4.2 Open fractures

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1 Introduction

Open fractures imply communication between the external environment and the fracture and have been defined as a soft-tissue injury complicated by a broken bone.

Four components characterize the injury:
- fracture;
- soft-tissue damage;
- neurovascular compromise;
- contamination.

The extent of each component must be assessed individually in order to achieve a comprehensive understanding of the injury, upon which a treatment plan can be based.

Improved understanding of open fracture pathology, techniques of fracture fixation, soft-tissue care, and antimicrobial treatment has resulted in a significant reduction of morbidity and mortality associated with open fractures. Yet, the most severe open fracture types, even in the hands of experienced trauma surgeons, are still fraught with complications and impaired function.

Complex injuries, regardless of the location and extent, are today managed by early aggressive debridement, and early definitive reconstruction can be initiated once the deliberation over whether to salvage or amputate has been resolved. This requires experience and special skills, cooperation of plastic, vascular, and orthopedic surgeons, support staff and services, and specialized equipment in modern trauma centers [1–2].

2 Historical perspective

The concept of open fracture care has evolved from the experience of war surgeons, dating back to the preasepsis era. Only a century ago, the high mortality rate of patients with open fractures in major long bones frequently led to early amputation in order to prevent death. At the onset of World War I the mortality rate from open femoral fractures still was over 70%. The nature of the wounds sustained on the battlefield prompted Trueta to recommend “closed treatment of war fractures” in 1939. This included open wound treatment and subsequent enclosure of the extremity in a cast. Trueta was revolutionary in his approach to handling soft-tissue injuries associated with open fractures. Contrary to general opinion at the time, he believed that the greatest danger of infection lay in the muscle and not in the bone. He recommended wound debridement with excision of necrotic tissue. His method of leaving wounds open persisted until further experience was accumulated during World War II. In 1943, the use of penicillin on the battlefield quickly reduced the rate of wound sepsis. However, because of over-reliance on the antibiotic’s efficiency, careful debridement procedures were neglected. Prompted by the complications of inadequately debrided wounds, the concept of delayed closure was adopted. Hampton recommended closure between the fourth and seventh day after injury, depending upon the wound being clinically clean. Larger defects continued to be left open to heal by second intention.

Major advances over the last century have moved the focus of management of such injuries beyond the preservation of life and limb to preservation of function and prevention of complications. Nevertheless, there is no place for complacency. In the most severe open tibial fractures associated with vascular injury, the documented amputation rates still exceed 50% [3].
Open fractures tend to be caused by more severe trauma than closed fractures. However, fractures due to low-energy indirect torsional trauma can penetrate the skin from within, particularly where the bone lies close to the skin and is not protected by a muscular envelope. Severe open fractures usually occur as a result of direct high-energy trauma, either by road traffic collisions or falls from height. The degree of trauma induced is related to the energy imparted by the sudden deceleration at the time of impact. A prime example is the open fracture of the lower extremity in a motorcyclist (Fig 4.2-1). High-energy incidents frequently cause multiple, severe injuries to other parts of the body (head, chest, and abdomen), the management of which may take precedence over the open fracture(s) (chapter 4.1).

3 Etiology and mechanism of injury

4 Epidemiology

The frequency of open fractures observed in any area varies according to geographical and socioeconomic factors, population size, and trauma delivery systems. The incidence of open fractures in the Edinburgh Orthopaedic Trauma Unit in Scotland has been documented in detail [4]. This unit treats all fractures in a mixed urban and rural population of 750,000. Over a 75 month period between January 1988 and March 1994, 1,000 open fractures in 933 patients were reported, representing a frequency of 21.3 per 100,000 per year (Tab 4.2-1). The highest rate of diaphyseal fractures was seen in the tibia (21.6%), followed by the femur (12.1%), radius and ulna (9.3%), and humerus (5.7%).

In major long bones, diaphyseal open fractures were more common than metaphyseal ones (ie, 15.3% versus 1.2%).

