Management of Open Fractures

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Abstract

The large spectrum of open fractures is an amalgamation of injuries with the single variable in common of communication of the fractured bone with the outside environment, and thus an increased risk for infection. Contributing to the presence of bacteria within the fracture site is devascularized soft tissue, the degree of which can be directly attributed to the amount of energy imparted to the tissues. The currently used classification system aids in defining the degree of severity of these injuries and their subsequent risk for infection. The basic management principal for all of these injury patterns remains essentially the same, however: prevention of infection through debridement, wound management, antibiotic usage, and fracture stabilization. Frequently multiple surgical procedures will be required in order to obtain an infection free, united fracture with adequate soft tissue coverage (1).

KEY WORDS: open fractures, management

Open Fracture Classification

After initial trauma assessment and appropriate ATLS (Advanced Trauma Life Support) protocols have been met, the injured extremities often remain patient's most significant injuries. Evaluation and treatment of these injuries includes not only the fracture itself, but also includes the soft tissue envelope, to include ligaments, tendons, nerves, and vascular structures. Further, the presence of a compartment syndrome must be ruled out despite the existence of an open fracture (2). Gustilo and Anderson (3) modified the proposed classification system of Veliskakis (4) and was later re-modified by Gustilo et al. (5). This system, which was initially intended for tibial fractures, has nonetheless found widespread acceptance for most long-bone open fractures. As modified by Gustilo et al. (5, 6), Type I fractures include puncture wounds up to 1cm in size with minimal contamination and devascularization of muscle and other soft tissues. Type II fractures include injuries in a spectrum of 1 to ten centimeters with only moderate soft tissue compromise. There are three sub-classifications of type III injuries. Type IIIA injuries comprise those open fractures with extensive soft-tissue damage and or heavy contamination with segmental or severely comminuted fractures. However, these wounds do have adequate soft tissue coverage of the exposed bones. Type III B injuries have all of those components found in IIIA injuries with the addition of periosteal stripping and with the exception of adequate soft tissue coverage. These injuries will generally need more complex treatment and management of the soft tissue component of their wounds (local or distant flaps, Figure 1). Often multiple procedures will be required in order to obtain adequate debridement, to manage infection, and to obtain soft tissue coverage, in addition to fracture fixation and union. Type IIIC injuries include any of the above open fracture types with the addition of an arterial injury which requires repair. Although widely accepted this classification system has been questioned with regards to its inter-observer reliability. Brumback and Jones7 found that only 60% agreement was obtained as to classification of open fractures amongst orthopaedic surgeons. Perhaps the most important caveat to this classification system, and an explanation as to this level of inter-observer disagreement, is that the true classification can only be determined intra-operatively, after wound exploration and debridement has been performed. More importantly, this classification system helps draw the attention of and direct the care of the most significant limb threatening injuries in a systematic fashion.

Wound Management Irrigation and Debridement

The techniques of irrigation and debridement are unquestionably the most important tools available to the surgeon during the early phase of open fracture management. There has been no ideal method established however to address the important variables of volume, delivery method and type of irrigation solution to be used (8). High-pressure irrigation is excellent at the removal of wound debris and bacteria. However, there remain questions as to the potential that this technique has for damaging bone (9). Chemical antiseptic solutions may damage healthy tissues and in general should not be used. Detergent solutions are however showing some promise as an alternative to antibiotic laden irrigation solutions (10, 11). The use of antibiotic containing solutions for wound irrigation remains controversial due to questions about its effectiveness, it's potential for selecting out resistant organisms, and its cost versus benefit ratio. More important perhaps than irrigation is proper surgical debridement of these wounds. The desired end result is a sterile wound with viable tissues in which to prepare the bone for fixation and eventual union. Tourniquets should be used only when necessary, as they tend to interfere with the identification of ischemic, nonviable tissues. Often the skin laceration is insufficient for adequate debridement and is extended in a longitudinal fashion as far as is necessary. The skin and subcutaneous tissues are trimmed sharply, yet minimally in order to establish healthy, bleeding edges. Muscle debridement is performed on the basis of the 4-C's; color, consistency, contractility, and capillary bleeding. With the exception of articular fragments, devascularised sections of cortical bone, without soft tissue attachment, should be removed, as they will continue to act as a nidus for infection. Repeat debridement should be performed every 24 to 48 hours as needed until the desired surgical wound is obtained. If implant (nail or plate) is going to be used for fracture fixation immediately after debridement, extremity should be first reprepped and re draped, and than all new sterile instruments, gowns and gloves must be brought in.

