Open Fractures: A Systematic Review

by Nicole Nicolosi, DPM

Abstract: Open fractures are very complex and serious injuries that require meticulous planning and care to prevent potential complications which are sometimes unavoidable. Many topics are controversial in the management of open fractures. Such topics will be systematically reviewed in this article, including but not limited to: timing of surgery, type and duration of antibiotics, irrigation, time to wound coverage, negative pressure therapy, fixation, and primary amputation.

Key words: Gustilo and Anderson, antibiotics, irrigation, negative pressure therapy, amputation

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An open fracture involves a break in the overlying skin potentiating a direct communication between fractured bone and the environment. (1) Approximately 250,000 open fractures per year occur in the United States with approximately 30% of these patients having multiple injuries. (1,2) Compared to closed fractures, open fractures have a significantly higher risk of infection, nonunion, wound healing complications, and often require multiple surgeries for definitive care. (3) Goals of treatment include restoration of the soft tissue envelope, osseous healing, absence of infection, and return of function. (2) The stages for open fracture management include the initial (emergent) management, primary surgical treatment, and delayed surgical treatment. (2)

There are many topics that are controversial in open fractures which will be discussed in this article, including timing of surgery, type and duration of antibiotics, type of irrigation fluid, and time to wound coverage. (2,3) A multidisciplinary treatment approach is often required, including trauma, vascular, and plastic surgery. (3)

Initial management

Since open fractures are often associated with high energy trauma, such as MVA or a fall from a height, it is important to evaluate the patient for any prioritizing concomitant life threatening injuries. (4) Patients should be assessed and stabilized according to Advanced Trauma Life Support (ATLS) principles. (1,4,5) Early adequate resuscitation and stabilization may help to minimize secondary local injury from hypoxia, hypovolemia, and hypothermia. (4) External hemorrhaging can be controlled by direct pressure or, as a last resort, through the use of a tourniquet. (4,5) It is recommended that all complex open fractures be immediately transferred to major trauma center, with
the exception of a patient who can’t be transferred safely.(4) Trauma centers are equip and efficient at handling open fractures and it may reduce the risk of patient complications, particularly in injuries that require a multi-disciplinary approach (2,5)

Once the patient is determined to be stable, the open fracture should be handled as little as possible (one look approach).(4) The open fracture should be photographed, covered with a moistened saline gauze and an overlying occlusive dressing, and the dressing should not be removed until the patient is in the operating room.(1,4,5) Not only are photographs useful for potential legal ramifications but a one look approach prevents repeated exposure of the wound to potential bacterial contamination from the hospital environment.(6) There is no evidence to support the concept of splinting a deformed extremity as it lies in the field. This can cause unnecessary pain, increased neurovascular compromise, and increased tension on soft tissue.(1)

Gross contamination may be removed with 1L sterile normal saline but there is no evidence that washout in the ED reduces infection rates.(4) In fact, Nanchahal et al states that that exploration, lavage, and debridement of the wound in the ED is unnecessary, uninformative, drives particulate matter into the wound, and should be avoided.(5) Emergency room cultures are also unnecessary as bacteria require 24 hours to colonize and most open fracture infections are nosocomial.(7)

Neurovascular status is assessed, analgesic medication given, and compartment syndrome must be ruled out.(4,5) Capillary fill time to the digits can be misleading as blood pooled in the extremity can refill after pressure is released.(5) Palpation of pulses or a doppler is recommended for assessment.(5) Paresthesia symptoms of numbness and tingling are usually the first signs of compartment syndrome, although assessment can be difficult in the unconscious or anesthetically blocked patient.(5,6) Compartment syndrome is classically identified by the 6 P’s of paresthesia, pallor, paralysis, pulselessness, poikilothermia, and diagnosed with 30 mm Hg of pressure within the suspected compartment using a Wick catheter.(6) In patients with acute blood loss, subtract their compartment pressure from their diastolic pressure to obtain their perfusion pressure, which should be greater than 30 mmHg.(6) A perfusion pressure less than 30 mmHg is more sensitive measure of tissue perfusion and is recommended as a threshold for fasciotomy in the presence of clinical symptoms.(5) An emergent fasciotomy will prevent ischemic necrosis of muscle and nerves, as muscle death occurs within 3-4 hours of ischemia.(5) It is important to give patients intravenous fluids and correct electrolyte imbalances in the setting of rhabdomyolysis associated with compartment syndrome.(5) This author recommends against any pedal fasciotomy being performed because the likely ramifications of forgoing additional fasciotomy incisions are minor—sensory loss and the development of Volkman contractures.(6) These minor consequences are secondary to the fact that the only musculature affected by a pedal compartment syndrome are those intrinsic to the foot.(6) A fasciotomy is not a benign procedure as it increases risk of infection, creates another wound that requires healing in an already

Figure 1A: Pedal open fracture of 45-year-old male who dropped a metal beam on his foot.
compromised patient, and can result in subsequent chronic venous insufficiency.(5)

