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# Surgical timing for open fractures

## Middle of the night or the light of day, which fractures, what time?

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**Abstract**

Controversy exists over the optimal management of open fractures as new clinical studies question open fracture management dogma. Open fractures are complex injuries requiring the orthopaedic surgeon to consider both the bone injury as well as associated soft tissue injury. Early intravenous antibiotics and tetanus prophylaxis remain instrumental in infection prevention. However, the "six-hour rule" for initial open fracture debridement and revascularization has come into question. New evidence supports initial debridement within 24 hours with the appropriate surgical team. Additionally, orthopaedic surgeons and vascular surgeons should collaborate on the sequence of management of open fractures with associated vascular injury. Whereas debates on the optimal irrigation pressure and solution have been answered by multicenter randomized controlled trials, further research is required to determine the optimal irrigation volume and timing of wound closure. With advances in management of open fractures, the utility of well-known classification systems including the Gustilo-Anderson classification and Mangled Extremity Severity Score need to be re-evaluated in favor of up-to-date classification systems which better guide management and predict prognosis.

**Keywords:** open fracture, antimicrobial prophylaxis, surgical timing, infection, debridement, six-hour rule, wound closure, vascular injury

### 1. Introduction

The optimal surgical timing for management of open fractures continues to be debated with new evidence-based clinical studies questioning open fracture management dogma. As per the 2015 American College of Surgeons Trauma Quality Improvement Program recommendations on open fracture management, intravenous (IV) antibiotics should be started within 60 minutes of presentation to hospital, patients should be evaluated for tetanus vaccination requirements on presentation to hospital, they should be taken to the operating room (OR) for irrigation and debridement (I&D) within 24 hours, and soft tissue coverage should be performed within 7 days of injury.[1] This narrative review will evaluate current literature and provide up-to-date recommendations for surgical timing for open fracture management to optimize patient outcomes.

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### 2. Classification of open fractures

In order to make decisions about surgical timing, the open wound and the extent of soft tissue injury must be quantified in a way that can be easily communicated between surgeons.[2] However, there continues to be limitations with available classification systems for open fractures and universal acceptance of a single classification system has yet to occur.[3] The most well-known classification system was described by Gustilo and Anderson in 1976, which was modified in 1984.[4,5] Unfortunately, the Gustilo-Anderson classification has several limitations. The classification was initially described for open tibia fractures and used vague language which has been shown to have low interobserver agreement, with only 60% agreement amongst observers.[6,7] Another limitation of the classification system is when it is applied preoperatively, underestimation of the extent of soft tissue injury is common, as the original study described grading of open fractures while in the operating room, following debridement.[2] Finally, the Gustilo-Anderson classification incorporates treatment concepts into the classification. An ideal classification system should guide treatment decisions rather than the treatment determining the classification retrospectively.[8]

The Orthopaedic Trauma Association (OTA) – open fracture classification (OTA-OFC) was devised using 5 categories deemed to be essential for classifying open fracture severity (skin injury, muscle injury, arterial injury, contamination and bone loss).[8] This offered several advantages, including applicability to various anatomic regions in both adult and pediatric patients, greater observer reliability, and a clear definition that the timing of classification was at the initial surgical debridement. Compared to the Gustilo-Anderson classification, the OTA-OFC better predicted treatment outcome and limb amputation need.[9] However, the OTA-OFC has not been widely accepted in daily practice due to the complex nature of the scoring system.[10]

As a result, the familiarity of the Gustilo-Anderson classification and the categorization of the OTA-OFC were combined to form the Unified classification of open fractures.[10] In the Unified classification of open fractures, open fractures are described based on contamination, integument injury, muscle damage, bone loss, and arterial injury forming the acronym "CIMBA." Each of the 5 categories is then paired with the well-known Gustilo-Anderson classification categories I-IIIC. Finally, 1 devastating condition is added on to each of the 5 categories as the committee felt they deserved special attention: high-risk contamination (C), circumferential degloving (I), compartment syndrome (M), critical bone loss (B), subtotal/total amputation (A).[10] Initial evaluation of the unified classification of open fractures has shown excellent interobserver reliability attributed to the simplification of the OTA-OFC; however, further validation is required.[10]