Prevention of Infection

By definition all open fractures are presumed to be contaminated due to their communication with the outside environment. Factors including bacterial colonization of the wound, devitalized tissue, foreign bodies, dead space areas, and poor vascularity contribute to the high rates of infection seen with these injuries. There is a direct correlation between the type of open fracture and the relative risk of infection. Reports range from 0%-2% for type I injuries, 2%-10% for type II injuries, and 10% to 50% for type III injuries (3, 12). Countermeasures to the development of infection include irrigation and debridement as previously mentioned, in addition to the use of immediate broad-spectrum antibiotics. Further, tetanus prophylaxis should be included in the initial treatment of these injuries due to the propensity for soil contamination, which is frequently seen, with these injuries.

Wound Cultures

The use of wound cultures during the initial stages of open fracture care is not uniformly recommended. Although the cultures may indicate a probable infecting organism and its antibiotic sensitivity, they often fail to identify the correct causative organism (13, 14). This may in part be due to early broad-spectrum antibiotic usage, and the development of late nosocomial infection. One level-1 study showed that only 18% (3/17) infections seen in a series of 171 open fractures were the result of the organism identified by initial cultures (15). Routinely only post-debridement cultures should be obtained or in those injuries sustained in abnormal or marine environments.

Antibiotics

Patzakis et al., (15,16) initially demonstrated the critical role played by the initial early administration of antibiotics in these fractures. They showed a significant reduction in infection rates by administering cephalothin (2,4% or 2/84 fractures) compared to those given no antibiotics (13,9% or 11/79 fractures) or with penicillin or streptomycin administration (9,8% or 9/92 fractures). Of note, they administered their antibiotic regimens before the initial irrigation and debridement.

Antibiotic Selection

Typically open fractures are contaminated with a mixture of both gram-positive and gram-negative bacteria. Therefore patients with open fractures should be treated with a combination of antibiotics to sufficiently cover the wide spectrum of potential infecting agents. A first Generation cephalosporin such as cefazolin is chosen for its gram-positive coverage, and an aminoglycoside such as gentamicin or tobramycin is chosen to control gram-negative organisms. Aminoglycoside alternatives include agents such as quinolones, aztreonam, and third generation cephalosporins. Ampicillin or penicillin should be included in injuries at high risk for the development of clostridial infections, i.e. anaerobic infections. Farm type injuries are at particularly high risk for the development of clostridial infections. Patzakis and Wilkins (17) reported that the combination of a cephalosporin with and aminoglycoside resulted in a 4,6% infection rate (5/109 open tibial fractures), whereas use of a cephalosporin alone was associated with a 13% infection rate (25/192 open tibial fractures). Some authors14 support the use of single agent cephalosporin coverage for type I and II injuries, however, this is fraught with hazards such as the potential for misclassification and under-treatment of a wound based on initial evaluation is high. The use of quinolones as a single agent in type I and II injuries is showing promise. They are particularly attractive in situations in which the use of oral antibiotics is favored such as in austere environments. One trial comparing ciprofloxacin compared to a combination of cefmandole and gentamicin revealed a similar infection rate of 6% for both groups, but a drastically increased infection rate of 31% for the quinalone group vs. 7,7% in the combination therapy group for type III fractures (15). Questions remain however regarding the association of fracture healing and the use of quinolones (18, 19).

Duration of Therapy

The proper duration for antibiotic coverage remains somewhat controversial as well. It is known that a delay of greater than 3 hours is associated with an increased risk of infection (15). Dellinger at al. (20) showed that a 5 day course of anti-microbial agents was not superior to a 1 day course. General consensus is that an initial therapy regimen lasting 3 days, followed by repeat courses at wound closure, bone grafting, or other major procedure related to the open fracture is appropriate (12, 14).