Patients should also be provided with analgesic medications and their tetanus status should be checked. For patients whom haven’t been immunized within 5-10 years, they should receive a tetanus toxoid injection.(1) Patients who have never been immunized should receive tetanus immunoglobulin in addition to a tetanus toxoid injection.(1) In cases of tetanus prone wounds (such as penetrating injuries or those contaminated with soil or manure), human tetanus immunoglobulin is recommended.(4) Radiographs should be obtained but supplementary imaging, such as computerized tomography (CT) or magnetic resonance imaging (MRI), should not delay primary surgical treatment.(2,4,5)

**Antibiotics and infection**

Intravenous antibiotics should be started as soon as possible, especially within 3 hours of the injury, because administering antibiotics after 3 hours is associated with an increased risk of infection.(4,8) Burke in 1961 performed a study on animal tissue contamination and found that there was no increase in bacterial colony in animals treated within 3 hours of time of contamination.(9) Patzakis et al also showed an infection rate of 4.7% in 364 patients given antibiotics within 3 hours compared with 7.4% in those given antibiotics after 3 hours.(2,10) However, this was a retrospective study that did not control for fracture pattern.(3) A prospective study by Al-Arabi et al in 2007 assigned 237 patients into 6 groups based on their timing of antibiotics (in hours): less than 2, 4, 6, 8, 12, and greater than 12.(3,11) They revealed no correlation between timing of antibiotic administration and infection rate.(3,11)

A first generation cephalosporin is recommended, unless the patient has a penicillin allergy should be given clindamycin.(12) Broad spectrum first generation cephalosporins have been shown to reduce infection rates in grades I and II fractures by as much as seven times.(2) In a landmark study by Patzakis et al. in 1974, he performed a prospective, controlled, randomized study on 330 patients and compared 3 groups of open fractures.(1,10) The first group received cephalothin, the second group received penicillin and streptomycin, and the third received no antibiotics.(1,10) The infection rates were 2.3%, 9.7% and 13.9% respectively.(1,10) Braun et al in 1987 performed a similar study and found that infection rate was 4.8% with antibiotics compared with 28% in patients treated with a placebo.(1,13) A Cochrane review in 2004 revealed that antibiotics reduced overall risk of infection by 59%.(2,5) Therefore antibiotic administration has proven value in the immediate management of open fractures.

![Figure 1B](image)

Figure 1B: Radiograph of open fracture pictured in Figure 1A.

**Type III open fracture antibiotics**

Type III open fractures have been classically associated with a higher incidence of gram-negative infection.(3) Gustilo and Anderson reported that 77% of bacteria isolated from type III infections were gram-negative organisms.(3,14) Therefore he proposed that an aminoglycoside should be added for type III fractures for gram-negative coverage.(2,3) In a follow-up retrospective study by Patzakis et al in 1983, he reported that the addition of aminoglycosides decreased infection compared to cephalosporins alone (13% vs. 5%).(3,15) However this study had several flaws, including varied wound closure timing.(3) A single dose of gentamicin (6 mg/kg) is as effective as divided doses and is not associated with an increase in adverse effects.(1) However, the literature to support that the addition of gram negative coverage decreases infection is weak and the addition of aminoglycosides is not
Currently supported in the literature. This is supported by the Infectious Disease Society of America (IDSA) and the Surgical Infection Society (SIS). However, the Eastern Association for the Surgery of Trauma (EAST) still recommends the aminoglycoside addition. Therefore, this lack of consensus leaves aminoglycoside use to the discretion of the surgeon.

Aminoglycoside alternatives include quinolones, aztreonam, and third generation cephalosporins. Patzakis et al in 2000 compared ciprofloxacin as a single agent versus cephalosporin plus gentamicin in 200 open fractures. A similar infection rate of 6% was revealed for both groups in type I and II fractures. However, patients treated with ciprofloxacin alone were over 4 times more likely to develop infection in type III fracture (31% versus 7.7%).

Farm injuries and antibiotics

Historically, for farm injuries, penicillin should be added for anaerobic coverage of a possible clostridial infection. Injuries in water may result in infection with aeromonas or pleisomonas and pedal puncture wounds are associated with pseudomonas aeruginosa. However, there is no evidence to support the addition of a penicillin. In fact, Gustilo and Anderson reported no cases of gas in their original study of 1025 patients.