## 3. Importance of early antibiotics

Perhaps the most critical step in open fracture management is administration of intravenous (IV) antibiotics, based on degree of contamination as soon as possible after injury.[11–13] As per the 2015 American College of Surgeons Trauma Quality Improvement Program recommendations on open fracture management, intravenous (IV) antibiotics should be started within 60 minutes of presentation to hospital and should be continued for not longer than 24 hours after surgical treatment, with the exception of severely contaminated fractures, where antibiotics can be continued up to 72 hours.[1] In a recent survey of 1197 AOTrauma registered members worldwide, 86% of surgeons reported ordering the first dose of prophylactic antibiotics for open fractures on arrival to the emergency department (ED).[14]

Based on 2011 Eastern Association for the Surgery of Trauma (EAST) open fracture management guidelines, systemic antibiotic prophylaxis choice is dependent on Gustilo-Anderson classification.[13] A first-generation cephalosporin is recommended for type I and II fractures, a first-generation cephalosporin plus aminoglycoside is recommended for type III fractures and penicillin is added if there is potential fecal or clostridial contamination.[13,15] In type III fractures, antibiotics should be continued for 72 hours after injury or 24 hours following soft tissue coverage.[13] In type III open fractures, piperacillin/tazobactam has been proposed as an alternative to cefazolin plus gentamicin as it has a better safety profile, more optimal bone distribution, can be given as the sole antibiotic, and is as effective as cefazolin plus gentamicin.[16] Fluoroquinolones are no longer recommended as antibiotic prophylaxis as they may have a detrimental effect on bone healing and may result in higher infection rates in type III open fractures.[13]

## 4. Light of day—timing of surgical debridement

The most appropriate timing remains controversial and continued research efforts are required in this area. Since Freidrich's 1898 guinea pig soft tissue contamination study, where bacteria replication rates were observed to increase exponentially after 6 hours, orthopaedic surgeons have followed the "six-hour rule" performing surgical debridement and irrigation within 6 hours.[17] Clinically, only Klindsfater et al's retrospective review of Gustilo-Anderson type II and III fractures has shown a decreased infection rate when fracture debridement occurred within 6 hours.[18]

Growing evidence suggests that the "six-hour rule" is based on historical perspective and numerous studies have failed to support this rule.[17,19] Early antibiotic administration, and performing a thorough debridement with the appropriate surgical team are more important factors in infection prevention than performing debridement within 6 hours of injury.[17] Among OTA members, 99.7% of respondents in a survey believed that I&D within 12 hours was acceptable for patients with contaminated type IIIA fractures.[20]

New evidence continues to show that I&D of open fractures performed within 24 hours does not increase infectious complications.[12,21] In a prospective cohort study of 315 open fractures, patients were stratified by time from injury to time of surgical debridement (less than 6 hours, 7–12 hours, 13–18 hours, and 19–24 hours).[21] The primary outcome measure was the development of early (within 30 days from admission) or late (after 30 days from admission) local infectious complications.[21] Of these, 70.2% of patients had lower extremity fractures and 47.9% of fractures were Gustilo-Anderson type III.[21] Implants were placed during the initial surgery for 59% of the patients and a total of 289 (91.8%) of patients were treated with metal implants. Controlling for mechanism of injury and metal implant use, no difference between the time to I&D and rate of infection between the 4 groups was found.[21] The authors concluded that provided I&D was performed within the first 24 hours after emergency department admission, time to I&D did not affect the early (4.4%) or late (3.2%) infection rates.[21]

