# Current Concepts Review: Open Tibial Fractures

## Otevřené zlomeniny tibie – souborný referát

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## INTRODUCTION

The tibia is the most commonly fractured long bone with frequency of approximately 11–26 fractures per 100,000 population per year (24, 38, 87, 103). There is a bimodal distribution in age of incidence of fracture with younger males and older women being affected in greater proportion (22). Grutteret al. identified that the majority of fractures occurred in those under 40 years of age, with males being affected approximately twice as often (43). The differentiation of mechanism of tibial fractures into those of high-energy or low-energy is important for the associated increase in bone and soft tissue compromise with increasing force of injury. Because of the poor anteromedial soft tissue coverage of the tibia, fractures are often open, even from low-energy mechanism such as a fall. Infection rates of open tibial fractures have historically been noted as 10–20 times that of other open skeletal fractures (80). Improved understanding of open fracture pathology, techniques of soft-tissue care, fracture fixation and antimicrobial treatment has resulted in a significant reduction of morbidity and mortality associated with these fractures. Yet, the most severe open fracture types, even in the hands of experienced trauma surgeons, are still fraught with complications and impaired function.

## CLASSIFICATION

Open fractures of the tibial shaft are most commonly classified according to the Gustilo classification (46, 47) see Fig. 1. The classification system takes into consideration the extent of soft tissue injury, the extent of contamination and fracture severity. This relates to the amount of energy of injury. Progression from grade 1 to 3C implies a higher degree of energy involved and with increasing soft tissue and bone damage a higher potential for complications. The classification system, therefore, has a prognostic element. It should be noted that there is evidence suggesting relatively poor interobserver reliability with regard to this classification system (16, 53). Brumback and Jones showed surgeons video presentations of the history, physical examination, radiographs, and operative debridements of wounds in 13 open fractures. The overall interobserver agreement amongst the 245 surveyed surgeons was approximately 60% (16).

**GUSTILO CLASSIFICATION OF OPEN FRACTURES**

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|---|---|
| **TYPE I** | Clean wound of less than 1 cm in length with a simple fracture pattern |
| **TYPE II** | Wound larger than 1 cm in length without extensive soft tissue damage and a simple fracture pattern |
| **TYPE III** | Wound associated with extensive soft tissue damage<br>Or, multifragmentary fracture, segmental fractures or bone loss<br>Or, severe crush injuries<br>Or, severe contamination of wound<br>Or, vascular injury requiring repair |

**Further subdivision of type III open fractures**

| | |
|---|---|
| **A:** | Adequate soft-tissue (periosteal) coverage despite extensive soft tissue damage |
| **B:** | Bone exposure or significant periosteal stripping, or major wound contamination |
| **C:** | Associated arterial injury requiring repair |

*Fig. 1. Gustilo classification of open fractures.*

As classification requires assessment of extent of soft tissue injury, coverage, contamination as well as assessment of bone viability, true classification of an open fracture should be performed after proper debridement (44, 106). This makes definitive pre-debridement management planning based on Gustilo classification impossible. As such, the various options for the stabilisation and definitive management need to be considered and available following the debridement.

The most comprehensive classification system for tibial shaft fractures has been developed by the AO group and utilised by the Orthopaedic Trauma Association (72). This is a classification system based on anteroposterior and lateral radiographs of the lower leg. Type A fractures are unifocal and subdivided into groups based on orientation of the tibial fracture and the presence or absence of fibula fracture. Type B fractures are wedge fractures and are subdivided into whether they are spiral, bending or fragmented wedges. Type C fractures are complex fractures and include complex spiral, comminuted and segmental fractures. This system also has an association of increasing energy of mechanism between the type A, B and C fractures. However, the type of fracture may not be a good predictor of functional outcome at 6 or 12 months. Swiontowski et al., found in 200 patients with isolated tibial fractures that there was no consistent pattern in terms of functional performance, health status and functional impairment scores at 6 or 12 months with the tibial fracture AO/OTA type (97).

Increasing energy of injury is associated with an increased incidence of open fractures. The tibia, with a large surface area of anteromedial thin soft tissue coverage, is the most common bone affected in long bone open fractures. The Swedish Registry of over 10,000 patients over seven years lists that 12% of tibial fractures are open (103), although historical literature has a greater incidence of up to 63.2% (58). This is incomparison to approximately 3% of all fractures (25). The wide variability in the literature with regard to the percentage of tibial fractures that are open, reflects the variability in environments, activities, and changing behaviour of the populations that these various studies assessed.

