Review Article

Open Tibial Shaft Fractures: I. Evaluation and Initial Wound Management

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Abstract

Open fractures of the tibial diaphysis are often associated with severe bone and soft-tissue injury. Contamination of the fracture site and devitalization of the soft-tissue envelope greatly increase the risk of infection, nonunion, and wound complications. Management of open tibial shaft fractures begins with a thorough patient evaluation, including assessment of the bone and soft tissue surrounding the tibial injury. Classification of these injuries according to the system of Gustilo and Anderson at the time of surgical débridement is useful in guiding treatment and predicting outcomes. Administration of antibiotic prophylaxis as soon as possible after injury as well as urgent and thorough débridement, irrigation, and bony stabilization are done to minimize the risk of infection and improve outcomes. The use of antibiotic bead pouches and negative-pressure wound therapy has proved to be efficacious for the acute, temporary management of severe bone and soft-tissue defects.

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The subcutaneous location of the anteromedial tibial surface is the reason for the high proportion of diaphyseal fractures that are open. These fractures are associated with severe bone and soft-tissue injury. The often high-energy nature of these injuries can lead to gross contamination of the bone and soft tissue, thereby greatly increasing the risk of infection, nonunion, and wound complications.

Appropriate initial management of open tibial shaft fractures can profoundly affect the overall outcome. The first step in treatment is assessment of the patient and the involved extremity. The goals of initial treatment are to accurately define the extent of the injury and minimize the risk of infection through prompt administration of antibiotics as well as urgent débridement and copious irrigation.

Epidemiology and Patient Evaluation

Fractures of the tibial diaphysis are the most common long bone fracture, and approximately 24% of these fractures are open.[1] Road traffic accidents are the mechanism of injury in more than half of all open tibial shaft fractures, with most of the remainder caused by falls, sports-related injuries, and direct blows.[1] The high-energy nature of most of these fractures contributes to the increased proportion of Gustilo type III (ie, high-energy open) injuries. In their large epidemiologic study, Court-Brown et al[2] found that nearly 60% of open tibial shaft fractures were Gustilo type III.

Because more than half of patients with open tibial shaft fracture present

with other injuries, the initial evaluation should follow the guidelines of the Advanced Trauma and Life Support protocol.[2,3] After initial resuscitation, a detailed history of the injury should be sought, with a focus on the mechanism and setting. Tetanus immunization status should also be determined. During physical examination of the injured extremity, special attention should be paid to the neurovascular examination, status of the compartments, and the extent of soft-tissue injury and contamination. It is important to compare pulses between legs and to observe for capillary refill. In all patients with an abnormal vascular examination, the fracture should be reduced and the extremity evaluated using the ankle-brachial index or Doppler ultrasonography. A patient with an ankle-brachial index of <0.9 should be evaluated with angiography. Absent pulse and clinical ischemia constitute an emergency and should prompt angiographic evaluation in the operating room with emergent vascular surgery consultation. Temporary revascularization should be performed for all arterial injuries, followed by débridement, irrigation, external fixation, fasciotomy, and definitive vascular repair. Definitive fracture fixation is often best deferred until closure of the fasciotomies. Compartment syndrome can occur in open fractures. Following initial assessment and in the absence of vascular injury, the wound should be cleared of gross debris and covered with a sterile permeable dressing, after which the limb should be realigned and immobilized in a well-padded splint. The decision to perform limb salvage or to pursue primary amputation is made at this time.

Classification

The AO classification system of open fractures offers a comprehensive method of classifying both bony and soft-tissue injuries. Bony injury is classified according to the standard AO/OTA classification scheme; soft-tissue injury is categorized by the damage imparted to three distinct anatomic structures: integument, muscle and tendon, and neurovascular system. Injury to the skin is further classified as open or closed (Table 1). This framework enables accurate classification of the fracture and associated soft-tissue injury; however, it is not commonly used in the United States.[4]