Similarly, a meta-analysis of 16 studies (6 prospective and 10 retrospective), including 3906 open fractures, showed no significant difference in overall infection rate between early and late debridement with an odds ratio of developing an infection after late compared with early debridement of 0.91 (95% CI of 0.70 to 1.18).[22] Additionally, no significant differences in infection rates were identified when comparing debridement at 5-, 6-, 8-, and 12-hour time cutoffs.[22]

Orthopaedic traumatologists are still more likely to take patients with contaminated wounds and higher degree of injury (type III) to surgery expeditiously, representing clinical decision-making.[20,22,23] When surveyed, 40.9% of OTA members elect to take patients with contaminated type IIIA fractures to surgery for debridement as soon as possible. However, it seems that increasing Gustilo type and open tibia/fibula fractures have a higher association with developing deep infection, irrespective of time to initial surgery debridement.[22,23]

## 5. Type and volume of irrigation

The question of optimal fluid type and irrigation pressure in the management of open fractures was answered by the Trial of Wound Irrigation in the Initial Management of Open Fracture Wounds (FLOW).[24] The trial found that reoperation rates were higher with fluid containing castile soap and similar regardless of irrigation pressure. Therefore, very low pressure irrigation (gravity flow) with normal saline is both recommended and low cost.[24]

The optimal volume of irrigation remains controversial, as current literature does not provide specific irrigation volume recommendations.[25,26] To date, there are no human clinical studies evaluating optimal irrigation volumes for open fractures.[26] As a general recommendation, 3 litres are suggested for type I fractures, 6 litres for type II fractures, and 9 litres for type III fractures.[26] However, there are no clinical studies to support this recommendation.[26]

## 6. Evolution of soft tissue injury and importance of fracture stabilization

Unlike the underlying bony injury, which is largely static, soft tissue injury evolves with time. The extent of the fracture severity

Figure 1. Open medial peritalar dislocation with associated complete posterior tibial tendon injury following a fall from height. The talar head is exposed within the medial wound. Following initial ED stabilization, IV antibiotics, and I&D, the patient was taken to the operating room within 6 hours for definitive management.

is known at the time of initial imaging, but the soft tissue injury may continue to worsen. Therefore, the initial assessment and classification of an open wound may be inaccurate, resulting in delayed surgical treatment. Though there are radiographic features that suggest higher energy injury, such as comminution, both bones fractures at the same level for forearm and lower leg fractures, segmental fractures etc., the full extent of the soft tissue injury may not be immediately apparent.

It is important to provide fracture stabilization to prevent further soft tissue injury and restore soft tissue tension. Fracture stabilization decreases swelling, improves circulation, and facilitates the host response to bacteria and alleviates pain.[3,25] Fracture stabilization can be in the form of splinting, application of an external fixator, insertion of an intramedullary nail, plate fixation, or a combination of these techniques.[3] In the case of a high-grade soft tissue injury, the application of an external fixator has the benefits of rapid application, ease of soft tissue monitoring and compartment pressure assessment, as well as avoiding any disruption of potential soft tissue reconstruction options.

## 7. Wound closure—primary or delayed

Historically, open fracture closure was delayed following initial debridement and closure was advocated by the seventh day if the wound was clean, or left open to heal by secondary intention in cases of larger soft tissue defect due to concern of gas gangrene.[11] However, with modern advances in open fracture management including early antibiotics, tetanus prophylaxis, and thorough I&D, concerns regarding deep infection with primary wound closure may be less relevant.[11,27]

Recent evidence supports early primary closure of open fractures in appropriately selected patients and fractures.[27,28] In a prospective cohort of Gustilo-Anderson type IIIA or lower fractures who underwent primary wound closure following surgical fixation, infection (4%) and nonunion (12%) rates were significantly lower than a matched delayed closure cohort.[27] Similarly, in a retrospective cohort study by Jenkinson et al, early primary closure of Gustilo-Anderson type I-IIIA fractures was associated with a lower infection rate (4.1%; 95% confidence interval (CI) of 0.86–11.5) compared to delayed primary closure (17.8%, 95% CI of 9.8–28.5). A deep infection rate ~4% (4.7%)