The open tibial fracture with the associated exposure of fracture fragments to environmental contamination, and disruption of periosteal blood supply with soft tissue injury is associated with poorer outcome than closed tibial fractures. The Gustilo classification does have a predictive component with regard to outcome as type III fractures, understandably, have an increased incidence of infection, non-union and requirement for amputation over types I and II injuries (37, 47).

The requirement for amputation of the traumatised limb is one of the more difficult and emotionally laden decisions confronting the patient and orthopaedic surgeon. The Lower Extremity Assessment Project (LEAP) attempted to define the characteristics of individuals who sustained these injuries and their outcomes with a multi level 1 trauma centre, prospective observational study (98). They found in a study of surgeons practice, for more than 500 patients with lower extremity trauma, that the most significant factors in the decision for amputation were tibial fracture pattern, presence of an open foot fracture, bone loss, muscle injury, vein injury, arterial injury and the absence of plantar sensation. Despite the anxieties over management, at 2- and 7-year follow-ups the LEAP study found no difference in functional outcome between patients who underwent either limb salvage or amputation. Of note, however, was that average outcomes were poor for both groups, compared to the normal population. Interestingly, the significance of plantar neurological compromise leading to poor outcome and propensity to amputation has been challenged by the same group in more recent literature (12). They identified that more than half of the patients who presented with an insensate foot that were managed with salvage and reconstruction, ultimately regained sensation within two years.

## MANAGEMENT

### Assessment

As mentioned, open fractures are often associated with high energy injuries, and in this circumstance are rarely in isolation. Life-saving treatment must always take priority and the surgeon must consider both the local injury and the whole patient. In the polytraumatised patient, a co-ordinated multidisciplinary trauma team approach provides optimised outcomes with regards to morbidity and mortality.

With respect to the open fractured tibia, the surgeon needs to know when, where and how the injury occurred. For example, a patient with an open tibial fracture that occurred in a moving farmyard motorcycle injury will present with a different set of management issues than the patient who had a motorcycle fall on them at rest. Most important, is the knowledge of the amount and direction of force causing the injury.

It is essential to assess the vascular status of all injured limbs. The peripheral pulses, temperature and capillary refill of the distal limb should be checked and compared with the uninjured side. If the mechanism of injury or the clinical findings of limb assessment are concerning, Doppler examination and ankle-brachial index measurement should be performed (an ABI >0.9 is normal). If concern persists then arteriography should be performed following consultation with a vascular surgeon. This should not be at the expense of delay in treatment and often operating room arteriography on a radiolucent table is preferable.

The emergency room assessment of soft tissue injury is usually only superficial, but location and dimensions of the open wound should be noted. This assessment should be with sterile technique. Skin viability and loss, muscle crush and level of contamination should be assessed. Gross, visible easily accessible contaminants should be removed prior to any irrigation and dressing. While privacy issues are to be respected, a photograph is useful for documentation and to prevent recurrent assessment, which increases the risk of further contamination.

### Irrigation

Extensive wounds should then be lavaged with an adequate quantity of sterile saline solution. A number of different additives have been used in irrigation fluid over the years. These are most commonly in the form of antiseptic, antibiotic or soap (2, 21, 29). There is lack of well designed, controlled clinical trials to definitively conclude benefit in additives to irrigation fluid. Moreover, the use of antibiotics and antiseptics are not without risk, with potential for anaphylaxis and antibiotic resistance, and unjustified increase in cost (27). Antiseptics and soaps are toxic to host cells and have not been shown to be efficacious (84). Antibiotics have similarly,

*Fig. 2. Type I open fracture.*

*Fig. 3. Type II open fracture.*

*Fig. 4. Type III open tibia.*

*Fig. 5. Severe blisters over tibial fracture.*

*Fig. 6. Cool blue left leg working on one vessel only.*

not been shown to be efficacious when used as irrigation supplements. Tissue concentrations may well fall short of minimum required concentrations for their bacteriostatic or bacteriocidal requirements. Therefore, additives to sterile saline should not be used routinely for irrigation (2). The delivery method of irrigation has been assessed in various studies (8, 29, 64, 86). In vivo animal studies have suggested that high pressure lavage is more effective than low pressure lavage at removing adherent bacteria (8). However, there is evidence that high pressure lavage may drive contaminants deeper into tissue rather than remove them (29), and that it may also be more damaging to bone and soft tissues (64).