Duration of antibiotics

The general consensus is that antibiotics are administered for 3 days in types I and II fractures and 5 days in type III fractures, although antibiotic duration is somewhat empiric. In a retrospective study by 18

<table>
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<th>Table 1: Timing and Antibiotic Delivery</th>
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<td><strong>&lt; 3 hr of injury</strong></td>
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<tr>
<td><strong>Debride</strong></td>
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<tr>
<td><strong>Closure</strong></td>
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In 1988, antibiotics administered for less than 24 hours had a less infection rate than antibiotics given for 3 days. However, this can be attributed to the fact that more severe fractures were treated with a longer duration of antibiotics. Dellinger et al in 1988 studied 240 patients and found that a 5 day course of antibiotics was not superior to a 1 day course. The literature reveals that the duration of antibiotics for open fractures does not adequately predict infection rate. Jaeger et al in 2006 recommended that 24 hours of antibiotics are recommended for grades I and II fractures and 72 hours for grade III. Nanchahal et al recommended that grade I fractures should receive 24 hours of antibiotics, and grades II and III 48 hours of administration.

Infecting organisms

Staphylococcus aureus and coagulase negative Staphylococci are the most common organisms resulting in infection in open fractures, although the incidence of gram-negative infection have increased recently. Although, Lenarz et al in 2010 reported that Staphylococcus aureus was the infecting organism.
in 65-70% of infected open fractures and Pseudomonas aeruginosa in 20-37%.(5,21).

Current evidence indicates that open fracture infections are not caused by the initial contaminating organisms but often are acquired in the hospital (nosocomial) or a result of natural skin flora.(12,22) Although 10 in 1989 reported an open fracture contamination incidence of 64%, infection requires $10^5$ bacteria per gram of tissue which is unlikely to occur less than 5 hours of the injury.(1,10) This is consistent with other studies that report that less than 20% of initial cultures predict infecting organisms.(3) Therefore, wound cultures during the initial management of an open fracture are not recommended because they often fail to identify the correct infective organism.(3,8) Patzakis et al. found that only 18% of infections were caused by the same organism initially isolated in the perioperative cultures.(10,22) In a study by Lee in 1997 entitled “Efficacy of cultures in the management of open fractures,” only 8% of the 226 pre-debridement cultured organisms caused infection.(2) Of 106 patients with negative cultures, 7% went on to develop infection.(2,23) Gustilo and Anderson reported in 1976 in their prospective study of 326 open fractures that most infections developed secondarily.(22) Carsenti-Etesse et al reported that the organisms isolated from initial cultures are often not sensitive to the initial antibiotics.(3,24) They reported that 92% of infections were hospital acquired and the cultures taken at time of closure correlated with infection and were clinically useful.(2,3,24) Although post-debridement cultures did not predict the infecting organism, they did correlate with infection.(3,24) Therefore the prevalence of iatrogenic infections emphasizes the importance of early wound coverage and post-debridement cultures only.(8,22)

Current recommendations

The British Association of Plastic and Reconstructive and Anesthetic Surgeons published “Standards for the Management of Open Fractures of the Lower Limb” in 2009 by Nanchahal et al. Their recommendations for antibiotics are depicted in Table 1.(5)

Antibiotic penetrance

Penetration of antibiotics into necrotic tissue is still under investigation.(22) There may be decreased penetration secondary to an interruption in blood supply or an increased penetrance secondary to local inflammatory mediators.(22) However, antibiotics alone cannot be relied upon to prevent infection in an inadequately debrided wound.(1)

Classification Systems

There are several classifications systems used for open fractures (Table 2).(5) However the most universally used and accepted classification is the Gustilo and Anderson classification.

Table 2: Open Fracture Classification Systems

<table>
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<th>Classification System</th>
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<tr>
<td>Mangled Extremity Severity Score (MESS)</td>
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<tr>
<td>NISSA (Nerve injury, Ischemia, Soft tissue injury, Skeletal injury, Shock, Age)</td>
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<tr>
<td>LSI (Limb Salvage Index)</td>
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<tr>
<td>Bryd and Spicer</td>
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<tr>
<td>AO System</td>
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<tr>
<td>Ganger Hospital Score</td>
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<td>Gustilo and Anderson</td>
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Gustilo and Anderson Classification

Gustilo and Anderson’s article was published in JBJS in 1976 and originally described open tibial fractures. (1,2) (Table 3) The classification scheme has been shown to correlate well with risk of infection and other complications.(2) In fact, the only factor that has been predictably shown to correlate with infection rate is the Gustilo and Anderson grade of fracture.(11) Both time to OR debridement and time until initiation of antibiotics, however, have repeatedly been shown to not correlate with infection.(11) Brumback and Jones in 1994 revealed in their study on 245 orthopedic
surgeons evaluating the Gustilo and Anderson Classification found it to have poor inter-observer agreement. This inter-observer variability can be minimized by classifying the fracture after the final debridement of all non-viable tissue has been performed.