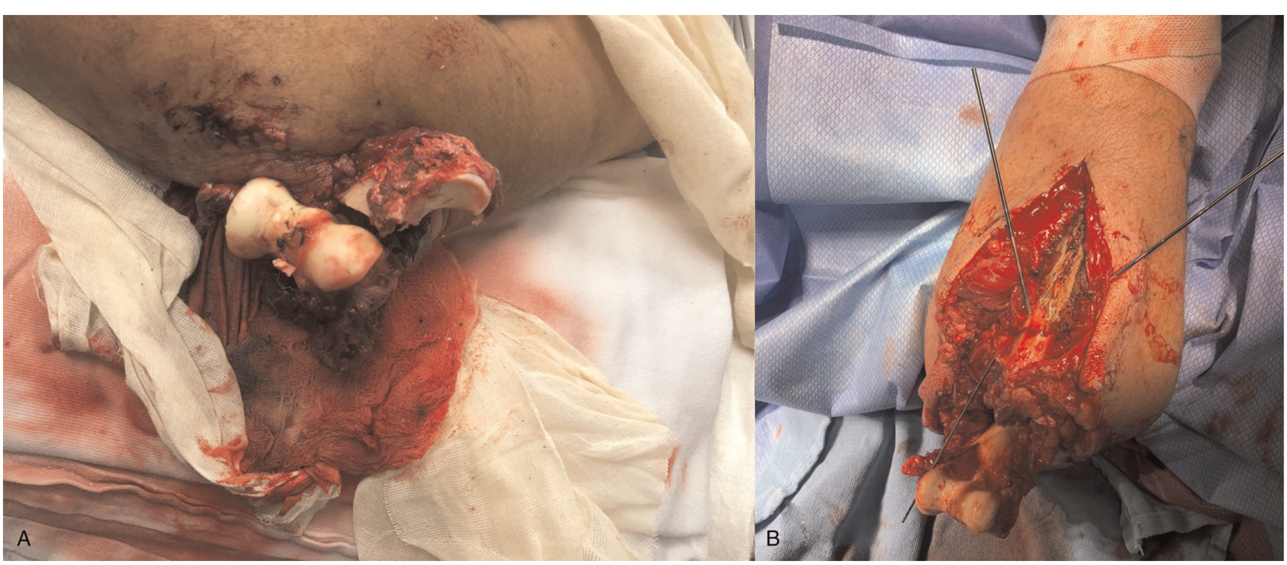


Figure 2. (A) Open transolecranon fracture dislocation following a head-on motor vehicle crash at highway speeds. Following initial ED stabilization, the patient was neurovascularly intact and taken to the operating room within 6 hours for management of the open fracture. (B) Intraoperative findings demonstrate complete denuding of the distal humerus.