Table 1

AO Classification of Soft-tissue Injury in Open Fractures

Type of Injury	Description
Skin lesion (open fracture)	
IO 1	Skin breakage from inside out
IO 2	Skin breakage from outside in <5 cm, with contused edges
IO 3	Skin breakage from outside in >5 cm, with increased contusion and devitalized edges
IO 4	Considerable, full-thickness contusion, abrasion, extensive open degloving, and skin loss
IO 5	Extensive degloving
Muscle/tendon	
MT 1	No muscle injury
MT 2	Circumscribed muscle injury, one compartment only
MT 3	Considerable muscle injury, two compartments
MT 4	Muscle defect, tendon laceration, and extensive muscle contusion
MT 5	Compartment syndrome/crush syndrome with a wide zone of injury
Neurovascular	
NV 1	No neurovascular injury
NV 2	Isolated nerve injury
NV 3	Localized vascular injury
NV 4	Extensive segmental vascular injury
NV 5	Combined neurovascular injury, including subtotal or even total amputation

Adapted with permission from Rüedi TP, Murphy WM: Soft-tissue grading system of the AO, in Rüedi TP, Buckley RE, Moran CG, eds: *AO Principles of Fracture Management*. New York, NY, Thieme, 2000, pp 72-73.

More commonly, open fractures of the tibial diaphysis are classified according to the system of Gustilo and Anderson.[5] First proposed in 1976, this classification was modified to its current form in 1984[6] (Table 2). Type I injuries are low energy and are associated with small soft-tissue wounds (usually <1 cm in length) with minimal contamination. Type II injures have a wound >1 cm in length but do not present with extensive soft-tissue damage, flaps, or avulsions. Generally, type II open fractures are low-energy injuries, but they have more soft-tissue involvement than do type I fractures. Type III injuries are high-energy wounds. These have been subclassified into categories A, B, and C. Type IIIA injuries have extensive soft-tissue damage secondary to high-energy trauma but have adequate soft-tissue coverage. Type IIIB injures exhibit severe periosteal stripping and bone exposure, often associated with massive contamination. The patient with type IIIB injury may require treatment with soft-tissue coverage procedures.

Table 2

Gustilo Classification of Open Fractures[6]

Type	Description
I	Clean wound <1 cm in length
II	Clean wound >1 cm in length without extensive soft-tissue damage, flaps, or avulsions
IIIA	Adequate soft-tissue coverage despite extensive soft-tissue damage, flaps, or high-energy trauma irrespective of the wound size
IIIB	Inadequate soft-tissue coverage with periosteal stripping, often associated with massive contamination
IIIC	Arterial injury requiring repair

Type IIIC fractures require vascular repair. The full extent of the injury to the deep soft tissue and its viability is often underestimated on presentation and may not correlate with the size of the skin defect. The definitive classification of an open fracture should be made in the operating room.

Despite the widespread use of the Gustilo classification, interobserver agreement has been reported to be only 60%.[7] Nevertheless, the Gustilo classification is useful in communicating the severity of open fracture among surgeons and in helping the treating physician predict the outcome of an open fracture. The Gustilo classification system also has prognostic significance; increasing infection rates and worse outcomes are associated with increasing severity of injury.[5,8] Infection rates range from zero to 2% for type I fractures, 2% to 10% for type II fractures, and 10% to 50% for type III fractures.[5,8]

Infection Risk and Wound Culture

Infection of an open tibia fracture is a serious complication that can lead to significant morbidity, delayed union or nonunion, and even amputation. In the absence of antibiotic prophylaxis, infection occurs in approximately 24% of open fractures.[9] In a series of 1,104 open fractures, Patzakis and Wilkins[8] showed the tibia to be more prone to infection than are other long bones (10.5% [38/363] versus 5.3% [39/741], respectively). This is likely because of the large subcutaneous extent of the tibia, which leads to greater soft-tissue stripping and increased difficulty in obtaining muscular coverage as well as the frequent disruption of significant portions of the vascular supply.

There is no benefit in obtaining preoperative or intraoperative cultures of open tibia fracture wounds. In early studies, routine wound culture indicated that 8% of predébridement wound cultures resulted in infection.[10-12] However, many subsequent studies have demonstrated that initial wound cultures in the early postfracture setting are ineffective in predicting either infection or the identity of causative organism.[11,12] Additionally, postdébridement wound cultures fail to isolate the infecting organism in 58% of cases.[12] Thus, early postfracture wound cultures are not routinely recommended. In general, wound culture should be obtained only through sterile technique when clinical signs of infection are present.