High pressure irrigation has not been shown to be of any advantage over gravity administered irrigation clinically (86). The FLOW investigators identified in their pilot multicentre, blinded trial of 111 patients that low pressure lavage may decrease the reoperation rate for infection, wound healing problems or non-union. They continue to investigate this process with the ongoing multicenter, randomised control trial (34).

## Splintage

The fractured limb should then be reduced in a well padded splint to minimise further soft tissue insult prior to the surgical debridement. Pulses should again be assessed after splintage and documented. Pulses often improve with realignment and temporary stabilisation of the fractured limb. Gross motor function and sensation of the foot and leg should be assessed when possible. The presence or absence of plantar sensation is a significant factor in limb salvage outcome.

*Fig. 7. Antibiotic bead pouch technique in a Type 3B open tibia.*

**Tetanus prophylaxis**

*Clostridium tetani*, is an anaerobic, gram positive bacterium. It is transmitted from the environment via breached skin. It is more commonly found in areas where soil or animal excreta are likely. The incubation period is between 3–21 days and active infection results toxin release in muscle spasms and rigidity, often in the jaw and neck. In the most severe form, respiratory failure and death can occur. The worldwide occurrence is approximately 50,000 cases per year, however it is relatively uncommon in industrialised countries. The incidence in the US is approximately 50 cases per year. Given the incubation period and difficulty managing active infection, prophylaxis is a mandatory part of management of all open wounds. A history of adequacy of immune status of the patient needs to be established. In situations where a history is not attainable, it should be assumed that the patient is not immune. In patients under the age of 6, yet to complete immunisation schedule tetanus vaccine should be administered. In adults who have not completed immunisation schedule, tetanus vaccine and immunoglobulin should be administered. If the most recent vaccination was over 5 years since injury, then a further tetanus vaccination should be administered (18).

**Antibiotic prophylaxis**

Prophylactic intravenousantibiotics should be administered as soon as practical, ideally within 3 hours of injury. Prophylactic antibiotics reduce the incidence of early infections in open limb fractures (41). Patzakis showed that empiric cephalosporin administration lowered the infection rate in the treatment of open fractures (79). If administered within 3 hours, this can be up to 6 fold (82). In an animal study, Penn-Barwellet al. showed that the delaying antibiotic administration had a profoundly detrimental effect on the infection rate, regardless of the timing of surgery (85). In patients with hypersensitivity to penicillins, administration of clindamycin may be appropriate (79). Clindamycin also has increased benefit in coverage of anaerobic bacterial infection.

Some have recommended the addition of antibiotic cover for gram-negative organisms, such as *Pseudomonas sp.,* with the addition of an aminoglycoside, such as gentamicin (81). The dominant organism for post-operative surgical site infection is *Staphylococcus aureus*, with up to one third being MRSA (4, 13, 17). Patzakiset al., in 2000, outlined that additive gram negative cover is beneficial in all grade II and grade III open fractures in reducing infection complications (79). The EAST work group published an evidence-based guideline after performing a systematic literature review on antibiotic prophylaxis in open fractures (51). They concluded that Gram positive coverage is recommended for all type I and type II fractures and that broader antimicrobial coverage is recommended for all type III fractures.

**Wound cultures**

There is no role for wound cultures in open fractures in the predebridement setting. It has been shown that any infection following open fractures were caused in 0–8% of cases by organisms that were identified on a pre-debridement wound sample (67, 100). Bacteriological studies focussing on wound cultures in open fractures have identified that in patients who develop deep infection, the lack of coverage of the prophylactic antibiotic was the biggest factor in the pathological


*Fig. 8a. Severe open segmental tibia fracture.*


*Fig. 8b. Severe open segmental tibia with reamed locked nail.*

organism (17). Carsenti-Etesseet al., identified that in those provided with prophylaxis against gram-positive bacteria, predominantly gram-negative organisms grew on wound cultures. Similarly, those given prophylaxis against gram-negative bacteria had a predominance of gram-positive organisms grow on culture from deep infected tissue. This may explain Patzakis' original recommendations, on a relatively limited study (81), for gram negative coverage in the greater trauma environment of a grade II and III fractures. What has been derived from these and further studies, is that bacteria that cause fracture wound infection are almost universally commensal or, hospital-acquired flora, and initial wound cultures have no role to play.