Local Administration

The usage of locally applied antibiotics in combination with polymethylmethacrylate (PMMA) beads is rapidly becoming recognized as a useful adjunctive therapy to irrigation, debridement and the systemic application of antibiotics. Ostermann at al. (21) showed in their series of 1,085 open fractures that the use of PMMA beads laden with aminoglycoside antibiotics significantly reduced the rate of infection versus the use of intravenous antibiotics alone. They noted an infection rate of 3,7% vs. 12% in the two groups ($P<0,001$). However, when analyzed by fracture type, only the type III fractures showed a significant reduction in infection rates at 6,5% vs. 20% for the two groups respectively. Typically the antibiotic impregnated PMMA beads are placed directly within the wound and are covered with a semi-permeable barrier when the wounds are left open. Unfortunately to date Food and Drug administration approval has not been obtained for the use of commercially produced antibiotic beads, and thus physicians must make them at the time of surgery. Typically 40 g of PMMA cement is mixed with a heat stable antibiotic such as Tobramycin (3,6 g of antibiotic per 40 g PMMA) or Vancomycin. These beads are strung on 24-gauge wire or equivalent while still moldable, for ease of removal. Bead pouches have many potential benefits vs traditional daily dressing changes and systemic administration of aminoglycosides; a) they obtain higher local concentration of antibiotics (up to 10 to 20 times greater) than is seen with systemic administration (22), b) the patient is conversely protected from high systemic concentrations of aminoglycosides and potential severe side effects, c) there exists a potential for decreased risk of nosocomial infection by reducing the amount of contact between the wound and the outside environment through use of the semi-permeable membrane. It is important to remember not to establish an anaerobic environment with potentially devastating infections by using only semi-permeable membranes and not occlusive dressings.

Closure of Wounds

Management of wounds as regards the preferred method and timing of closure also remains controversial. Advantages of primary closure following irrigation, debridement and fracture fixation include a low risk of infection with type I and II fractures, decreased hospital length of stay and subsequent overall cost (9). However, if an infection such as clostridial myonecrosis does arise within a closed wound, devastating consequences can result to include limb and life threatening complications (23). This is exacerbated by inadequate debridement and antibiotic therapy (16). Many authors recommend delayed wound closure for all open fractures, often 3-7 days following initial care. Delaying closure has the benefits of preventing the development of anaerobic conditions, providing the opportunity for repeat debridement and the potential use for antibiotic pouch therapy. Some authors do recommend letting small type I wounds close secondarily and only partial closure of type II wounds (closing only the surgical extensions and leaving the original traumatic laceration open) (24). Loosely closing soft tissue is however recommended to provide soft tissue coverage of directly exposed bone, tendons, nerves and major blood vessels.

Soft-Tissue Reconstruction

In certain instances such as open type IIIB fractures and those that have required extensive surgical debridement, adequate soft tissue coverage of bone and other structures cannot be obtained. In such instances, alternative soft tissue coverage techniques must be employed. Once a healthy, well-vascularized bed has been established, a local (fasciocutaneous or muscle flap, Figure 1) or free flap can be performed (25). Typically a local pedicle flap is used from the gastrocnemius for proximal third tibia fractures, and soleus flaps are likewise used for middle third fractures of the tibia. Distal third fractures of the tibia typically require free muscle flaps. Most commonly free muscle flaps include the rectus abdominis, gracilis, and latissimus dorsi muscle groups. Important in the consideration of flap coverage type is the quality of the tissue to be transferred. Damaged tissue or that which has been subjected to compartment syndrome is likely to do poorly and alternatives should be considered (26). Whenever practicable, soft-tissue reconstruction should be performed within the first 7 days post-injury. Further delays are associated with increased wound complications and infections (13). Certain authors have advocated coverage within 72 hours to be ideal (27, 28, 29). Godina (27) reported that free muscle flaps had a less than 1% (1/134) risk of failure when performed within 72 hours as compared to a 12% (20/167) failure rate when performed later than 72 hours after initial injury. Infection rates were also favorable to early flap coverage within the same study with 1,5% (2/134) in the early group as compared to 17,4% (29/67) within the delayed group. Of note, no antibiotic bead pouch technique was used in their series, thus nosocomial infection may have played a role in the higher infection rates and flap failure rates in the delayed group.

Fracture Stabilization Techniques

Available fracture stabilization techniques span the range of external fixation, plate fixation, and intramedullary fixation. Regardless of the specific technique used, benefits include protection of soft tissues from further injury, improved host response to infecting microorganisms, improved wound care and early joint range of motion and rehabilitation. The specific technique to be used is based on multiple factors and each fracture should be individually assessed and treated based on its unique characteristics.