Host Factors

Many factors contribute to the overall outcome of an open fracture of the tibial shaft. However, diabetes, HIV status, and smoking, in particular, have been associated with delayed union as well as a higher rate and increased severity of infections. Aderinto and Keating[13] reported deep infection in two of four open tibial shaft fractures in patients with diabetes. One patient with deep infection required transtibial amputation 4 months after intramedullary nailing. Infection rates of 71% to 100% were reported in two series of open tibia fractures in HIV-positive patients.[14,15] In addition, a trend toward nonunion was demonstrated in HIV-positive persons with open tibia fracture compared with persons with such fracture who were HIV-negative. Smoking has been more extensively evaluated as a factor in wound healing. Several retrospective studies have demonstrated decreased union rates and slower time to healing as well as increased infection rates and complications in persons who smoke.[16,17] It is important to consider these factors in the treatment plan and when counseling patients on their prognosis. Appropriate medical or subspecialist consultation to optimize glycemic control or to initiate HIV treatment as well as counseling on smoking cessation may improve outcomes in patients with open tibia fracture.

Antibiotic Prophylaxis

Antibiotics were long believed to prevent infection in open fractures. However, until publication of the prospective randomized placebo-controlled study by Patzakis et al[10] in 1974, there was no evidence to support this assumption. This series was the first to investigate infection rates with respect to specific antibiotic use. The authors demonstrated a significant reduction in infection with administration of cephalothin (2.4%

[2/84 fractures]) compared with no antibiotics (13.9% [11/79]) or a regimen of penicillin and streptomycin (9.8% [9/92]) ($P \leq 0.05$). Coagulase-positive *Staphylococcus aureus* and β-hemolytic streptococci were the most common pathogens isolated, accounting for 14 of the 22 infected wounds. Only two of these infections occurred in the cephalothin group. Open tibia fracture was the most common fracture studied in this group. This and subsequent series established strong evidence for the efficacy of first-generation cephalosporins in the management of open fractures.[10,18] However, investigators also concluded that antibiotic prophylaxis should include gram-negative coverage as well, which is suggested but not directly supported by data. Currently, there are insufficient data to conclude that gram-negative prophylaxis is beneficial in the management of open fractures.[18]

Penicillin G is commonly recommended for prophylaxis against clostridial myonecrosis.[18] However, data are insufficient to support this recommendation. Moreover, it is rare for *Clostridium perfringens* to be resistant to antibiotics typically used for open fracture prophylaxis.[19] Nevertheless, the importance of adequate débridement and delayed closure for wounds thought to be at high risk for clostridial myonecrosis (eg, farm injuries, prolonged ischemia) cannot be overemphasized.

Quinolones have been evaluated as an alternative to intravenous cephalosporins for infection prophylaxis.[20] This class of drugs is attractive for several reasons. These drugs offer broad-spectrum bactericidal coverage, they can be administered orally, they require less frequent administration, they achieve good bone penetration, and can provide prophylaxis for patients who are allergic to penicillin. In 2000, Patzakis et al[20] published the results of a study comparing single-agent ciprofloxacin with a combination of cefamandole and gentamicin. Both regimens provided similar rates of infection prevention in type I and II open fractures. However, for type III open fractures, the infection rate with ciprofloxacin alone was 31%, compared with 7.7% for combined prophylaxis with cefamandole and gentamicin. Approximately one third of the fractures in this study involved the tibia. Based on these results, the authors recommended that ciprofloxacin not be used alone as prophylaxis for type III open fractures. The benefits of prophylaxis with fluoroquinolones must be weighed against experimental evidence suggesting that fluoroquinolones adversely affect the early phases of bone healing.[21]

Timing and Duration of Prophylaxis

Antibiotic prophylaxis should be initiated as soon as possible after injury. The benefit of early antibiotic prophylaxis was demonstrated by Patzakis and Wilkins,[8] who showed a significantly increased rate of infection in fractures managed with antibiotic prophylaxis >3 hours after injury compared with <3 hours after injury (7.4% versus 4.7%, respectively). However, the appropriate duration of antibiotic prophylaxis is less clear. There is evidence that shorter courses of antibiotics are as effective as longer courses, but the most appropriate duration has not been determined. Dellinger et al[22] found no difference in infection rates between a 1-day course of cefonicid sodium (12.7% [10/79]), a 5-day course of cefonicid (11.8% [10/85]), and a 5-day course of cefamandole (13.1% [11/84]).