**Duration of antibiotics**

There has been no evidence that continuing antibiotic prophylaxis beyond 72 hours post debridement construes any benefit. Whilst accepting that trauma patients are immunosuppressed and at risk of infection, prolonged antibiotic prophylaxis increases the risk of hospital-acquired infection and may precipitate multi-drug-resistant organisms becoming the pathogens of the trauma patient (71, 77).

Hauser et al., on behalf of the Surgical Infection Society (48), concluded in their systematic review of 53 papers, that there was very little quality evidence guiding the practice of prophylactic antibiotic administration and that very large numbers of patients would be required for such evidence to be generated. They also concluded that a cephalosporin should be initiated as soon as possible after injury and that this significantly lowers the risk of infection when used in combination with prompt debridement and modern wound management. They did not feel that there was sufficient evidence to support the common management practices of gram-negative bacterial coverage or any prolongation of prophylactic courses of antibiotics. They recommended 24 hours for grade I and II fractures, and up to 48 hours for grade III fractures was of sufficient duration. They also concluded that large, randomised, blinded trials in patients with high grade fractures needed to be performed, but that this was likely to be difficult.

**Debridement**

Historical literature has suggestedopen injuries require emergent debridement to minimise the risk of significant complications related to infection (45, 55, 60, 63, 82). It still holds true that proceeding to formal debridement should be as prompt as possible with consideration of several factors. The historical timeframe of a 6 hour restriction before increase in infection complications is probably related to Friedrich's animal study data from late 19th century where he identified 6 hours as the critical time for massive replication rates of bacteria in contaminated wounds (36, 82). This recommended time frame for debridement of open fractures was accepted and purported before the era of modern resuscitation, antibiotics, operating room sterility practices and systematic debridement protocols. Only recently has this dogma been evaluated.

More recent literature has widely suggested that timing from injury or operative debridement is not a significant independent predictor of infection risk in compound fractures (1, 88, 89, 91) as much as the thoroughness of the debridement (56). Khatodet al., found in their consecutive series of 106 open tibial fractures, that regardless of Gustilo grade there was no increase in infection rate in those receiving initial debridement within 6 hours of injury compared to those receiving the procedure after 6 hours (58). However, they did identify that there was no complications of infection in those treated within 2 hours.

Pollaket al., found in the LEAP Study Group of 315 severe high-energy lower extremity injuries that 27% of patients developed infection within 3 months after injury. They identified that timely admission to the definitive trauma treatment centre had a significant beneficial influence on the incidence of infection, but time from injury to debridement did not (88).

No literature encourages the delay of surgical debridement specifically, but in reality, there are logistical and physiological factors that influence the ability of the patient to be brought to the operating room for emergent surgical management. The interventions mentioned above, appropriate resuscitation, emergency irrigation, antibiotic administration, as well as gaining appropriate imaging, timing of emergency presentation after injury, the transfer of patient to the appropriate trauma level facility, and accessibility of the operating room at variable times of the day and night can all contribute to delaying the surgical debridement procedure. The breadth of more recent literature, in an area where randomisation for level 1 trials is not likely to be ethically supported, suggests that there is no detrimental effect with regards to infection and non-union when there is anessential delay created to allow for optimal resuscitation and operating environment to be provided. This includes the expedient transfer of the patient to the appropriate trauma facility.

The operative debridement procedure itself requires a step-by-step approach such as the one established in 2010 by the British Orthopaedic Association and the British Association of Plastic, Reconstructive and Aesthetic Surgeons working party on the management of open tibial fractures (14). They define a sequential approach for initial wound debridement that includes initial soapy solution application followed by preparation of the limb with chlorhexidine alcohol solution, avoiding direct contact with the wound. The wound should be extended, but only after consideration of the requirement for fasciotomy incisions. The tissue assessment should be systematic from superficial to deep and from the periphery to centre of the wound. Non-viable fragments, organic and inorganic debris and non-viable soft tissue including muscle should be removed. Retention of devitalised bone has been shown to increase infection rates (31), and must be avoided. Once debridement has been completed following this systematic and radical approach, thorough irrigation with normal saline can be performed.