### Table 3: Gustilo and Anderson Classification

<table>
<thead>
<tr>
<th>Classification</th>
<th>Description</th>
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<tr>
<td>I</td>
<td>Wound &lt; 1cm with minimal soft tissue injury</td>
</tr>
<tr>
<td>II</td>
<td>Wound &gt; 1cm with moderate soft tissue injury</td>
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<tr>
<td>IIIA</td>
<td>Extensive soft tissue laceration or flaps with adequate soft tissue cover of fractured bone</td>
</tr>
<tr>
<td>IIIB</td>
<td>Extensive soft tissue injury with periosteal stripping</td>
</tr>
<tr>
<td>IIIC</td>
<td>Presence of arterial injury requiring repair</td>
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**Perioperative management**

Hair around open wounds should be removed to facilitate wound care and healing. This should be done using clipping, not shaving, because shaving increases wound infection rate by traumatizing skin and hair follicles, resulting in dermatitis. Tourniquets should only be used when necessary, as they tend to interfere with the identification of ischemic, non-viable tissue. For this same reason, epinephrine use is not recommended.

**Timing of Operative Debridement**

Some authors state that early accurate wound debridement is the most important surgical procedure in the management of open fractures and should be performed within the first 24 hours of the injury. However, the benefit of emergent treatment is not supported in the current literature. The current trend is to perform urgent, rather than emergent, debridement of open fractures.

Classically, it is thought that open fractures should be taken to the OR within 5 hours because this is the “golden period” after which bacteria can exceed $10^5$ colony forming units and result in infection. Thus, it was thought that for fractures taken to the OR after this time, the risk of infection dramatically increases. Additionally, the “6-hour rule” has been theorized to originate from a study in 1898 by Friedrich in which he used garden mold and dust to infect guinea pig open fractures. This study reported that early phases of bacterial growth stopped after 6-8 hours, it was more difficult to obtain a clean wound after 6-8 hours of being contaminated, and a significant reduction in bacterial colony counts occurred if debridement occurred within 6 hours from injury. Bhandari et al in 1999 reported low pressure irrigation was less effective in removing bacteria if performed more than 3 hours after the injury. Evidence for the 6 hour rule is limited, with the exception of injuries that are grossly contaminated, compartment syndrome, a devascularized limb, or a multiple injury patient.

In type IIIC fractures, circulation should be restored as quickly as possible to increase limb salvage. In general, injuries associated with vascular compromise should be taken to the OR within 3-4 hours to restore circulation in accordance with BOAST guidelines. More than 3-4 hours of ischemia results in irreversible muscle damage and may result in systemic complications such as myoglobinuria, renal failure, and mortality. Howard and Makin in 1990 noted that revascularization greater than 8 hours after ischemic injury was associated with a 50% amputation rate. Lange et al in 1985 reported that a delay of revascularization more than 6 hours was associated with a worse outcome. Although devascularization is more common with femur fractures and knee dislocations than tibial fractures, one should always maintain vigilant suspicion. Angiography is not recommended and vascular surgery should be consulted for revascularization using vascular shunts.

Several studies suggest that the timing of surgery does not influence infection incidence. Patzakis and Wilkins documented an infection incidence of 6.8% in
396 wounds debrided within 12 hours compared with 7.1% in 708 wounds debrided after 12 hours. (2,31) Bednar and Parikh found no statistically significant difference in deep infection rates for those treated within 6 hours compared with those treated within 24 hours in 82 open fractures. (2,32) Harley et al reported no increase in infection or non-union rate in patients who were taken to the operating room up to 13 hours after the injury. (5,33) Pollak et al in 2010 studied 315 type III open fractures and reported a 27% infection rate and no correlation to timing of OR debridement. (3,34) Noumi et al in 2005 found no benefit from early debridement as well but reported that time of injury to ED arrival was an independent risk factor for infection. (3,35) Schenker et al in 2012 performed a systemic review of 3,539 open fractures. (36) They described no difference in infection incidence between patients taken to surgery less than 6 hours after injury versus those taken greater than 6 hours after injury, regardless of classification, depth of infection, or anatomic location. (36) Nairque et al reported no increase in infection in patients debrided between 6-24 hours compared to those within 6 hours. (5,37)

A study by Namdari et al in 2011 reviewed current trends by surgeons and found that 40% of patients received debridement greater than 6 hours after initial presentation and 25% greater than 24 hours. (3,38) Webb et al in a multicenter study on 156 grade III open fractures reported that debridement delays between 6 and 24 hours did not affect outcome including: infection, time to union, non-union rates, number of surgical procedures, admissions, time in hospital, time to weight-bearing, walking speed, and time to return to work. (5,39)

Thus, the current trend is for urgent, and not emergent, OR debridement of open fractures. Nanchahal et al recommended that time to OR debridement should be still performed as soon as the patient is medically optimal and when experienced staff is available, even if it is 6 hours after the injury. (11) Bennett and Smith in 2013 reported that there is good evidence that grade 1 and 2 injuries can be delayed beyond the 6 hour period without detriment, but it should be carried out at the earliest opportunity, and by an appropriately trained surgeon. (2) Grade III injuries should be taken to the OR emergently to ascertain the true extent of the injury and to minimize secondary injury. (2)