Intramedullary Nailing

The biomechanical advantages of intramedullary nailing are unquestioned; however questions persist as to the relative risk of infection using this technique. Diaphyseal fractures of the lower extremity (Figure 1) are particularly appropriate for intramedullary nailing (30-33). The advantages of intramedullary nailing primarily include; a) stable fracture fixation, especially with modern interlocking techniques, and b) lack of interference with wound care and soft-tissue management. The disadvantages include a) potential for deep seeding of infection, and b) disruption of endosteal blood supply

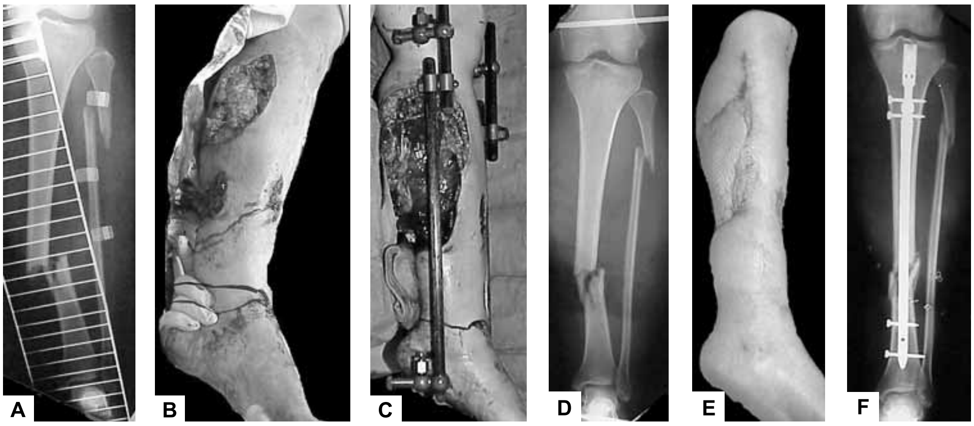

FIGURE 1. A. X-ray of midhsaft comminuted tibia fracture and high fibula fracture. B. Clinical photo on admission presenting posteromedial soft tissue defects. C. Photo after debridements and "traveling"external fixator frame in place. D. Proximal pin is in distal femoral condyles, distal pin into calcaneus. F. Clinical photo of healed soft tissues after local soleus muscle flap and fasciocutaneous flaps have been used. F. X-ray of healed fractures with locked intramedullary nail. Nailing was performed fifth day after injury, immediately before soft tissue coverage with local flaps.

with reamed technique. Brumback et al. (30) found no infections in a cohort of 62 type I-IIIA fractures, however 3 (11%) of type IIIB open femoral fractures developed infection. Open tibial fractures have likewise been successfully treated by intramedullary nailing (31-34).

External Fixation vs. Intramedullary Nailing

There are few studies that have directly compared external fixation for final stabilization vs intramedullary nailing. Torneta et al. (31) presented a case series using either method, which demonstrated no increased risk of infection. Henly et al. (32) found no difference in infection rates between undreamed nails and external fixation, but did note a rate of 31% malalignment in the external fixation group plus a 50% incidence of pin tract infection. Overall the risk of infection appears to be decreased with the use of intramedullary nails, as is the risk for revision surgery and malunions established by meta-analysis (33). Further, patient compliance is generally less problematic with those treated with intramedullary nailing. Intramedullary nailing is thus acceptable for treatment of types I-IIIB diaphyseal fractures with external fixation reserved for heavily contaminated/severe soft tissue compromised IIIB fractures, and for IIIC injuries

External Fixation

The advantages of external frame fixation for fractures are multiple; a) there is decreased risk for implant related deep infection, b) the devices are quickly and easily applied with little blood loss or compromised vasularity, c) there is no added obstacle to wound management, especially with spanning external fixation which avoids the zone of injury, d) fine wire ring fixators are particularly useful for periarticular fracture fixation (Figure 2). Multiple authors (35-37), with the adjunct of early bone grafting as appropriate, advocate definitive treatment of these injuries by use of external fixation. Marsh et al. (37) noted that 95% (96/101) type II and III fractures healed with little malalignment in over 95% of patients and a 6% infection rate Pin tract infections continue to be problematic to external fixation devices however. Techniques which can help decrease the rate of such infections include pre-drilling of holes for half pin fixators in order to avoid thermal necrosis of the bone, as well as careful selection of patient population, and rigid pin care protocol. Often a temporary spanning external fixator is placed during the initial phases of wound management with the intention of later conversion to intramedullary or plate fixation. This has been associated with infection rates of up to 50% if performed in an overly delayed fashion (13, 38). Blachut et al. (39) studied early vs late conversion to internal fixation and noted that when performed early, with a mean of 17 days, and in the absence of active pin tract infection, conversion to intramedullary nail an be performed with an infection rate of 5%. Further disadvantages to external fixation include the potential for loss of alignment and/or refracture after removal of the external-fixator.