**Coverage of the open wound**

The open fracture wound has several options available for closure as well as for the timing of the closure. As we accept the evidence that following thorough debridement and appropriate early antibiotic administration, the potential infective pathogens tend to originate from the patient and hospital environment, then earlier closure of these wounds may help minimise these infections. Timing of closure can be separated into immediate (at time of initial surgical intervention), early (within 24–72 hours), and delayed or late closure (beyond 3 days). Historically, delayed closure was preferred by surgeons because of the observations of clostridial infections and gas gangrene (15).

Several studies have examined immediate closure of open tibial fracturesand identified decreased infection rates, decreased reoperations, shorter hospital stays and decreased time to bony union (28, 40, 50, 52). Hohmannet al., analysed 95 patients with Gustilo-Anderson grade I to IIIA open tibial fractures treated with primary stabilisation and either delayed or primary wound closure (52). With infection rates of just 2% and 4% respectively, they felt primary wound closure was safe and substantially more cost effective. Gopalet al., retrospectively reviewed 84 consecutive patients who suffered more severe, grade IIIb or IIIc, open tibial fractures with blunt trauma over 9 years (40). They had a 95% limb salvage rate with only four, including two late, amputations. They identified that there were increased complications in patients who had delay in their soft tissue reconstruction beyond 72 hours. They acknowledged that these patients had more systemic illness leading to their delay to definitive wound closure and this may have lead to the increased rate of complications. They concluded that early referral to a specialist trauma centre whenever possible, and in environments where this was not possible, initial debridement and bridging external fixation, followed by transfer, is the safest procedure.

The Cochrane Database has not identified any randomised controlled trials comparing primary vs delayed wound closure (32). However, a systematic review of early versus delayed wound closure in patients with open fractures by Wood et al., suggested that any delay in flap coverage may provide suboptimal bone healing, infection, and complication rates (105).

Options for closure of the open fracture wound include primary closure of the skin, split-thickness skin-grafting, the use of local cutaneous flaps, and the use

Fig. 9a. Open tibia with dead bone.

*Fig. 9b. Open tibia, nailed with 3 cm bone gap with 100% chance of nonunion.*

of either free or local muscle flaps. The most important factor in the decision making process is the adequacy of the initial debridement. If there is any concern over the degree or persistence of wound contamination then a second surgical debridement procedure should be planned within 48 hours. Temporary stability may then be provided by a bridging external fixator, with pin site placements avoiding the definitive stabilising procedure wound requirements. Tension to skin across the wound closure site should be avoided as this will compromise vascularity across the wound and compromise healing. Close relationships with plastic surgical teams will facilitate early flap coverage when deemed required.

If it is felt that there is a requirement for a second debridement procedure then there are options for minimising infection risk, although evidence is limited. The first is through the use of local administration of antibiotics using antibiotic loaded cement and the second is through negative pressure wound therapy.

**Antibiotic beads**

Extrapolation of arthroplasty data that shows an 11-fold reduction of infection rates when antibiotic-loaded cement was used (69), encouraged the use of polymethylmethacrylate beads for the local elution of antibiotics into wounds. Although the concept was originally used for treatment of chronic osteomyelitis, they have been found to provide high local levels of antibiotics with no systemic side-effects (61, 62, 92). The environment of the wound needs to be “closed” for the beads to have the desired effect. In the circumstance of the concerning open fracture wound, this “closure” can be provided by sterile, sealed dressings. The antibiotics then elute from the beads into the environmental haematoma by diffusion. The wound will then require serial debridement until such time as definitive closure can be achieved. There is no strong evidence to assist in the assessment for timing of this definitive closure procedure in the scenario of serial debridements. The principle persists however, the sooner the wound is covered definitively, the better.

Many antibiotics have been shown to maintain efficacy when mixed with PMMA. The requirements are that they be heat stable and hydrophilic. The most commonly used antibiotics include gentamicin, tobramycin and vancomycin. Gentamicin sulphate is an excellent additive to PMMA, particularly in the prophylactic setting, due to its broad spectrum of action, its bactericidal properties, low rate of primarily resistant pathogens, and good thermostability (39). The PMMA-antibiotic beads may be created by the surgical team at the time of procedure, or come as a commercially prepared product. The addition of more than 2 g of antibiotic to 40 g of cement powder reduces the cement’s mechanical strength, which is not relevant when the intention is for the PMMA to act as a local antibiotic delivery mechanism and potentially as a void filler. Vacuum mixing decreases the porosity of the cement, thus reducing elution of the antibiotic, and is therefore contraindicated in the circumstance of infection prophylaxis (20).