<table>
<thead>
<tr>
<th>Location</th>
<th>Total fractures</th>
<th>Open fractures</th>
<th>% open fractures</th>
</tr>
</thead>
<tbody>
<tr>
<td>Upper limb</td>
<td>15,406</td>
<td>503</td>
<td>3.3</td>
</tr>
<tr>
<td>Lower limb</td>
<td>13,096</td>
<td>488</td>
<td>3.7</td>
</tr>
<tr>
<td>Shoulder girdle</td>
<td>1,448</td>
<td>3</td>
<td>0.2</td>
</tr>
<tr>
<td>Pelvis</td>
<td>942</td>
<td>6</td>
<td>0.6</td>
</tr>
<tr>
<td>Spine</td>
<td>683</td>
<td>0</td>
<td>0.0</td>
</tr>
<tr>
<td>Total</td>
<td>31,575</td>
<td>1,000</td>
<td>3.17</td>
</tr>
</tbody>
</table>

Tab 4.2-1 Relative frequencies of open fractures [4].

Fig 4.2-1a–b Open tibial fracture after high-energy motorcycle injury.

a Moderate size skin wound on the medial aspect of the lower leg with some closed degloving of the skin.
b Complex fracture of the tibia.
4.2 Open fractures

The immediate effect of a high-velocity injury producing an open fracture is contamination of the soft and hard tissues. In addition, there may be systemic shock, reducing the blood supply to bone and muscle for a period of time. The result is poor tissue oxygenation and devitalization of the surrounding tissues including the bone, which provides a perfect medium for infection and bacterial multiplication.

Most acute infections after open fractures are caused by pathogens acquired in hospital. Gustilo and Anderson reported in 1976 that most of the infections in their prospective study of 326 open fractures developed secondarily. When left open for an extended period (≥ 2 weeks), wounds were prone to nosocomial contaminants such as *Pseudomonas* species and other gram-negative bacteria [5]. During the past 25 years, it has become increasingly difficult to predict a subsequent infecting pathogen on the basis of initial wound cultures. In a recent study, Patzakis et al found that only 18% of infections were caused by the same organism initially isolated in the perioperative cultures. This contrasts with a 73% correlation in an earlier study [6–7]. This phenomenon of hospital acquired bacteria and their prominent role in the pathogenesis of infection emphasizes the importance of a strict protocol for in-hospital management and early wound coverage.

5 Microbiology

The purpose of any classification scheme is to accurately describe similar injuries in order to provide a basis for treatment, to estimate prognosis, and to enable comparison between centers. To do so, the individual components that constitute the injury must be observed. It is now evident that an open fracture classification should be comprehensive and based on the mechanism of injury, severity of soft-tissue damage, fracture pattern, and the degree of contamination.

In early attempts at classifying open fractures (Ellis 1958, Nicoll 1964, Cauchoix 1965) the emphasis was on the relationship between soft-tissue and bone damage and on the prognosis of the fracture. The classification of open fractures as described by Gustilo and Anderson [5] and later modified by Gustilo, Mendoza, and Williams [8] is the most frequently quoted system in contemporary literature and is widely used. Open fractures are divided into three types in ascending order of severity, based on skin and soft-tissue damage (Tab 4.2-2). A later modification subdivided type III injuries based on the degree of contamination, the extent of periosteal stripping, and the presence of vascular injury (Fig 4.2-2) (Tab 4.2-3).

This classification is relatively simple and remains a useful tool, although not very accurate. It has been validated with regard to time to union, incidence of nonunion and the need for bone grafting. Its major disadvantage derives from the subjective nature of injury description resulting in high interobserver variability [9].
Tab 4.2-2  Gustilo and Anderson classification of open fractures [8].

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
</table>
| I    | Skin wound less than 1 cm  
Clean  
Simple fracture pattern |
| II   | Skin wound more than 1 cm  
Soft-tissue damage not extensive  
No flaps or avulsions  
Simple fracture pattern |
| III  | High-energy injury involving extensive soft-tissue damage  
Or multifragmentary fracture, segmental fractures, or bone loss irrespective of the size of skin wound  
Or severe crush injuries  
Or vascular injury requiring repair  
Or severe contamination including farmyard injuries |

Fig 4.2-2a–b  Gustilo type IIIC open fracture of the distal humerus after a high-energy motor vehicle collision. There was disruption of the brachial artery and vein and a neuropraxia of the median, radial, and ulnar nerves. (Müller AO Classification 12-C3, IO4-MT4-NV-4).

Tab 4.2-3  Gustilo classification of type III open fractures [8].