FIGURE 2. A. X-ray of segmental tibia fracture and complex fibula fracture after motor vehicle collision injury. B. Clinical photo presenting proximal-medial wound, and very compromised soft tissue envelop around distal leg. C. Ring external fixator was applied, with minimal additional trauma, minimal risk of infection and good reduction and fixation.

Plate Fixation

Open reduction and plate fixation of intra-articular, peri-articular and metaphyseal fractures remains the current standard of care due to the unique ability of this technique to stabilize and support intra-articular and peri-articular fractures. Further, plate fixation is the preferred method of treatment for most upper extremity diaphyseal fractures as well (Figure 3). However, in the tibia, plate fixation of open fractures has been associated with an increased incidence of hardware failure and infection (40, 41). The newer generation of locking plate technology has the improved advantage of minimally invasive insertion and fixation with minimal periosteal stripping and thus improved preservation of bone perfusion (42, 43).

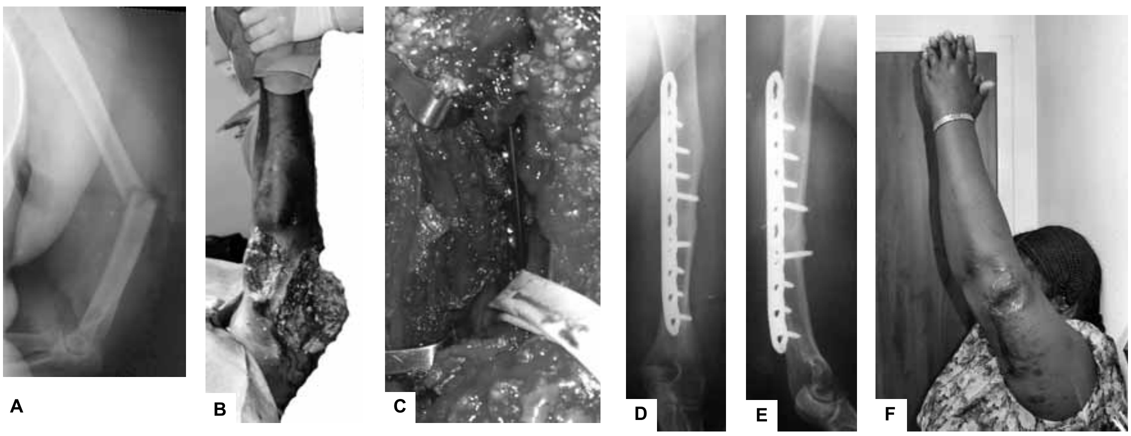

FIGURE 3. A. X-ray of transverse humeral shaft fracture with some free fragments and foreign bodies. B. Clinical photo three hours after turn-over vehicle accident with posterolateral and anteromedial soft tissue defects. C. Clinical photo of locked compression plate covered well by soft tissues and put in immediately after irrigation and debridement, reprapping and redraping of the extremity. D. AP x-ray view of the healed fracture 16 months after injury. E. Oblique x-ray view with healed fracture and two classical screws used to achieve axial compression, and locked unicortical screws to enhance fixation. F. Early motion facilitated by stable fixation, healing without infection resulted in excellent function after couple of months, here on 16 month follow-up.

Conclusion

The principals for management of open fractures remain largely unchanged by newer technical advances. The corner stone of treatment remains adequate irrigation and debridement with early broad-spectrum antibiotic usage. Delayed wound closure remains, as a valid, and often preferred technique in order to avoid the complications of late infection and clostridial myonecrosis. The use of antibiotic bead pouches is a new and useful addition to the surgeon's armamentarium. Early stabilization through external fixation, internal fixation, and/or intramedullary nailing is critical to the restoration not only of the bony anatomy, but to stabilization of the soft tissues as well. If external fixation is to be removed as a temporary stabilization device in preference to intramedullary fixation or plate fixation, then this should be done through a healthy soft tissue bed within the first 17 days after initial fixation.

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