It is clear that antibiotic prophylaxis reduces the rate of infection in open fractures and should be routinely administered. However, it is important to consider the available data and avoid the use of broad-spectrum antibiotics because their use has been shown to increase the risk of nosocomial infections in general as well as the risk of death resulting from nosocomial pneumonia.[18] There is evidence to support a short course of first-generation cephalosporin or a similar agent active against gram-positive bacteria as prophylaxis for all types of open tibia fractures.[18] Alternatively, a quinolone can be considered for treatment in type I and II fractures.[20] We recommend that the duration of initial wound prophylaxis be limited to a 24- to 72-hour course.[8,22] There is no clear evidence supporting or opposing the recommendation to administer subsequent 24- to 48-hour courses of antibiotic prophylaxis for each additional surgical procedure until definitive wound closure; thus, this decision must be made at the surgeon's discretion.[18]

Wound Management

Timing of Débridement and Irrigation

The timing of initial surgical débridement of open tibia fractures is controversial. Most current guidelines recommend that débridement be performed within 6 hours of injury.[23] However, few recent data exist to support this recommendation, which is believed to stem from Friedrich's 1898 study of guinea pigs.[24] Most of the current literature is unable to demonstrate a decreased infection rate for open tibia fractures that are initially débrided within 6 hours of injury compared with those débrided later.[25] We feel that surgical management of low-energy, type I open fractures may be delayed until the following morning; however, although the evidence does not mandate the

emergent débridement and irrigation of open tibia fractures within 6 hours of injury, treatment should not be delayed until the end of an elective schedule the following evening. Most surgeons agree that highly contaminated type III open tibia fractures are best treated with urgent surgical débridement and irrigation.

Débridement and Irrigation

Débridement and irrigation are vitally important to the successful management of open tibia fractures. Although the details and methods of irrigation are debated, the role of careful and complete débridement is clear. Gustilo stated that adequate débridement is the single most important factor in the attainment of a good result in the treatment of an open fracture[26] (Figure 1).

Systematic débridement, beginning with removal of gross contamination and debris, should be done as soon as possible in the operating room. However, if the patient is too obtunded for urgent surgical intervention, removing the gross contamination can begin in the resuscitation bay or the emergency department. A tourniquet should be applied before prepping and draping, but it should not be inflated. Tourniquet use should be minimized because it is more difficult to assess the viability of tissues in the presence of an inflated tourniquet. Furthermore, an elevated tourniquet may cause additional ischemic damage to an already compromised region. The injury shock wave can devitalize tissues beyond the extent of the skin defect. Often, it is necessary to extend the traumatic wound to adequately evaluate the nature of the soft-tissue injury and to address bony contamination. Extension of the traumatic wound should be longitudinal and carefully planned, with consideration made for future rotational flaps.

All necrotic tissue is excised, and muscle viability is determined by the four Cs: contractility, color, consistency, and capacity to bleed.[26] Completely free, large cortical bone fragments may be preserved in a sterile fashion to aid in determining length and rotation at the time of fracture stabilization. However, these fragments should be removed before definitive fixation and closure. Significant articular fragments should be thoroughly cleansed and retained when possible. In high-energy injuries, it is often difficult to fully determine the viability of all tissues within the zone of injury at the time of initial débridement. Repeat débridement at 48- to 72-hour intervals should be done to eliminate devitalized tissue that subsequently develops.

Irrigation is used to supplement systematic and thorough débridement in removing foreign material and decreasing bacterial load. Despite its importance and the frequency with which irrigation is employed, there is a relative paucity of high-quality literature pertaining to the optimal solution, volume, additive, and method of irrigation for open tibia fractures.