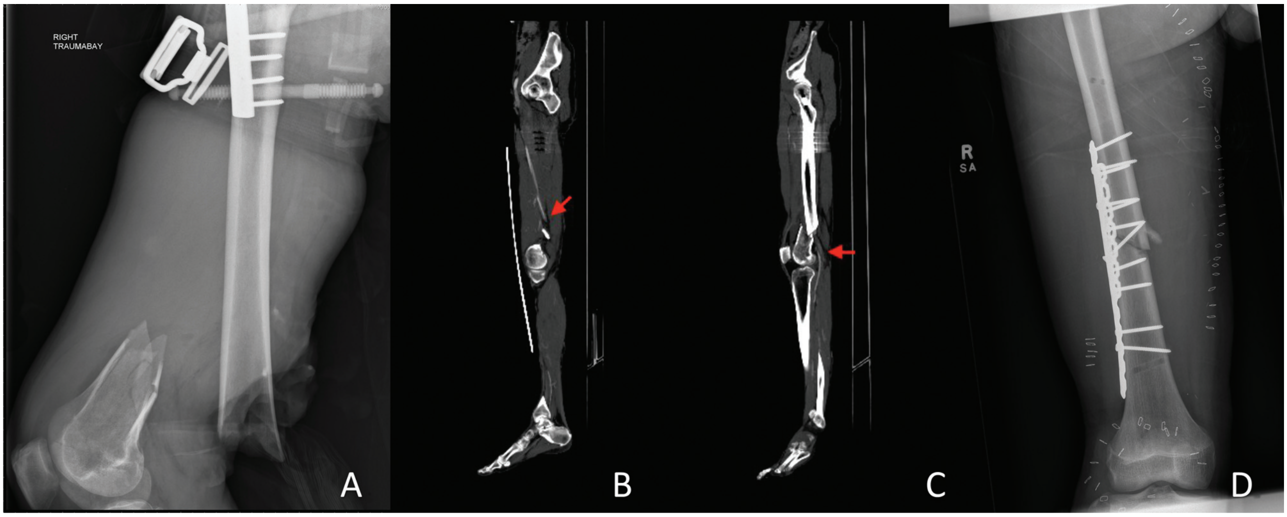


Figure 3. (A) Lateral radiograph of right femur performed in the trauma bay demonstrating type IIIC open distal femur fracture with vascular injury secondary to bicyclist versus motor vehicle crash. (B) CT angiogram sagittal images demonstrate traumatic injury involving the distal femoral and proximal popliteal arteries, (C) with reconstitution of flow distally at the level of the distal popliteal artery from collateral vessels. The injury was managed emergently with application of a knee spanning external fixator by orthopaedic surgery followed by femorotibial bypass and 4 compartment fasciotomies. (D) On postoperative day 1, the patient was taken back to the operating room for repeat I&D and open reduction internal fixation with a distal femoral locking plate.

was also found in a retrospective review of 297 Gustilo-Anderson type I-III fractures, which supported attempting primary closure for all open fractures.[29] Early primary closure requires the orthopaedic surgeon to determine that the open fracture has been "adequately debrided," a decision that requires experience.[11,27] Most type 1 and type II open wounds can be closed primarily following systematic I&D.[11] Most type IIIA wounds can be closed following a repeat I&D, if clean and tension-free closure can be achieved.[11] Obvious contraindications to early primary closure include gross contamination with feces, dirt, stagnant