Wound Debridement

Adequate surgical debridement is the single most important factor in minimizing infection risk, although adequate debridement is difficult to define. (1) The wound should be generously extended to expose the entire wound area to healthy tissue. All devitalized tissue must be excised because it is a nidus for infection and it can directly inhibit leukocytic phagocytosis. (1,4) A 50% increase in infection rate has been reported in one study in which large segments of necrotic bone were retained. (1,40). With the exception of articular bone, osseous fragments without soft tissue attachment should be excised. (2) Retained necrotic muscle is a medium for bacterial growth and can have potential systemic effects including myoglobinuria and renal failure. (1) Scully et al. 1956 used the 4 C's to evaluate for devitalized muscle: color, contraction, consistency, and capacity to bleed. (4,41) Therefore muscle that is not contractile, is discolored, and doesn’t bleed when cut, should be excised. (1) Muscle debridement should be more aggressive than skin and “when in doubt, take it out.” (12) Tendons are not a major source of infection and should be preserved when possible. (1) The paratenon is vital for tendon survival and should be kept moist until the wound can be closed. (1) Minor vessels are ligated and major vessels and nerve are preserved. (1) The wound is washed to remove gross...
lavage should only be performed after meticulous removal of all particulate foreign material. A second OR visit after 24-48 hours will allow easier visualization of demarcated devitalized skin. However, multiple serial debridements should be avoided because they have been associated with poorer outcomes.

Yang et al in 2003 reported that macroscopically clean low grade fractures do not require formal operative debridement. Although, the grade and severity of injury may be underestimated if formal debridement is not undertaken. One study revealed that all surgically treated open fractures grades demonstrated lower infection and non-union rates than those treated without surgical debridement.

**Irrigation**

Lavage is used to remove contaminants from wounds. Some studies have shown no benefit of pulse lavage over continuous flow irrigation. Anglen in 2005 found that the use of power irritation increased the removal of bacteria by 100 fold versus bulb syringe irrigation of the same volume. This was consistent with the findings of Gross et al., where the pulse lavaged wounds had fewer bacteria, less inflammation, and less debris up to 12 days post-operatively. Necrosis was higher in bulb syringe wounds up to 6 days post-op. Alternating pulse compression and decompression phases allows for soft tissue recoil which may enhance dislodgement of particulate matter.

Pressure at the tissue level appears to be the most important determinant in successful decontamination of the wound. Quinn et al in 2006 stated that low pressure irrigation is considered 8 psi (pressure per square inch) and is the pressure exerted through a 19 gauge needle with a 35 mL syringe or with a 22 gauge needle with a 12 mL syringe. Low-to-moderate pressure is considered 15-25 psi and high pressures is greater than 25 psi.

Increased pressure improves removal of debris and bacteria but higher pressures settings (>70psi) have been reported to have detrimental effects on bone healing. One in vivo study by Dirschl et al in 1998 demonstrated visible bone damage at the fracture site and delayed healing associated with high pressure pulse lavage. Bhandari et al in 1998 reported that high pressure irritation resulted in macroscopic osseous damage and inoculated surface bacteria into the medullary canal.

Low-to-moderate pressure settings (15-25 psi) appear to balance potential bone damaging effects with the proven contaminant clearing properties of pulse lavage. Bhandari et al in 1999 reported less microscopic and macroscopic bone damage with low pressure than high pressure irrigation and no difference in ability to remove bacteria if either procedure was performed within 3 hours of contamination. However, low pressure irrigation was less effective in removing bacteria if performed more than 3 hours after the injury. An animal study by Madden et al in 1971 found that when comparing psi of 0.5, 10, and 25, only irrigation at 25 psi significantly decreased rate of infection.

Figure 1E: Patient underwent a transmetatarsal amputation status post demarcation of viable tissue and is functioning well.
Newer studies, however, recommend low pressure irritation. Owens et al in 2009 found that a bulb syringe was as effective as pulsatile lavage with saline solution in removing approximately 75% of bacteria.\(^{(47)}\) However, after 48 hours, the bulb syringe had a lower rebound bacteria count (48%) compared with pulse lavage (94%).\(^{(47)}\) A multicenter study called the FLOW trial (fluid lavage of open wounds) was conducted on 89 patients in 2011 with a 1 year follow-up.\(^{(48)}\) The low pressure (6-10 psi) irrigation group had a better outcome in every complication category (infection, wound healing issues, and non-union) when compared with the high pressure (25-30 psi) group.\(^{(48)}\) This is consistent with the literature which states that high pressure may propagate bacteria into the medullary canal and have deleterious effects on bone architecture, stem cell differentiation, fracture healing.\(^{(48)}\) This study did not control for co-interventions such as antibiotic bead use, wound vacuum-assisted closure therapy, or the use of free flaps and soft tissue transfers.\(^{(48)}\) This study concluded that low pressure lavage may decrease the re-operation rate for infection, wound healing problems, or nonunion.\(^{(48)}\)