In a consecutive series of 1085 severe open fractures, Ostermann et al. examined infection rates between a group managed with PMMA-tobramycin loaded beads and IV tobramycin, cefazolin and penicillin, versus a second group treated with the IV antibiotics alone (78). The majority of the fractures (78%) were managed with beads, and not in a randomised fashion, but at the discretion of the attending surgeon and availability of the PMMA beads. They found the infection rate was 3.7% in those that had the addition of PMMA beads vs 12% for the latter group. Statistical significance was achieved for acute infection for IIIB and IIIC fractures. Of note, there was a requirement for serial debridement (at 48–72 hour intervals) in the group that were treated with the beads, which is a significant confounding factor to this study.

**Vacuum assisted therapy**

Negative pressure wound therapy (NPWT), in which a vacuum is applied across an air-tight topical dressing, has been used in the treatment of chronic and surgical wounds for many years (3, 33, 101). The negative pressure is thought to aid in the drainage of excess fluid and increase localised blood flow. It is also known as vacuum-assisted closure (VAC). There is some evidence for its benefit in reducing infection over standard dressings (10, 94), reducing wound area and causing healthy granulation tissue to appear (93). Blum et al. (10), reviewed 229 open tibial fractures in 220 patients over a six year period who received either NPWT or conventional dressings. It was a retrospective, nonrandomised case series that trended for NPWT usage to increase through the study time period. There was also a tendency for the higher Gustilo grade and higher patient injury severity patients to receive NPWT. The NPWT group had a significantly higher proportion of free flaps for soft tissue coverage and a significantly lower proportion of secondary intention closure. There was a downward trend of deep infection rate over the study time period, that the authors could only identify one variable, the increasing usage of NPWT. Stannard et al., performed a prospective randomised trial of 58 patients with 62 severe (primarily III A and IIIB) open fractures over 5 years (94). Their primary variable was interval dressing between serial debridements with either conventional (saline moistened, sterile gauze) dressings or NPWT (VAC dressing) for those patients who it was felt were not amenable to primary wound closure. The infection rate in those treated with standard dressing was 28% vs 5.4% in those treated with NPWT. Two selection biases are identifiable in this study. The first, is that the fractures were not limb or site specific and there was a greater percentage of tibial fractures in the standard dressing group. Secondly, there was also a difference in the number of debridement procedures between the two groups, with the standard dressing group having a mean 2.4 irrigation and debridement procedures vs 3.5 in the NPWT group. Taking these into account, there certainly appeared to be a trend towards significant reduction in infection rate in the problematic open tibial fractures compared to normal dressings.

A Cochrane review, however, has failed to identify any strong evidence to show benefit in NPWT over standard dressings in acute wounds or as a supplement to increase the success of split skin grafting (102), which is a further common utilisation in difficult wounds.

Some authors have identified the possibility of a "combination therapy" where NPWT is used in combination with antibiotic-impregnated PMMA beads (11, 90). The theory is that the "best of both worlds" will be adopted with better soft tissue management with NPWT, and local antibiotic levels will be elevated by the antibiotic eluding PMMA beads. However, the contrary has been identified in an animal model study (96). The authors concluded that the effectiveness of the local antibiotics was significantly reduced by the NPWT. The combination therapy still seemed to be more effective than previous animal studies results of NPWT alone, highlighting the benefits of the antibiotic therapy. Therefore, the role of NPWT beyond acting as a sterile dressing, remains unclear and requires further investigation with well designed large trials.


*Fig. 10. Masquelet PMMA distal tibia 6 cm gap at 8 weeks post injury.*

Ultimately, the aim of soft tissue management in open fractures is to achieve coverage before infection develops. NPWT, or other temporary dressings, can simplify the soft tissue management but does not allow significant delay to definitive bone coverage procedures. Delaying flaps or free tissue transfers, and prolonging such interventions as VAC dressing, increases complication rates with regards to nonunion (19), infection and amputation rates (54). Where possible, early definitive soft tissue reconstruction is likely to be of most benefit to patients. Studies suggest particular timing within the first seven days does not have a significant effect on outcome (95), but delaying definitive soft tissue coverage beyond this time increases adverse event rates (70).

