with the addition of intravenous antibiotics.

In summary:

- Patients should be started on intravenous antibiotics within 3 hours of injury.
- Antibiotics are an adjunct to a thorough debridement, not a substitute.
- Level I data support the use of antibiotics in open fractures.

**Organism-Specific Antibiotics**

The role of wound culture in open fracture has been challenged. Lee\(^9\) confirmed that infections following open fractures were caused in only 8% of cases by organisms identified at the predebridement stage, whereas 7% of open fractures with negative cultures during the predebridement phase eventually developed an infection. Valenziano et al\(^10\) reached similar conclusions.

Bacteriological studies focusing on wound cultures in open fractures have taught us that, among patients who developed a deep infection, patients who were given prophylaxis against gram-negative bacteria grew primarily gram-positive bacteria, whereas patients who were given prophylaxis against gram-positive bacteria grew gram-negative bacteria from deep infected tissue.\(^11\)

Among 4 Level I trials studying antibiotic prophylaxis in open fractures,\(^3,6,7,11\) all highlighted a prevalence of *Staphylococcus aureus* as the number one cause of surgical site infection, and one\(^11\) reported the rate of methicillin-resistant *S aureus* (MRSA) as being nearly one-third of the total staphylococcal infections. With increasing use of antibiotics in the general population, we are faced with a new concern that was probably not present in clinical trials from prior decades: the changing epidemiology of the colonizing organisms.

It is essential to provide coverage against gram-positive bacteria in open fractures; however, Carsenti-Ettese et al\(^12\) raised concern about the potential development of gram-negative bacterial infection in this setting. In 2000, Patzakis et al\(^5\) compared the use of ciprofloxacin alone vs a combination of cefamandole and gentamicin. For open type I and II fractures, no differences in the infection rates were noted between the 2 groups. However, when type II open fractures were isolated, the infection rate decreased from 31% in the ciprofloxacin group to 7.7% in the group of patients who were prescribed gram-positive and gram-negative prophylaxis. This fact is supported by the recently published East guidelines\(^12\) (Level I) emphasizing the importance of additional gram-negative coverage for type III fractures.

Moreover, it is only following the initial debridement that the severity and type of open fracture can be accurately determined and classified. This is often underestimated at the time of arrival in the emergency department. Hence, although antibiotics should be given in the emergency department as soon as the patient arrives, and ideally within 3 hours from the injury, the current authors believe that final antibiotic prophylaxis protocol should not be based on the initial open wound size but rather should be chronologically based, following a clear algorithm with a prophylaxis tailored to the surgical management of the open wound, the fracture, the associated bone, and vascular and muscle injury.
Another controversial topic is the total duration of antibiotic prophylaxis for open fractures. Dellinger et al.13 performed a randomized trial comparing 24 hours vs 5 days of cefonicid. The infection rate in both groups was comparable, with no added benefits in patients who were provided with a prolonged prophylaxis. Others still believe that continuing the antibiotic prophylaxis until 24 to 72 hours after injury, at least for type III fractures, is beneficial in reducing the infection rate.14

In summary:

- Systematic culture of open fractures is not recommended.
- S aureus is the top cause of surgical site infection.
- MRSA is found in one-third of S aureus infections.
- Level I evidence exists to add gram-negative coverage (gentamicin) in type III fractures.
- Antibiotics prophylaxis can be discontinued 24 hours after injury or surgery.

**Timing of Debridement**

In 2009, the British Orthopaedic Association and the British Association of Plastic, Reconstructive and Aesthetic Surgeons modified the guidelines on debridement timing of open tibia fractures from within 6 hours to within 24 hours from injury.15 Historically, the main drive for emergent debridement was Gustillo and Anderson’s5 classic article, which concluded that it was essential to manage the wound with urgent debridement and thorough irrigation to reduce the risk of infection. This mantra has been strongly criticized because several confounding factors were present in their study. As a consequence, it is not feasible to reach significant conclusions as to which factors contributed to the reduction in infection rates.