**Type of irrigation**

The types of additives to saline irrigation include antiseptics, antibiotics, and surfactants.\(^{(1)}\)

Antiseptics act by damaging the cell wall or membrane of a pathogen, but may also be toxic to host cells.\(^{(1)}\) Examples include povidone-iodine solution, hydrogen peroxide, hexachlorophene, sodium hypochlorite.\(^{(1)}\) There is few evidence to support a lower infection rate but there is substantial evidence that further wound damage may occur with their use.\(^{(1,43)}\) Therefore use of antiseptics is not recommended.\(^{(8)}\)

The addition of antibiotics to saline irrigation is also controversial.\(^{(1,8)}\) There is little evidence of benefit over systemic administration, and reports of anaphylaxis and other major complications have been reported.\(^{(1)}\) Anglen in 2005 conducted a randomized controlled trial comparing castile liquid soap with bacitracin in 398 lower limb open fractures using a high pressure pulsatile lavage system.\(^{(2,43)}\) He found that

![Figure 2A: Open fracture of a 45-year-old male who slipped on some rocks while fishing on Lake Erie.](image)

![Figure 2B: Radiographs of the open fracture pictured in Figure 2A](image)

**Volume of irritation**

Although the optimal volume of irrigation is unknown, the recommended volume is between 3 and 9 L, often based on the severity of the injury, with larger volumes for more extensive and contaminated wounds (grade I, 3L; grade II, 6L; grade III, 9L).\(^{(22)}\) Gainor et al in 1997 performed a study on animals and reported that increasing volume of irrigation from 0.1 to 1.0L increased the effectiveness of bacteria removal but further increases up to 10L provided no additional benefit.\(^{(1,49)}\) However, no human studies have been reported.\(^{(1)}\)
infection rates were similar in the 2 groups but wound healing problems were higher in the bacitracin group.(2,43) Therefore use of antiseptics is not recommended.(1)

The addition of surfactants to saline irrigation act by inhibiting bacterial adhesion.(1) Although some surfactants are also antiseptic agents, most just enhance removal of bacteria through irrigation.(1) There are reports of toxicity to host tissues with the use of surfactants, but this may be due to the in vitro nature of these studies and the high concentration with prolonged exposure.(1) The FLOW trial revealed that the castile soap group had an increase in total infections which was theorized to be a result of the soap acting as a local irritant causing local erythema at the surgical site.(48) Owens et al in 2009 studied the effectiveness of irrigation methods in a goat model and found that the greatest reduction in bacteria count was seen with castile soap (13% of pretreatment level), compared with benzalkonium chloride, bacitracin, and saline solution at 18%, 22%, and 29%, respectively.(47) After 48 hours, the highest bacterial count rebound was found with castile soap (120% of pretreatment level), compared with bacitracin and saline at 89% and 68%, respectively. In addition, the optimal concentration of surfactant is not known. Therefore the use of surfactants is not recommended.(47)

Antibiotic Beads

The usage of locally applied antibiotics in combination with polymethylmethacrylate (PMMA) beads is rapidly becoming recognized as a useful adjunctive therapy in severely contaminated wounds.(8) Ostermann et al in 1995 reported in their series of 1,085 open fractures that the use of PMMA beads with aminoglycoside significantly reduced incidence of infection versus IV antibiotics alone, 3.7% and 12% respectively.(8,50) However, when analyzed by fracture type, only type III fractures showed a significant reduction in infection incidence.(8,50) With delayed primary closure, the beads are placed within the wound and covered with a semi-permeable barrier.(8,50) A semi-permeable membrane avoids the creation of an anaerobic environment.(8,50) Other modes of antibiotic delivery include antibiotic loaded bone graft substitutes, such as calcium sulphate, and antibiotic coated intramedullary nails.(2)

Delayed versus primary closure

The major deterrent of primary closure is the possibility of gas gangrene secondary to an anaerobic environment. Clostridial myonecrosis can result in devastating limb and life consequences.(8) However, anaerobic infections may be a consequence of inadequate debridement and antibiotic therapy.(8) Brown and Kinman documented 27 patients between 1963 and 1973 with clostridial wound infections.(22,51) In many cases, “foreign material such as dirt or vegetable matter” was noted throughout the tissues at the time of wound breakdown, indicating incomplete debridement.(22,51) Only 5 patients received initial coverage for anaerobic organisms, and 4 patients received no antibiotics at all.(22,51) Thus, perhaps the more likely cause of these infection was inadequate debridement and inappropriate selection for early wound closure.(22,51)