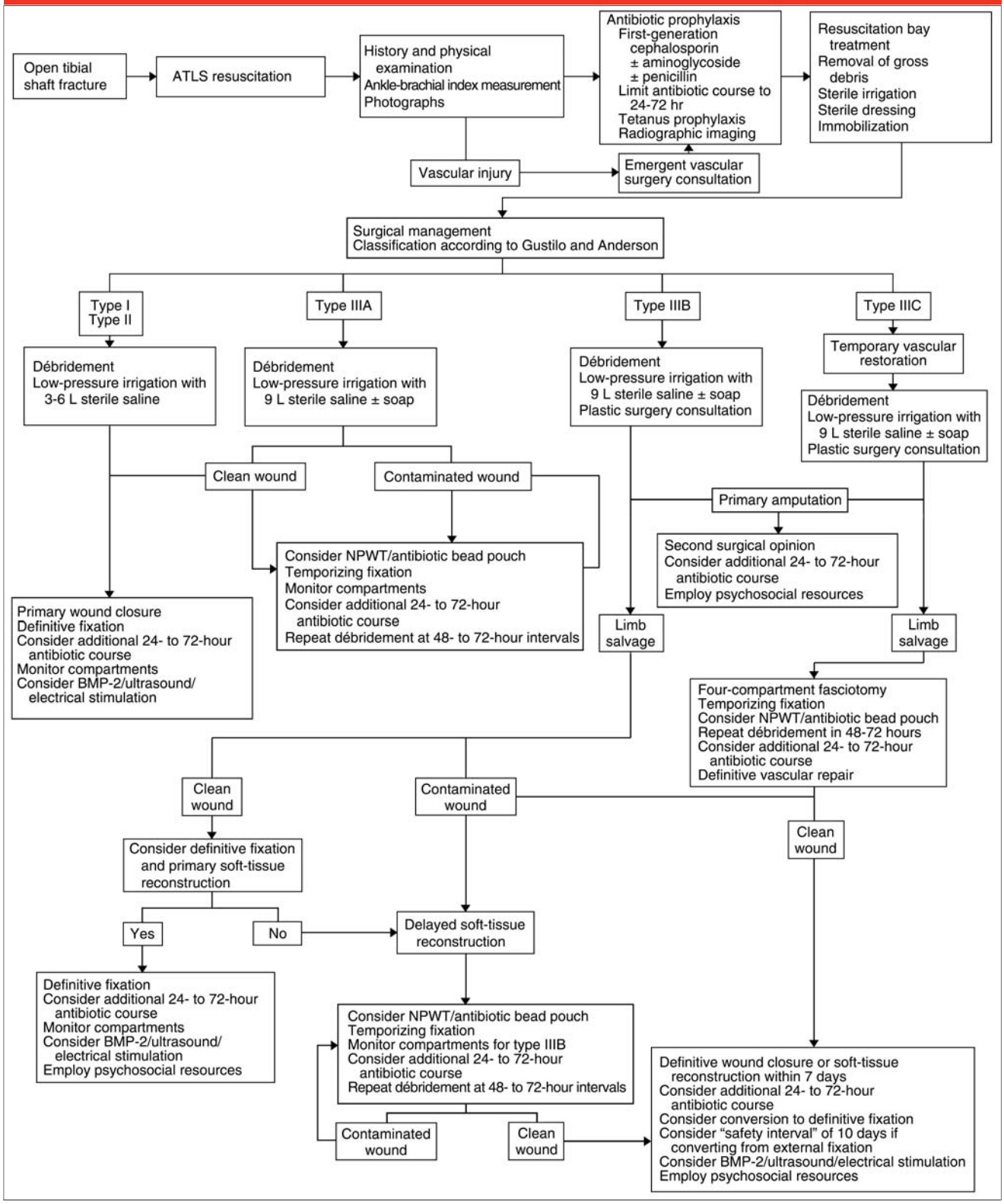
There are scant animal data suggesting that increasing the volume of irrigation improves the removal of bacteria and debris; however, the optimal volume has not been determined.[27] Based on the widespread availability of 3-L bags of normal saline, Anglen[27] recommended using 3 L of irrigation for type I fracture, 6 L for type II fracture, and 9 L for type III fracture.

Some surgeons use sterile saline alone for irrigation. The use of antiseptics, antibiotics, and surfactants in combination with saline has been studied in an attempt to determine the efficacy of these agents in reducing bacterial load and their effects on local tissue viability and healing. Antiseptic solutions such as povidone-iodine, Dakin solution, and chlorhexidine disrupt the bacterial cell wall or membrane; these solutions have not been shown conclusively to lower infection rates.[27] Additionally, there exists substantial in vitro evidence that these solutions adversely affect the viability of host cells grown in cell culture and, thus, that they should be avoided as additives for irrigation.[27]

Antibiotics differ from antiseptics mechanistically in that antibiotics interfere with bacterial physiology. Most animal studies have shown antibiotic irrigation (typically, bacitracin) to be superior to saline irrigation alone at preventing infection in contaminated soft-tissue wound models.[27] However, human studies in the orthopaedic literature have failed to demonstrate the superiority of antibiotic irrigation compared with standard irrigation.[27] Moreover, although the risk of antibiotic irrigation is low, it adds cost, may promote resistance, and carries a small risk of anaphylaxis.[27] Thus, in the absence of a proven benefit in humans, the potential risks and additional costs of antibiotic additives should be carefully considered in regard to the irrigation of open fractures.