More recently, some articles have emerged in support of debridement within 24 hours. Patzakis and Wilkins16 reviewed the infection rates of patients with open fractures treated with irrigation and debridement within 12 hours from injury or in a delayed fashion (more than 12 hours from injury); the infection rate in both groups was 7%. Charalambous et al.17 studied a cutoff of 6 hours after injury for the timing of initial irrigation and debridement, and no statistically significant difference between early and delayed treatment groups was noted in terms of infection rates. Basic science studies support the common thought that thoroughness of debridement is more important than its timing: a well-done debridement by an experienced surgeon is better than an inadequate debridement performed within 6 hours. Schlitzkus et al.18 identified that fracture grade, revised trauma score, and male sex were all independent predictors of wound complications but timing of initial debridement was not.

In summary:

- Grossly contaminated wounds or sewage/farmyard injuries might benefit from irrigation and debridement within 6 hours.
- Other nonlimb-threatening open fractures can undergo irrigation and debridement within 24 hours.

**Surgical Technique**

In 2010, the British Orthopaedic Association and the British Association of Plastic, Reconstructive and Aesthetic Surgeons working party on the management of open tibial fractures16 agreed on a protocol that is now followed nationwide across the United Kingdom. This includes antibiotic prophylaxis, but also a well-defined step-by-step approach for initial wound debridement that includes removal of all dead tissue. Systematic debridement occurs in the following sequence: (1) application of a soapy solution; (2) preparation of the limb with a chlorhexidine alcohol solution, avoiding direct contact of the chlorhexidine with the open wound; (3) wound extension, ideally following potential fasciotomy incisions; and (4) systematic assessment of the tissues, from superficial to deep and from the periphery to the center of the wound. Next, to ensure bone viability during the debridement process, deflation of the tourniquet should be performed to assess bleeding of the bony segment. At this stage, nonviable fragments or loose fragments of bone with no attachment to soft tissue should be discarded. Finally, once the debridement has been performed, thorough irrigation can be achieved.

It is only following this radical and systematic approach that the injury can be classified and a multidisciplinary treatment plan elaborated by the orthopedic and microvascular surgery teams.

In summary:

- Wash the limb with soapy solution, then prep with chlorhexidine alcohol, avoiding the traumatic wound.
- Perform a systematic debridement.
- Classify the injury and plan definitive reconstruction after debridement.
- If definitive fixation is delayed, plan for vacuum-assisted closure or a bead pouch.
- Release the tourniquet to assess bone end viability.
- Perform a “tug test” to assess bone fragments that require excision.

**Management of the Traumatic Wound**

Wounds that can be closed primarily should be closed. Placement of temporary antibiotic beads reduces infection rates in type III open fractures.

**Primary or Delayed Closure**

No good evidence exists to guide the decision of early vs delayed closure of the skin wound. A review of the Cochrane Database by Eiliya and Bandi20 found that no randomized, controlled trials compared primary vs delayed wound closure. In the absence of data, it seems reasonable to advocate mitigating the risk of infection in open fractures by delaying wound closure until the risk of wound infection has been declared.
Antibiotic Beads
A classic trial in arthroplasty and infection was performed by Lidwell et al\textsuperscript{21} and published in the \textit{British Medical Journal} in 1982. The authors assessed factors that most significantly reduced the risk of infection in 8000 patients undergoing hip or knee replacement and quantified them individually. Of note, infection rates were reduced 11-fold when antibiotic-loaded cement was used. Ostermann et al\textsuperscript{22} studied a consecutive series of 1085 severe open fractures and examined infection rates in a group managed with intravenous antibiotics alone vs a second group managed with the addition of polymethylmethacrylate (PMMA)-loaded gentamicin beads. The infection rate was 12% in the former group vs 3.7% in the latter group. Statistical significance was achieved for type IIIB and IIIC fractures for acute infection and for type II and IIIB fractures for chronic osteomyelitis. Henry et al\textsuperscript{23} performed a similar nonrandomized study and reached similar conclusions with a lower infection rate in the group managed with antibiotic beads and intravenous antibiotics than in the group managed with intravenous antibiotics alone (both groups had early irrigation and debridement).