<table>
<thead>
<tr>
<th>Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>IIIA</td>
<td>Adequate soft-tissue cover of bone despite extensive soft-tissue damage</td>
</tr>
</tbody>
</table>
| IIIB | Extensive soft-tissue injury with periosteal stripping and bone exposure  
Major wound contamination |
| IIIC | Open fracture with arterial injury requiring repair |
Other classification systems have been proposed. Oestern and Tscherne (1984) suggested a classification based on soft-tissue damage and on the extent of muscle contusion rather than on the size of skin wound [10]. The most recent classification system is that of the AO group (1990). This very detailed classification is designed to be used in conjunction with the Müller AO Classification of fractures—long bones. It provides grading systems for injuries of the skin, muscles and tendons, and neurovascular damage, each of which is divided into five (chapter 1.6) degrees of severity. It is designed to provide a unique, unequivocal definition of an injury and thus, allows accurate comparison. When used in a large database this classification permits superior comparison of injury types and so is most useful as a research tool. However, its complexity may make it impractical for everyday clinical practice.

Classification of open fractures is most reliably done in the operating room at the completion of primary wound care and debridement.

7 Goals of treatment

The treatment of high-energy injuries aims to preserve life, limb, and function, in that order of priority. The intermediate objectives are:

- prevention of infection;
- fracture stabilization;
- soft-tissue coverage.

As these goals are interdependent, a coordinated treatment plan with early surgical intervention is required. Preservation and restoration of function are often extremely difficult to achieve in the presence of compartment syndrome and ischemia as well as nerve and muscle injury. Coordination of the reconstructive procedures with rehabilitation of the injured muscle is mandatory to obtain maximal possible function.

8 Stages of care

Achievement of these goals requires a disciplined, logical, and sequential management approach. This commences with good prehospital care and is followed by careful assessment and mature clinical judgment in the emergency and operating rooms. Primary surgical intervention focuses on the prevention of infection by staged wound debridement and fracture stabilization. Secondary surgical procedures address the issues of early skin cover and soft-tissue reconstruction, followed by bone reconstruction. Rehabilitation with early movement and mobilization is initiated as soon as possible as an integral part of this staged management protocol (Tab 4.2-4).

| 1 | Initial assessment | ABC’s (according to ATLS: airways, breathing, circulation) |
|   | Emergency room management |
|   | Wound dressing and fracture splinting |
| 2 | Primary operations | Staged wound debridement |
|   | Fracture stabilization |
| 3 | Secondary operations | Skin and soft-tissue reconstruction |
|   | Bone reconstruction |
| 4 | Rehabilitation |

Tab 4.2-4 Stages of care for open fractures.
When evaluating a patient with a high-energy extremity injury, the first priority is to identify and treat life-threatening injuries. Survival of the patient is the ultimate goal, and even a severe limb injury must be kept within this “whole patient” perspective. When the immediate life-threatening conditions have been managed, the assessment of the viability of the injured limb comes next.

Brumback defined the important components of open tibial fractures, which may be employed in assessing any traumatized extremity as
1. history and mechanism of injury;
2. vascular and neurological status of the extremity;
3. size of the skin wound;
4. muscle crush or loss;
5. periosteal stripping or bone necrosis;
6. fracture pattern, fragmentation, and/or bone loss;
7. contamination;
8. compartment syndrome.

Meticulous assessment of these components enables the surgeon to give an accurate description [11].

Some of the components of the injury are immediately evident; evaluation of others can be performed only at the time of initial debridement, subsequent debridement, or later.

Therefore, assessment is an ongoing process with continuing reevaluation.

Management begins at the trauma scene, where prehospital personnel should splint the limb and protect the wound with a sterile dressing. Thereafter, to protect the wound from further bacterial contamination, the dressing should be disturbed as little as possible.

The vascular status may be assessed by means of pulses, capillary refill, limb color, temperature, and the presence of bleeding from wounds. The vascular integrity is determined by palpation or by Doppler assessment of the ankle-brachial index (> 0.9 is normal). Arteriography may also be required, but can lead to delays in treatment. It is often better to perform an “on-table” arteriogram in the operating room.