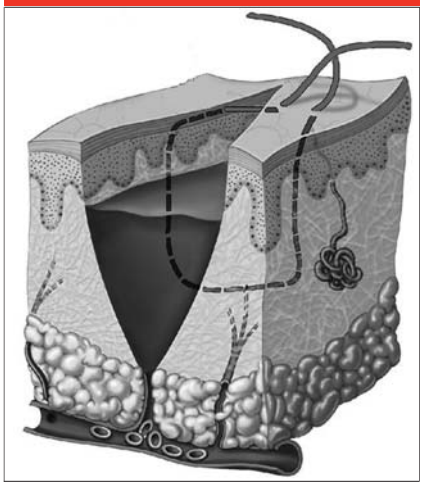
Surfactants or soaps have been used in wound irrigation since the preantibiotic era. Surfactants work by disrupting the hydrophobic forces that function in bacterial surface adhesion. In an in vitro study, Anglen et al[28] demonstrated that a castile soap solution was several orders of magnitude more effective than an antibiotic solution in removing a glycocalyx-producing bacteria from stainless steel screws. Bhandari et al[29] studied the effects of several irrigating solutions on canine tibias that had been inoculated with *S aureus* for 6 hours. They found that a soap solution best preserved the number and activity of osteoblasts and removed the great-

Figure 1



Treatment algorithm for open tibial shaft fracture. ATLS = Advanced Trauma and Life Support, BMP-2 = bone morphogenetic protein-2, NPWT = negative-pressure wound therapy

Figure 2



The Donati-Allgöwer suture pattern. The suture does not exit the epidermis; instead, it anchors vertically in the dermis on the far side of the wound. Increasing tension pulls the far side into opposition with the near side of the wound, but this does not seem to result in kinking or folding of the skin and, thus, does not compromise blood flow. (Adapted with permission from Sagi HC, Papp S, Dipasquale T: The effect of suture pattern and tension on cutaneous blood flow as assessed by the laser Doppler flowmetry in a pig model. *J Orthop Trauma* 2008;22:171-175.)

est number of bacteria.

More recently, Anglen[30] prospectively randomized patients with open fracture of the lower extremity to either irrigation with a bacitracin solution or a nonsterile castile soap solution. Infection developed in 18% of patients irrigated with bacitracin and in 13% of patients irrigated with the castile soap solution. This difference was not statistically significant. Significantly increased wound healing problems were reported in the antibiotic irrigation group ($P = 0.03$). Anglen[30] concluded that antibiotic solutions offer no advantage over nonsterile castile soap in the irrigation of open fractures and that antibiotic solutions may, in fact, adversely affect wound healing. We believe that soap added to irrigation is most useful for all fractures with visible contamination and for those fractures for which initial débridement and irrigation is delayed >12 hours.

The effect of irrigation pressure has also been evaluated. Evidence indicates that high-pressure pulsatile lavage (HPPL) (nozzle pressure ≥50 psi) is effective in removing bacteria and debris from wounds.[31] However, recent animal studies have suggested that HPPL may be detrimental to bone and soft-tissue structure as well as bone healing and that it may drive bacteria into wounds.[27,31-33] Hassinger et al[32] evaluated fresh ovine muscle specimens contaminated with bacteria and demonstrated deeper bacteria penetration and greater bacterial retention with HPPL compared with low-pressure lavage. In a similar model, Boyd and Wongworawat[33] showed that HPPL penetrates and disrupts soft tissues to greater a degree than does low-pressure lavage. Dirschl et al[31] demonstrated a detrimental effect of HPPL on early new bone formation in New Zealand white rabbits that underwent osteotomy of the medial femoral condyle and subsequent HPPL. In that study, HPPL was compared with control and bulb syringe irrigation groups. A follow-up study showed that early new bone formation is inhibited by HPPL pressure ≥50 psi.[34]

We have found that continuous gravity irrigation via cystoscopy tubing using 6 to 9 L of normal saline (with a soap solution for heavy contamination) provides excellent wound irrigation without the potential detrimental effects of HPPL, antiseptic, or antibiotics. A prospective multicenter international study is under way to examine the effects of both fluid pressure (high versus low) and solution type (normal saline versus normal saline with soap) on the infection rate of open fractures.