The use of more modern antibiotic carriers is a challenge for the industry. McKee et al\textsuperscript{24} studied the efficacy of calcium sulphate loaded with tobramycin vs PMMA loaded with tobramycin to reduce and treat chronic non-hematogenous osteomyelitis or an infected nonunion. They reported a similar rate of eradication of infection but a slightly superior number of returns to the operating room in the PMMA group, reaching statistical significance.\textsuperscript{24} To the current authors’ knowledge, calcium sulphate use as a carrier for antibiotics is not approved by the US Food & Drug Administration.

Vacuum-assisted Therapy
Negative-pressure wound therapy, in which vacuum suction is applied across an airtight topical dressing, has been used in the treatment of chronic and surgical wounds. The negative pressure is thought to aid the drainage of excess fluid, reduce infection rates, and increase localized blood flow. It is also known as topi
cal negative-pressure therapy, vacuum-assisted closure, and sealed-surface wound suction. A systematic review in 2008 by Ubbink et al\textsuperscript{25} found only a small number of flawed trials, and thus little evidence to support the use of negative-pressure wound therapy in the treatment of wounds.

The Figure highlights the authors’ multidisciplinary algorithm for the management of open fractures. If antibiotics were not administered en route, they should be administered immediately on arrival to the emergency department, and ideally within 3 hours of the injury. The authors propose systematic coverage against gram-positive bacteria using intravenous cefazolin, 1 gram every 8 hours for patients weighing less than 80 kg and 2 grams for patients weighing more than 80 kg, continued for 24 hours after the first debridement. Intravenous vancomycin is added for patients with a history of MRSA infection. For grossly contaminated wounds or farmyard/sewage injuries, cefazolin is replaced with 600 mg of clindamycin intravenously every 8 hours for 24 hours after initial debridement.

Intraoperative assessment of the injury during the debridement will determine the final antibiotic regime. If the wound edges are not closeable or muscle necrosis or bone loss is present, a single intravenous dose of 5 mg/kg of gentamicin should be added at the time of the initial debridement.

At the time of definitive skeletal stabilization and skin closure, patients should be given a single intravenous dose of cefazolin 1 g <80 kg or 2 g >80 kg. One gram of vancomycin intravenously should be added.
to this regime if the patient has a previous history of MRSA infection. If none of the previously mentioned findings are present during debridement, the initial 24 hours of cephalosporin plus or minus the vancomycin (if previous history of MRSA infection exists) will suffice. Patients with anaphylaxis to penicillin should receive intravenous clindamycin (600 mg preoperatively, 4 times a day) in place of cephalosporin. Fluoroquinolones offer no advantages compared with a combination of cephalosporin and gentamicin and may actually have a detrimental effect of fracture healing and increase the infection rate in type III fractures.12

CONCLUSION
The authors present an evidence-based treatment algorithm for acute management of open fractures. It is the authors’ belief that a standardized, evidence-based decision tree will help streamline and improve care, specifically at teaching institutions with multiple staff and residents (Figure). Open fractures should be taken care of by well-trained, experienced orthopedic surgeons who are aware of the intricacies and potential complications of this complex injury. A clear algorithm should be implemented in every institution dealing with such trauma, and ideally a multidisciplinary approach should be the gold standard, with early involvement of the orthopedist, microvascular surgeon, and infectious disease department. Centers that do not have the capacity to manage such injuries should have a clear pathway of referral. This algorithm is currently being used for decision making at Denver Health Medical Center, Denver, Colorado.

REFERENCES