In the emergency room, often only superficial assessment of soft-tissue injuries can be performed. The history, dimensions, and location of all open wounds should be recorded. A photograph of the open wound helps to document its characteristics (Fig 4.2-3) and prevents multiple examinations, which increase the risk of bacterial contamination.

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**Fig 4.2-3a–b**  Recording of injury by digital photography. There is a small lesion injury following a crush injury to the forearm with a fracture of the radius and ulna (22-C3). Note the ischemic hand distal to the wound indicating a vascular obstruction.
4.2 Open fractures

- Open fractures may be missed if the examining physician does not elevate the extremity to inspect it circumferentially.

Extensive or contaminated wounds should be lavaged with an adequate quantity of sterile saline solution. Superficial foreign bodies, such as leaves and grass, which are immediately accessible, should be removed from the wound before it is covered. The surgeon must use a sterile technique in order to minimize the contamination of the wound during the initial inspection phase. A clean sterile dressing should be applied to the wound and not be removed until the patient is in the operating room. The reduced limb is then placed in a well padded splint.

Pulses should be documented before and after alignment. Pulses often improve with realignment; persistently diminished pulses may indicate a vascular injury and the need for arteriographic evaluation. Gross motor function and sensation of the foot and leg should be documented whenever possible. The presence or absence of plantar sensation can be an important factor in the determination of whether limb salvage or primary amputation is to be undertaken. Tetanus prophylaxis should be considered in any open fracture.

10 Antibiotics

10.1 Systemic administration

Most orthopedic surgeons treat severe, open extremity trauma with antibiotics that cover both gram-positive and gram-negative organisms. In a prospective study, Patzakis showed that empiric use of a first-generation cephalosporin lowered the infection rate in the treatment of open fractures [7, 12]. Use of an additional agent aimed at gram-negative organisms (gentamicin or equivalent) remains controversial, except in cases of severely contaminated, eg, farming wounds. Guidelines for the use of antibiotics are given in chapter 4.5, but it is essential to consult with the local microbiologists as antibiotic resistance will vary from unit to unit. Initial “prophylactic” administration of antibiotics should not exceed 72 hours.

10.2 Local administration

In a series of 1,085 open fractures, Ostermann et al demonstrated that the additional use of local aminoglycoside-impregnated polymethylmethacrylate (PMMA) beads significantly ($P < 0.001$) reduced the overall infection rate to 3.7%, compared to 12% when only intravenous antibiotics were used [13]. When the types of open fractures were analyzed separately, the reduction of infection was statistically significant ($P < 0.001$) only in the Gustilo type III fractures (6.5% versus 20%, respectively, for PMMA beads and intravenous antibiotics).

The advantages of the “bead pouch” technique include:
- high local concentration of antibiotics;
- low systemic concentration, which protects the patient from the adverse effects of aminoglycosides;
- a reduced need for the use of systemic aminoglycosides.

This technique prevents secondary bacterial contamination by nosocomial pathogens, which have been shown to be responsible for many of the infections in Gustilo type III open fractures.
11  Primary surgery

The objectives of the initial surgical intervention are:
- preservation of life and limb;
- wound debridement;
- definitive injury assessment;
- fracture stabilization.

The stages of open fracture management in the operating room are shown in Tab 4.2-5.

11.1  Timing of initial surgical management

The surgical treatment of open fractures is generally thought to be a surgical emergency. Most surgeons attempt to bring their patients with open fractures to the operating room within 6–8 hours of the time of injury. This early intervention is thought to reduce the risk of infection and other complications [5]. The 6–8 hour rule is based on basic scientific information that suggests that contaminated wounds not treated within this time frame will have sustained enough bacterial multiplication to result in early infection [14].

11.2  Definitive assessment, initial debridement, and irrigation

Definitive injury assessment is completed in the operating room and under anesthesia. The limb is reexamined clinically and additional x-rays are obtained as necessary. Traction views may be very helpful. The limb is cleansed with a “trauma scrub”. This involves scrubbing the limb and wound with soap and saline to remove all gross dirt, debris, and contamination. The limb is then formally prepped and draped.

The concept of “the zone of injury” is important. This delineates the true dimensions of the wound as opposed to the skin wound, which is merely the window through which the true wound communicates with the exterior. In many instances this window may be small while the underlying zone of soft-tissue injury is large. This is particularly true in fractures that have ample coverage of muscle (eg, femoral or humeral shaft fractures, posterior wounds with tibial fractures).