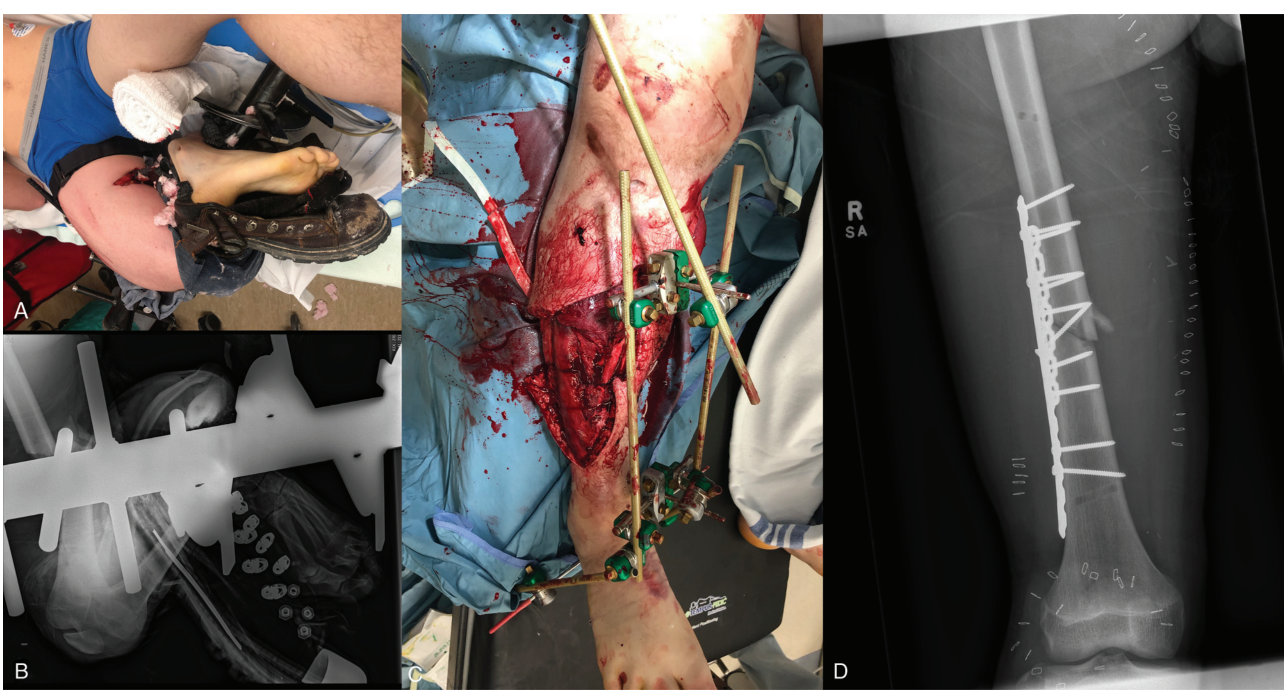


Figure 4. (A) Trauma bay photograph and (B) radiograph of mangled right leg with associated traumatic popliteal artery injury secondary to cotton auger accident (MESS score = 7). The patient had a prolonged extrication in a rural community and arrived at the level 1 trauma center at 4 hours warm ischemia time. (C) Following discussion between orthopaedic and vascular surgery services, the patient underwent application of knee spanning external fixator for fracture stabilization followed by superficial femoral artery to tibioperoneal trunk bypass. (D) On postoperative day 2, the patient underwent open reduction internal fixation of the right femur. Unfortunately, 6 days following initial presentation, the patient underwent a below knee amputation for insensate lower extremity with single-vessel perfusion.

water, farm-related injuries, freshwater boating accidents, antibiotic initiation greater than 12 hours postinjury, or questionable soft tissue viability during initial I&D.[11]

## 8. Middle of the night—open fracture cases requiring emergent treatment

Open fractures with associated irreducible joints and exposed articular cartilage require timely surgical management. For example, in the setting of open talar fracture dislocations, it is recommended that the fracture dislocation be reduced and stabilized emergently due to the increased risk for complications including skin necrosis, infection, and loss of bone perfusion (Fig. 1).[30] Early and adequate coverage of exposed wounds with viable skin or soft tissue is required as prolonged exposure of articular cartilage can lead to desiccation, necrosis, and increased chance of contamination and infection (Fig. 2).[3]

Although vascular injury associated with extremity fractures occurs in <1% of cases, orthopaedic surgeons need to have a high suspicion for vascular injury in open fractures (Fig. 3).[31] In general, vascular injury associated with open fractures should be addressed within 3 to 4 hours, but may be delayed up to 6 hours of warm ischemia time.[32] However, a recent meta-analysis showed that absolute ischemia time limits should be avoided as ischemia-related tissue injury is dependent on the proficiency of collateral flow.[33] Early communication between vascular surgery and orthopaedic surgery is key as the sequence of management of these injuries remains controversial. Early orthopaedic stabilization of the fracture can re-establish anatomic limb length to ensure adequate length of the subsequent vascular repair and protect the vascular repair from damage during further manipulation of the extremity.[31,34] However as the warm ischemia time increases, vascular repair prior to orthopaedic stabilization should be considered.[31,34] The rate of lower extremity amputation has been shown to be similar irrespective of whether fracture stabilization or vascular repair is performed first.[33] The Mangled Extremity Severity Score (MESS) provides a cumulative score based on the extent of skeletal/soft tissue injury, hemorrhagic shock, severity of ischemia, and patient age where a score less than or equal to 6 prompts limb salvage attempt and score equal to or greater than 7 predicts a low likelihood of extremity viability and is predictive of amputation (Fig. 4).[35] However, advances in management of mangled extremities have reduced the accuracy of the MESS score and new methods of predicting limb salvage versus limb amputation are required.[36]