Immediate Primary Wound Closure

Immediate primary closure of an open wound is possible when an adequate amount of viable soft tissue is available to allow closure of an open wound without tension. With modern antibiotic prophylaxis and surgical techniques, immediate primary wound closure is safe and may decrease nosocomial infection by sealing open wounds and providing biologic coverage. DeLong et al[35] managed 87 of 119 open fractures with immediate primary wound closure after irrigation and débridement. The authors found no difference in infection or nonunion rates compared with delayed closure. No cases of gas gangrene were reported. Hohmann et al[36] found no difference in infection rates among type I, II, and IIIA open tibia fractures managed with primary versus delayed wound closure.

In the setting of timely antibiotic prophylaxis and thorough débridement and irrigation in a healthy host, we recommend that type I through type IIIA fracture be closed primarily at the time of initial débridement provided that it is possible to achieve a tension-free closure. We advocate the use of Donati-Allgöwer sutures to minimize the amount of cutaneous vascular compromise. The Allgöwer modification of the Donati vertical mattress suture technique was shown in a porcine model to have the least effect on cutaneous blood flow compared with simple, horizontal mattress and vertical mattress sutures[37] (Figure 2). In wounds with limited soft-tissue viability, lack of soft-tissue coverage, or severe contamination, other methods of wound coverage should be considered, such as a bead pouch or vacuum-assisted closure.

Local Antibiotics

Local antibiotic-impregnated delivery vehicles can be a useful adjunct

to systemic antibiotic prophylaxis in managing large open tibial wounds. Polymethylmethacrylate (PMMA) cement is the most commonly used antibiotic delivery vehicle. Commercially prepared PMMA beads are not available in the United States, so they must be made by the surgeon. Typically, 40 g PMMA is mixed with 3.6 g tobramycin, molded into 5- to 10-mm spheres, and strung on suture or wire. Alternatively, a cement block spacer may be formed for placement in a segmental defect. Most often, aminoglycosides are used because of their broad spectrum of activity and heat stability; however, vancomycin and cephalosporins have also been employed. With the support of the hospital pharmacy, these beads can be prepared sterile and peel-packed for immediate use.

For wounds with inadequate soft-tissue coverage, local antibiotics are often administered through the creation of a bead pouch. The area is débrided and irrigated, the antibiotic-impregnated PMMA beads are placed into an open fracture defect, and the defect is sealed with a semipermeable sterile covering. Use of a bead pouch allows for high local concentrations of antibiotic (10 to 20 times higher than systemic administration) and reduces the potential for nosocomial contamination. The use of drains in addition to a bead pouch is controversial. We prefer not to use drains in combination with the bead pouch so as to maintain higher levels of antibiotics locally. In addition, the frequency of surgical intervention in a patient with an open tibia fracture may minimize the impact of drains.

In a series of 1,085 open fractures, Ostermann et al[38] found an infection rate of 3.7% for those treated with the bead pouch technique and systemic antibiotics compared with a 12% infection rate for fractures managed with systemic antibiotics alone ($P < 0.001$). Keating et al[39] retrospectively compared the use of the bead pouch technique at the time of reamed intramedullary nailing with delayed wound closure. A notably lower rate of deep infection was found in the group managed with a bead pouch and delayed primary closure than in the group managed with no bead pouch and with delayed wound closure (4% versus 16%, respectively). The bead pouch technique appears to be a useful temporizing option for severely contaminated open fractures of the tibial shaft with inadequate tissue for immediate closure.

Local antibiotics have also been used successfully in the management of large segmental bone loss in open tibia fractures. Masquelet et al[40] and Pelissier et al[41] used a two-stage protocol in which antibiotic-impregnated PMMA cement spacers were inserted into segmental defects to maintain length and induce a synovium-like foreign-body membrane. This membrane provides a contained space for future cancellous bone grafting and has been shown to secrete transforming growth factor-β1, vascular endothelial growth factor, and bone morphogenetic protein-2. Ristiniemi et al[42] used a similar two-stage technique in the management of 23 open tibia fractures with substantial bone loss (mean, 52 mm). Septopal beads (Merck, Damstadt, Germany) were placed at the time of wound coverage and bone stabilization to preserve the volume of the bone loss and to induce a foreign-body membrane. They were removed at a mean of 8 weeks after the soft-tissue cover procedure and were replaced with iliac crest bone graft within the foreign-body membrane. Twenty-two of the 23 fractures healed after a mean of 40 weeks.