**Stabilisation**

Following thorough debridement and irrigation, a decision needs to be made about stabilisation of the open

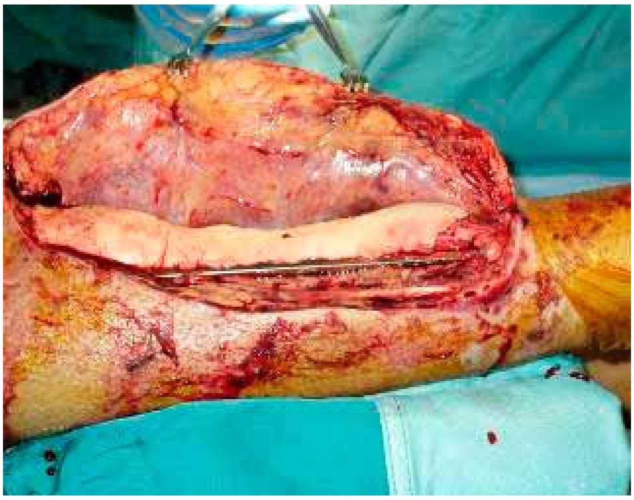

*Fig. 11. Masquelet technique with induced membrane at 6 weeks in an open femur.*

fracture. There are essentially four methods of treating tibial shaft fractures. All need to be considered with their ability to control length, rotation, and alignment with respect to the presenting fracture pattern, whilst minimising further soft tissue insult. Casting or bracing is an option in grade I fractures with some inherent stability to the fracture pattern. Long leg casts, patellar tendon bearing casting, or functional bracing are options in some situations where other forms of stabilising are either difficult or at risk of compromising patient outcome with a larger surgical insult. The second option is plate fixation. This option can be further broken down to compression plating for absolute stability in a fracture where anatomical reduction is possible, or bridge plating for relative stability in the situation of greater fracture instability. Both options should try to employ techniques that minimise further surgical compromise of soft tissues and fracture blood supply. Submuscular, "minimally invasive", approaches will minimise compromise of the fracture environment. Both locking and non-locking screws and plates may be employed with these techniques, but the surgeon should understand the functions, benefits and limitations of each. The third technique, for long bone fractures, utilises an intramedullary nail, either reamed or unreamed, and with the capacity for statically or dynamically locking the construct. The fourth option for treating tibial fractures is with external fixation which can be uniplanar, multiplanar or through a circular, tensioned, fine wire fixator.

By far, the most common technique for tibial shaft fractures employed by surgeon is intramedullary nailing (6). In a series of randomised, level I and II studies (5, 57, 65, 66) the outcomes of reamed and unreamed nails were assessed for both closed and open fractures. One study found that there is statistically shorter time to union, for both open and closed fractures with reamed nails (66). Keating et al., found no statistically different time to union in patients with open fractures using either technique (57). Patients in the reamed groups had a lower proportion of nonunions in either open or closed fractures (5, 26, 57). There was no difference noted in the rates of infection or malunions between the two techniques. The reoperation rates between the two groups were specifically assessed in the study of 1319 adults by Bhandari et al. (5). In closed fractures, the reamed group had significantly fewer reoperations than the unreamed group, which may be related to differing rates of dynamization, particularly autodynamization. In open fractures, there was no statistically significant difference in the risk of reoperation for reamed (29%) versus unreamed (24%) procedures.

External fixators are an option for the skeletal stabilisation of open fractures, in particular those with severe soft-tissue injury. They can be applied in the situation of "damage-control" of polytrauma patients who require rapid stabilization of fractures with minimal additional injury to the fracture zone. Anatomical safe zones need to be observed at time of pin placement. Pin site infection, usually superficial, is the most common complication of external fixator usage. This can be minimised by good pin site cares. There should be no skin tension after pin placement and pressure type dressings, with avoidance of frequent inspection, should be used.

External fixators have been identified as having increased infections, reoperations and malunions over unreamed intramedullary nails (7). They should ideally only be utilised for temporary fracture stability as required. Conversion to intramedullary nails should happen within 14 days as the risk of superficial pin site infection increases after this time and is associated with increased infective complications of the intramedullary device (9, 76).

**Bone loss**

In grade III open fractures, following debridement of devitalised bone segments, contaminated bone ends, or significantly comminuted devitalised non-reconstructable fragments, the issue of bone loss needs to be managed. Whittle et al., monitored 50 open tibial shaft fractures treated with debridement and interlocking unreamed nails for an average of 12 months (104). The authors empirically defined a loss of one third of bony circumference as an indication for later bone grafting. Court-Brown and colleagues also noted the frequent need for bone graft procedures after debridement of devitalised bone and attempted to quantify the amount of bone loss that lead to non-union (23). They found in their study of 33 cases, that bone loss of more than 2 cm and 50% of tibial circumference had a 100% incidence of nonunion.