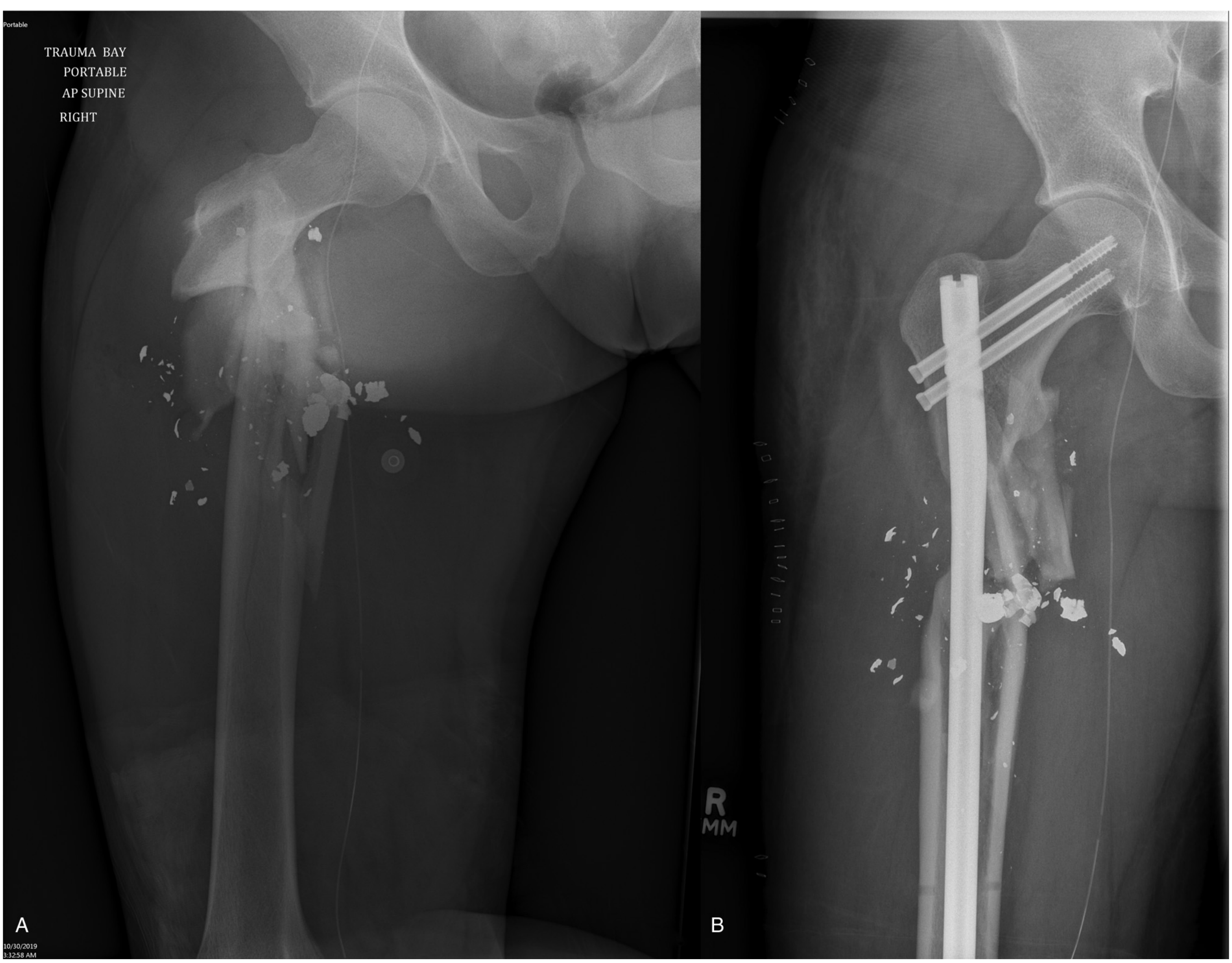


**Figure 5.** (A) Open comminuted proximal femur fracture from a close range shot gun. (B) The patient was neurovascularly intact with a 2-cm entry wound on ED presentation. He was monitored overnight, then surgically managed during daylight hours to ensure the appropriate surgical, nursing, and anesthesia teams were present.

## 9. Open fractures due to gunshot wounds

The management of open fractures due to gunshot wounds depends on the energy of the projectile and the resultant fracture. Gunshot wounds can be classified by velocity (low: 1000–2000 feet per second (fps) vs high: greater than 2000–3000 fps) or energy (dependent on projectile mass, velocity, and efficiency of energy transfer).[37] Classifying gunshot wounds by energy is preferred over velocity alone, as a low-velocity weapon such as a shot gun can produce substantial injury at close range. A minimum bullet velocity of 195 to 200 fps is required to breach the cortex of bone. Depending on the energy characteristics of the bullet, bone involvement can range from incomplete fracture (i.e., drill-hole, divot, chip) to complete fracture patterns (i.e., single and double butterfly, comminuted).[37]

Low-velocity gunshot wounds are treated conservatively with superficial irrigation, careful cleaning, and dressing, with or without antibiotics.[37] When associated with fracture, nonoperative management is preferred if the fracture can be managed nonoperatively to reduce further soft tissue and blood supply damage.[37] In the case of high-velocity and close range shotgun fractures, wounds should be debrided with special attention to foreign material and wadding within 6 hours,[38] and repeated during the first 2 to 10 days after injury until clean wound margins remain.[37] If possible, wounds should be closed primarily or skin grafted within the first 10 days.[37] Fractures should follow an open fracture management protocol with early stabilization using external fixation followed by definitive fixation (Fig. 5).[37] Gunshot wounds to the extremities are associated with a 17% incidence of vascular injury.[39] The incidence of vascular injury with gunshots to the calf and forearm/antecubital fossa can be as high as 22%.[39]