More recently, delivery of local antibiotics through bioabsorbable vehicles such as calcium sulfate, demineralized bone matrix, and fibrin clots has shown promise in preventing infection in animal models.[43,44] These delivery vehicles eliminate the need for removal of PMMA cement and may reduce the number or volume of autografts while providing osteoconductive and/or osteoinductive material to aid in fracture healing. Beardmore et al[43] created in a goat model a 12-mm–diameter unicortical defect in the proximal tibial metaphysis and contaminated the defect with an infecting dose of *S aureus*. Tobramycin-impregnated calcium sulfate pellets combined with demineralized bone matrix was found to be as effective as tobramycin-impregnated PMMA cement beads in preventing infection.

Negative-pressure Wound Therapy

The Vacuum-Assisted Closure device (VAC; Kinetic Concepts, San Antonio, TX) uses continuous subatmospheric pressure (typically, 125 mm Hg) applied through an open-cell foam dressing sealed over a wound to decrease edema, rapidly increase the amount of granulation tissue, and reduce wound size.[45] The popularity of the VAC device has increased tremendously since its introduction, and the device appears to be a versatile tool in wound management. Parrett et al[46] observed a shift in their treatment patterns for open fractures of the lower extremity over a 12-year period. Significantly fewer free flaps were placed in the last 4 years of their series than in the first 4 years (5% versus 20%, respectively). Additionally, there was an increase in the use of negative-pressure wound therapy (NPWT), from 7% during the middle 4 years (when NPWT was introduced) to 49% during the final 4-year period, even though there was no change in the severity of open fracture. With this shift in wound management, a decrease in reoperation rates was noted, from 19% in

the first 4 years to 4% in the final 4 years. During this time there was no change in infection, amputation, malunion, or nonunion rates. These results were attributed to the introduction of NPWT and improved local flap techniques. Dedmond et al[47] came to similar conclusions when they reported on the use of the VAC device for high-energy open tibial shaft fractures in adults, concluding that the VAC device likely decreases the need for free-tissue transfer.

Despite the apparent effect of NPWT on the method of soft-tissue coverage required, the use of NPWT does not appear to affect the infection rate for wounds that need soft-tissue coverage. Most infections of open tibia shaft fractures occur secondary to nosocomial pathogens.[18] Thus, it has been hypothesized that early coverage of the wound with a VAC device would lessen the rate of infection. However, Bhattacharyya et al[48] showed that VAC therapy did not allow delay of soft-tissue coverage >7 days without a significant increase in infection rate. In their series, type IIIB open wounds were covered with a VAC device at the time of initial débridement. The authors reported an infection rate of 12.5% for wounds that underwent definitive coverage at ≤7 days compared with an infection rate of 57% for those that underwent definitive coverage at >7 days ($P < 0.008$).

Summary

Open fracture of the tibial shaft can be devastating, involving severe bone and soft-tissue injury. Contamination of the fracture site as well as devitalization of the soft-tissue envelope greatly increases the risk of complications. The initial assessment and management of these fractures can affect functional outcome. It is important to accurately assess the full extent of damage to the bone and soft tissues. This is best accomplished at the time of surgical débridement, when classification of the fracture according to the system of Gustilo and Anderson will guide treatment and predict outcome. To minimize the risk of infection, antibiotic prophylaxis with a first-generation cephalosporin, along with appropriate tetanus prophylaxis, should be administered as soon as possible, preferably within 3 hours. Débridement and copious low-pressure irrigation should begin as soon after that as is feasible. The antibiotic bead pouch technique offers additional protection from infection for severely contaminated fractures, and NPWT provides excellent initial coverage for severe soft-tissue defects. Adherence to these guidelines will provide the best opportunity for optimal functional outcomes.

The second part of this article, "Open Tibial Shaft Fractures: II. Definitive Management and Limb Salvage," will be published in the February 2010 issue of the *Journal of the American Academy of Orthopaedic Surgeons*.

References

Evidence-based Medicine: Levels of evidence are described in the table of contents. In this article, level I studies include references 7, 14, 20, and 30. References 1-3, 11, 12, 17, 18, and 38 are level II studies. Level III studies include references 5, 6, 8, 10, 25, and 35. References 9, 13, 15, 16, 22, 31, 39, 42, and 48 are level IV studies. Reference 40 is a level V study.

Citation numbers printed in **bold type** indicate references published within the past 5 years.

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