- Full evaluation of the wound comprises a detailed assessment of the true extent of the zone of injury.
4.2 Open fractures

This often requires surgical extension of the traumatic wound, which must be planned carefully to minimize any further damage and should be done with consideration of the planned fixation (Fig 4.2-4) and potential plastic surgery procedures for wound covering.

The goal of surgical debridement and irrigation of the traumatic wound is to remove all foreign material, all devitalized soft tissue as well as bone, and to reduce the bacterial load. The debridement starts with careful excision of the skin margins of the traumatic wound. The subcutaneous tissue, fascia, and muscle are then methodically debrided as necessary to produce a clean, viable wound. Muscle of dubious viability must be resected to healthy tissue as assessed by color, consistency, capacity to bleed, and contractility. Major neurovascular structures should be preserved and repaired if necessary. The bone ends should be exposed and carefully cleaned.

The wound is then irrigated with warm saline or Ringer’s solution in an attempt to further reduce the bacterial load. Larger wounds benefit from larger volumes of irrigation. The traditional recommendation of 10 L is reasonable for Gustilo type III open wounds.

At the completion of debridement and irrigation, the injury should be reassessed. With the information about the severity of the wound now clearly available, the open fracture can be accurately classified.

Fig 4.2-4a–d Primary wound care in the operating room of a small wound associated with a femoral shaft fracture.

a The initial trauma scrub in the operating room consists of a formal scrub of the limb with soap and saline.

b The limb is then formally prepped and draped, and the wound is carefully debrided, starting with the skin and progressing layer by layer to bone. The traumatic wound may require surgical extension to allow full assessment and complete debridement.

c The bone ends are exposed and debrided.

d The wound is copiously irrigated.
However, it may not be possible to make the final distinction between Gustilo type IIIA and type IIIB wounds until the time of wound coverage. If in doubt, a second or third debridement after 24–48 hours should be planned.

11.3 Fracture stabilization

There is little debate about the need for reduction and stable fixation in the management of open fractures. As soon as primary wound care has been completed, treatment should proceed to fracture reduction and fixation. Depending on the extent of the injury, the fracture pattern, the location, and the general condition of the patient, temporary or definitive fixation will be chosen.

The fracture in a Gustilo type I injury may be treated in the same way as a comparable closed fracture. In most cases this involves surgical fixation. The outcome of these injuries is similar to that of their closed counterparts.

Gustilo type II and type III open fractures are almost inevitably displaced and unstable, which usually dictates surgical fixation. Restoring the limb to its normal length, alignment, and rotation as well as providing stability makes the ideal environment for soft-tissue healing and therefore reduces the risk of wound infection. Anatomical realignment reduces dead space and hematoma volume. Restoring stability at the fracture site prevents further damage from mobile bone fragments. The inflammatory response is dampened, exudates and edema are reduced, and tissue revascularization is encouraged.

The selection of the method of fixation remains controversial. Careful preoperative planning is essential, as the surgical approaches, implants, or external fixators should be placed in a way that does not compromise further orthopedic or plastic surgery procedures.

Articular fractures require anatomical reduction and fixation with absolute stability, while the nonarticular segment can be realigned and fixed with relative stability. Metaphyseal and diaphyseal fractures can be managed with a variety of techniques. The individual bone, the fracture pattern and location, the degree of periosteal stripping, and the nature of the soft-tissue envelope all influence decision making. There are situations where judicious use of a joint spanning external fixator for temporary fixation is useful. The fixator can be used to maintain length and alignment until swelling has subsided and the condition of the soft tissue has improved. Ideally, the fixator should be placed outside the zone of injury and the zone of future surgery. As soon as the soft-tissue condition permits, definitive fixation can be provided.

Regardless of whether the plan is for temporary or definitive fixation of the fracture, this segment of the treatment protocol should proceed immediately after the completion of the debridement and irrigation. The limb should be prepped and redraped as for a new procedure. The surgeons rescrub, regown, and reglove. A different set of sterile instruments than those used for the debridement is necessary.