Bullets that travel through joints can lead to bone, cartilage, ligaments, and menisci damage leading to complications like posttraumatic arthritis, joint sepsis, and chondrolysis.[40] It is recommended that intra-articular bullet fragments be removed and the joint debrided arthroscopically or through an arthrotomy as common metals used in bullets like lead and copper can dissolve leading to toxicity.[37] Additionally, patients should receive a minimum of 24 to 48 hours of intravenous antibiotic therapy.[37]

## 10. Summary

Open fracture management requires careful assessment of the bone injury including fracture characteristics and bone loss, as well as soft tissues including contamination, integument injury, muscle damage, and neurovascular injury. Despite their limitations, the Gustilo-Anderson classification and Mangled Extremity Severity Score continue to be the most utilized classification systems for open fractures. However, newer classification systems like the Unified classification system may better describe open fracture characteristics with better inter-rater reliability. The goals of open fracture management include decreasing infection risk and promoting fracture union. Initial management includes early IV antibiotics and tetanus prophylaxis. Contrary to open fracture dogma, initial debridement should be performed within 24 hours with an appropriate surgical team as opposed to within 6 hours. Irrigation of open fractures should be performed with normal saline by gravity flow; however, optimal irrigation volume has not been determined clinically. In the case of open fracture with vascular injury, early communication between orthopaedic surgery and vascular surgery is required to optimize patient outcomes. Early primary closure of open fractures should be considered if wounds are clean and tension-free closure can be achieved.

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