Options available include bone (and therefore, limb) shortening, with potential for lengthening distraction osteogenesis procedures at the same or later stage, reconstruction of bone with autograft and allograft, utilization of bone graft substitutes, prosthetic devices, and vascularized bone grafting.

Whatever option, it is mandatory to have healthy viable bone and soft tissue with adequate stability to the fracture zone. The simplest form of management for bone loss may involve shortening the bone and allowing for remodelling to address minor bone loss. The fixation construct will require relative stability principles to allow the secondary healing process to accommodate the remodelling phase (49). One centimetre in the lower limb and two centimetres in the upper limb can be very well tolerated, although there is no literature to categorically assist with quantifying tolerance of shortening. In larger defects, the limb may be shortened, and then distraction osteogenesis through a distant osteotomy site can restore limb length with an Ilizarov technique (99).

Primarily bone grafting the fracture zone is an option, but due to the absence of blood supply in the graft and the injured nature of the soft tissues it may be best to reserve this for a secondary procedure in the event of nonunion management, rather than as a prophylactic intervention, to minimise infection risk and any unnecessary (autograft) graft donor site complications.

Vascularised fibula grafts 6 cm (68). This is a demanding microvascular technique and should only be attempted in tertiary units with expertise to maximise outcomes.

A further option for managing bone defects of greater than 2 cm has been suggested by Masquelet (74, 75). The technique proposes the combined use of an induced membrane and cancellous bone graft to fill diaphyseal bone defects up to 25 cm in length. Following appropriate debridement and irrigation and at the time of soft tissue coverage procedure, an antibiotic-loaded polymethylmethacrylate cement spacer is placed within the bone defect with skeletal stabilisation established. The cement spacer has been found to induce a membrane surrounding it and therefore, lining the defect, that has a rich capillary network and a high concentration of growth (VEGF, TGFβ) and osteoinductive (BMP-2) factors (83). Following the healing of soft tissues some weeks later, a second procedure is performed, where the cement spacer is removed from within the membrane and the cavity is filled with autogenous bone graft. Supplementary allograft or bone substitute can be used for larger defects (73). The current evidence for this technique is limited to case series but shows promising results with regards to union in these reports.

The use of osteogenic and osteoinductive materials for stimulating bone formation is an area of increasing interest for management of bone loss. In non-union of the tibia, osteogenic protein-1 (BMP-7) has not been shown to have an advantage over allograft bone (35). BMP-2 use in open fractures of the tibial shaft resulted in increased rate of healing compared to controls (42). Although extensive research persists in this potentially commercially significant area, there is still no proven osteogenic or osteoinductive material of clinical value to manage significant post-traumatic bone loss. Osteoconductive materials such as calcium phosphate have been well utilised in small contained defects, usually of the metaphysis. However, they have poor resistance to torsional, shear or bending stresses and are therefore unsuitable for use in the presence of extensive bone loss.

## CONCLUSION

The management of open fractures continues to provide challenges to the treating orthopaedic surgeon. Concern persists regarding potential complications of infection and non-union, particularly with regard to tibial fractures. Early antibiotic administration is essential, and when coupled with early, planned, thorough debridement of all contaminated and devitalised tissue, followed by irrigation with normal saline at an appropriate trauma facility, the rates of infection can be significantly improved. The requirement for emergent debridement is probably not as important as has been historically suggested. Associated arterial injuries must be identified and treated emergently to salvage the limb. Compartment syndrome is possible in open fractures, and evaluation serially, is critical. When possible, judicious, prompt coverage of the compound wound, by either direct closure or flaps will also be beneficial in decreasing infection rate and optimising outcomes. Where necessary, a NPWT dressing for no longer than seven days, with alternate day dressing changes, can temporize the wound and may improve the outcome of a soft tissue flap. Early skeletal stabilisation, and in tibial shaft fractures preferentially with an intramedullary nail, will also optimise patient outcome in terms of return to normal function. The management of any associated bone loss needs to be considered early in the treatment process and in context of the patient, the surgeon and institutional resources.

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