11.3.1 Plates

Open diaphyseal fractures of the radius and ulna as well as the humerus are best managed with plate fixation. Plate fixation of lower extremity diaphyseal fractures is generally not recommended. In particular, plate fixation of open tibial shaft fractures has been reported to be associated with a high rate of infection [15, 16]. However, plating is the treatment of choice for many open periarticular fractures in both the upper and lower extremities. The availability of specially preshaped locking plates with angular-stable screws allows minimally invasive techniques to be used. Clinical data to support the use of newer implants are currently being studied (Fig 4.2-5) [17, 18].
4.2 Open fractures

Fig 4.2-5a–d
a–b Gustilo type IIIA open fracture of the distal femur (33-C2) and proximal tibia (41-C1).
c–d Treatment with wound care, ORIF, and LISS of both the distal femur and the proximal tibia.

11.3.2 Intramedullary nails
Locked intramedullary nailing has been established as the treatment of choice for most diaphyseal fractures in the lower extremity [19–21]. The technique has particular value for open fractures. Intramedullary nails can be inserted with no further disruption of the already injured soft-tissue envelope and preserves the remaining extra osseous blood supply to cortical bone. Concern has been expressed about reaming, causing additional damage to the endosteal blood supply. As the endosteal blood supply to cortical bone is disrupted by the fracture, it is unlikely that insertion of an intramedullary nail will have an additional negative effect. There are, however, data showing that solid intramedullary nails inserted without reaming have a lower risk of infection than tubular nails with a large dead space [22]. On the other hand reamed intramedullary nails are biomechanically stronger and when inserted in a statically locked mode they can reliably maintain fracture reduction with regards to angulation, rotation, displacement, and length. Malunion is uncommon after reduction and fixation of diaphyseal fractures with an intramedullary nail. In addition, intramedullary nailing allows unrestricted access to the limb, and facilitates soft-tissue management (Fig 4.2-6).

Prospective randomized trials that compared reamed with unreamed interlocked intramedullary nailing of open tibial fractures did not show any significant difference concerning outcome and risk of complication [23, 24].

11.3.3 External fixation
External fixation is useful for stabilizing open fractures and can be applied almost always and everywhere. Historically, external fixation has been used as the definitive fixation of open fractures, but is used more commonly now as a technique for temporary fixation. The advantages of external fixation are:
- It can be applied relatively easily and quickly.
- It provides relatively stable fracture fixation.
- There is no further damage done, if applied correctly.
- It avoids implantation of hardware in the open wound.
Fig 4.2–6a–f Stabilization of open segmental fractures of the tibia and fibula by closed unreamed nail (UTN 8 mm).

a Complex tibial fracture with two intermediate segments after crush injury in a 30-year-old mason (42-C3).
b Large laceration at the distal end of the leg and extensive abrasions over the tibial crest. Neurovascular status: intact. IO3-MT3-NV1.
c Postoperative x-ray after stabilization of the tibia with a statically locked 8 mm UTN.
d 36 hours after ORIF a cancellous autograft was added to the distal fracture and the soft-tissue defect was covered by a free musculocutaneous flap.
e Uneventful soft-tissue and fracture healing; follow-up x-rays at one year.
f Excellent functional result, no disability.
4.2 Open fractures

The major problems with external fixation are related to pin-track infections, malalignment, delayed union, and poor patient compliance.

External fixators are particularly useful in fractures with severe soft-tissue damage and contamination, where metallic implants—with the risk of bacterial adherence—are best avoided. External fixation may be an option in diaphyseal fractures that are not amenable to intramedullary nailing. Ring fixators can be useful for periarticular fractures. Joint spanning external fixation is a popular strategy for temporary fixation of fractures of the proximal and distal tibia as well as for fractures around the elbow and wrist (Fig 4.2-7).

Fig 4.2-7a–h
a–c  Intraarticular open fracture of the distal tibia 43-C2.
d–f  Initial management consisted of primary wound care, fibula plating, and temporary spanning external fixation.
g–h  Definitive ORIF on day 6 when the swelling is subsiding and the wound appears safer for further surgery.
External fixation is an option for definitive management of open tibial diaphyseal fractures (Fig 4.2-8), though—as noted earlier in this chapter—it appears that locked intramedullary nailing is a more effective technique. If the surgeon plans to treat an open tibial fracture with temporary external fixation, conversion to intramedullary nailing must follow within 3 weeks after injury and should only be undertaken as part of a planned staged protocol if no evidence of pin-track infection has been provided.