The practice of leaving wounds open after initial surgical debridement and performing delayed secondary closure is widely based on historical practices, before advancements in antibiotics, modern debridement methods and improved fracture stabilizations techniques.(22) In low energy open fractures with
minimal devitalization of tissue, and no concern for ongoing muscle necrosis or inadequate resection, primary closure is recommended because of a reduction in infection risk and hospital stay, especially in type I and II fractures. Secondary to devitilization, type III open fractures usually require repeat debridement of demarcated tissue at 48-72 hours after initial debridement. In a retrospective review of 83 pediatric open tibia fractures, Cullen et al supported primary closure in pediatric open fractures and stated the exception to primary closure was gross contamination of the wound or any concern of the adequacy of debridement. However, several studies argue that there is no difference in infection incidence between primary and delayed closure. In a double blind prospective study, Benson et al compared primary closure in 44 wounds with delayed closure in 38 wounds (mean closure 6 days after injury). Three superficial wound infections occurred in the primary closure group and 2 deep infections occurred in the delayed closure group. Statistical analysis revealed infection to be independent of closure method. DeLong et al in a review of 119 open fractures, utilized primary closure in 88% of grade I, 86% of grade II, 75% of grade IIIA, and 33% of grade IIIB fractures. This study revealed a 7% incidence of infection and 16% incidence of delayed or non-union. Statistical analysis revealed no significant difference in delayed or non-union and infection incidence between immediate and delayed closure. Webb et al in 2007 in a study on 156 patients with type III open tibia fractures revealed that there was no difference in infection incidence in those patients receiving early (<3 days) or late (>3 days) wound coverage. Pollak et al similarly found that there was no difference in infection incidence when comparing wound coverage at less than 3 days, 4-7 days, or greater than 7 days. However, they reported a 32% complication rate in those wounds covered at greater than 7 days. D'Alleyrand et al also revealed no difference in wound complications in those covered in less than 7 days but reported an increase in 15% complication rate for every day thereafter.

Figure 2D: ORIF of the open fracture pictured in Figure 2A.

Figure 2E: ORIF of the open fracture pictured in Figure 2A.

Obvious exceptions to immediate closure include wounds containing gross contamination with feces, dirt, or stagnant water, as well as farm related injuries or freshwater boating accidents. Other contraindications are a delay in the initiation of antibiotics beyond 12 hours post-injury or questionable tissue viability at the time of initial surgery. If a doubt exists concerning the adequacy of the debridement, or in a patient with confounding comorbidities, the wound should not be closed regardless of fracture type or antibiotic coverage. The British Association of Plastic Reconstruction and Aesthetic Surgeons in 2009 recommended that there should be soft tissue coverage over an open injury ideally within 72 hours but should not exceed 7 days. A plastic surgery consult is also recommended when soft tissue reconstruction is required.
**Negative Pressure Therapy**

In open fractures, wound vac devices theoretically increase blood flow to the wound bed and decrease the wound surface area that require coverage, but it is unclear whether it decreases infection incidence.\(^{3}\) Stannard et al in 2009 conducted a prospective randomized study on 62 patients and found that negative pressure therapy significantly decreased infection rate (28% versus 5.4%) versus patients treated with a gauze dressing.\(^{3,56}\) Similarly, Blum et al in 2012 reported an infection incidence of 8% in patients treated with a wound vac compared to 20% with controls.\(^{3,57}\) Dedmond et al in 2006 reported on grade III fractures in children and found that negative pressure resulted in a 50% decrease in the need for free tissue transfer but an infection incidence of greater than 30%.\(^{5,58}\) Mouses et al in 2004 conducted a randomized trial comparing negative pressure therapy with moist gauze and found there was no difference in time to achieve a granulation wound base, a significantly greater reduction in wound surface area in the negative pressure group, and a significant reduction in gram negative bacilli and increase in staphylococcus aureus in the pressure therapy group.\(^{59}\) They concluded that negative pressure dressings do not decontaminate open wounds.\(^{5,59}\) Bhattacharyya et al in 2008 reported that wounds treated with negative pressure therapy beyond 7 days had a significantly increased incidence of deep infection.\(^{5,60}\) Nanchahal et al in 2009 recommend that although negative pressure therapy is useful and safe to use in open fracture management, it should not be used as a substitute for a vascularized soft tissue cover.\(^{5}\)

**Grafting and Flap coverage**

Some authors advocate early, if not immediate, flap coverage to transform open fracture acutely into a well vascularized closed fracture.\(^{5}\) This ideally is performed at the time of definitive fixation.\(^{4}\) The microsurgical reconstruction techniques promoted by Godina revolutionized the concept of free tissue transfer for trauma.\(^{22,61}\) Godina evaluated 532 patients who underwent free flaps at 3 different intervals.\(^{22,61}\) Group I (early) received the free flap within 72 hours of injury, group II (late) between 72 to 3 months, and group III (delayed) between 3 months and 12 years.\(^{22,61}\) Infection occurred in 1.5% of group I, 17.5% of group II, and 6% of group III.\(^{22,61}\) Time to bone healing was 7 months, 12 months, and 29 months, respectively.\(^{22,61}\) Flap failure rate was 0.75%, 12%, and 10%, respectively.\(^{22,61}\) Authors concluded that coverage within the first 72 hours after injury provided superior results, with earlier bone healing and decreased rates of infection.\(^{22,61}\) The average hospital stay was 27 days for early versus 256 for delayed flap closure.\(^{22,61}\) Delaying definitive reconstruction resulted in extensive fibrosis, which complicated microvascular anastomoses and in many instances led to an additional loss of soft tissue and bone.\(^{22,61}\)

Gopal et al over an 8 year period, evaluated 84 fractures treated with definitive soft tissue coverage with a vascularized muscle flap and split thickness skin graft.\(^{22,62}\) Sixty-three fractures were treated with early (<72hours) flap coverage, and 21 underwent late (>72hr) soft tissue coverage.\(^{22,62}\) The deep infection incidence was 6% for patients with early flaps and 30% for late flaps.\(^{22,62}\)

In cases where vascularity has not been compromised, local fasciocutaneous flaps are sufficient and avoid the
need for microsurgical vascular anastomoses. Unless meticulously planned, these flaps have a high rate of tip necrosis, usually at the fracture site. A local pedical flap is used from the gastrocnemius for the proximal third tibial fractures and the soleus for middle third tibial fractures. The distal third of the tibia typically require free muscle flaps. Free flaps can be used for more extensive defects and effectively minimize dead space, reducing the risk of seroma, hematoma, and infection. These flaps are often harvested from the gracilis, latissimus dorsi muscles, or rectus abdominus. Careful monitoring of flap viability is required and a Doppler can be used to assess arterial inflow into the flap.

Fixation

Once adequate debridement and irrigation have been performed, the bone is then stabilized to protect the soft tissues from further injury. Stabilization can be achieved using external fixation, intramedullary nailing, or plate and screw fixation, and should be decided on a case by case basis. The British Association of Plastic Reconstruction and Aesthetic Surgeons in 2009 recommend that definitive fixation is performed within 72 hours of primary debridement. However, when there is significant contamination, bone loss or multilevel fractures of the tibia, external fixators should be used for skeletal stabilization instead. Often reconstruction is performed in a staged process. Although, internal fixation has been associated with increased deep infection rates, internal fixation has shown to reduce complication incidence because stability reduces soft tissue injury. The support for internal fixation has increased because of advances in antibiotics, wound care, and fixation techniques. Most type I and II open fractures can be treated with immediate open reduction and internal fixation (ORIF) if the wound is evaluated as clean and immediate closure can be obtained.

Bach and Hansen in 1989 conducted a randomized trial comparing internal with external fixation on 56 patients with grade II or III open tibial fractures and were followed for 1 year. Five internal fixation plates (19%) developed osteomyelitis and 3 plates failed. One external fixation case developed osteomyelitis and pin-tract infections occurred in 3 patients. They stated that the rate and extent of complications were lower with external fixation and recommended its use for stabilization of grade II and III open tibial fractures.

Amputation

The decision to amputate is made either immediately, as part of the primary treatment, or when attempts at limb salvage fail. The British Association of Plastic Reconstruction and Aesthetic Surgeons in 2009 provide the following indications for primary amputation: avascular limbs with a warm ischemic time exceeding 4-6 hours (decreased if patient is hypotensive), segmental muscle loss affective more than 2 compartments, segmental bone loss greater than 1/3rd of the length of the tibia, incomplete traumatic amputations where the distal remnant is significantly injured, and as method to control uncontrollable hemorrhage. Initial absent protective sensation should not be an indication for amputation. Bosse et al reported that greater than 50% of patients recovered plantar sensation suggesting neuropraxia as the initial inciting cause. Pape et al recommended prolonged limb salvage surgery should not be performed in the physiologically unstable patient because it may cascade the patient into adult respiratory distress syndrome (ARDS).
disseminated intravascular coagulation (DIC) and multiple organ failure.(5,66)

The estimated recovery for a below the knee amputation is approximately 5-6 months in order to return to normal ambulation.(5) Below the knee amputations offer superior quality of life and less physical demand during ambulation than above the knee amputations.(5) A review of the literature reveals that US Army Veterans with lower extremity amputations are able function with a quality of life similar to their peers.(5)

Complications

Complications are frequent and include infection and non-union with reported rates of up 50% and 18%, respectively.(1,2) The long term morbidity, in terms of pain and loss of function due to bone and soft tissue injury, cannot be underestimated.(2) Outcomes have been found to correlate with the number of pre-existing co-morbidities, age, smoking status, as well as severity of injury.(2)

Chandran et al performed a review of crush injuries of the midfoot treated with external fixation and split thickness skin grafts and found that the majority reported severe morbidity (stiffness and pain) at 1 year after external fixator removal.(68) Severe rearfoot injuries also result in severe joint stiffness that will also likely require later arthrodesis.(5)

Conclusions

In conclusion, open fractures are very complex and serious injuries that require meticulous planning and care to prevent potential complications which are sometimes unavoidable.

References