**Open wound coverage after primary surgery**

By the end of the initial operation, the full extent of the wound should have been carefully assessed, meticulously debrided and lavaged, and the fracture stabilized. The predictive value of wound culture is low. In a recent prospective trial only 18% of infections that developed were caused by an organism identified on the initial wound cultures [7].

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**Fig 4.2-8a–d Application of external fixator in a Gustilo type IIIA open tibial and fibular fracture involving the tibial plateau and most of the shaft.**

- **a** Extensive multifragmentary fracture of proximal tibia and fibula extending into the shaft in a 47-year-old male caught under a rock (41-B1/42-C2).
- **b** Lag screw fixation of the articular fracture and unilateral external fixation, x-rays after 5 months and after removal of one bar.
- **c** Follow-up after removal of the external fixator. Well consolidated fracture.
- **d** Clinical aspect 8 months after injury. Good function, no disability.
4.2 Open fractures

Surgical extensions of the open wound can be closed primarily, if it is possible to do so without tension. Coverage of the open wound is controversial in terms of timing and technique. The generally accepted principle is that the open wound should be left open. This will prevent anaerobic conditions in the wound, facilitate drainage, and allow repeated debridement [25]. Recently, there has been renewed interest in primary closure of the open traumatic wound. Primary wound closure may be associated with less morbidity, shorter hospital stay, and lower costs, without the wound infection rate increasing [26]. There is ongoing research into the safety and efficacy of primary wound closure.

- The current standard of care for all open fracture wounds is to be left open initially.

Delayed wound closure is accomplished within 2–7 days. There are several strategies available for temporary coverage of an open wound after the initial procedure until subsequent debridement and eventual definitive coverage.

Vacuum-assisted wound closure (VAC) is presently recommended for temporary management of open fracture wounds (Fig 4.3-3). The wound bed is exposed to mechanically induced negative pressure in a closed system. The system removes fluid from the extravascular space, reduces edema, improves microcirculation, and enhances the proliferation of reparative granulation tissue. An open-cell polyurethane foam dressing is placed into the wound and ensures an even distribution of negative pressure (Fig 4.2-9). The early results of this technique in open fracture wound care are encouraging [27].

The antibiotic “bead pouch” technique [28] as an alternative has been described earlier in this chapter.

Serial wound debridement is frequently necessary. If there is any question about the viability of the wound after the initial debridement, a second look procedure should routinely be performed. In high-energy or severely contaminated injuries, serial debridement may be necessary every 24–48 hours until wound viability is ensured.

**Fig 4.2-9a–c** Open-cell polyurethane foam dressing for temporary wound coverage in bilateral open tibial fractures. Low-pressure vacuum drainage (VAC pump) is commenced following surgery.
Skin cover and soft-tissue reconstruction

Skin cover and soft-tissue reconstruction procedures should be performed early. The risk of infection increases if the wound is left open for longer than 7 days. Small Gustilo type I wounds can be left open to granulate and heal quickly by secondary intention. Gustilo type II and type IIIA wounds may occasionally be closed by delayed primary suture, but care must be taken to avoid tension. Frequently, these types of wounds require coverage with a split-thickness skin graft. By definition, Gustilo type IIIB wounds expose bone and require flap coverage. Local transposition flaps or free tissue transfer may be necessary, depending on the size and location of the wound as well as on the condition of the surrounding soft tissue. Local fasciocutaneous flaps play a minor role in open fracture management. Muscle flaps have the great advantage of introducing a rich local blood supply to the wound and the underlying bone and are therefore generally the first choice in suitable wounds. Free flap coverage is required in large wounds and those not suitable for a local flap (chapter 4.3).

Rehabilitation

One of the goals of open fracture management is to return the patient to normal function as soon as possible. The great benefit of an aggressive approach, involving early fracture stabilization and early tissue reconstruction, is that joint and soft-tissue immobilization is avoided and early movement is facilitated. The patient and the rehabilitation team need to work together to maximize early motion of the injured limb.

Pitfalls and complications

The management of severe open fractures is time-consuming and difficult for the patient. It involves staged and often technically demanding surgical procedures, the timing of which is crucial and requires close cooperation between the members of the surgical team (orthopedic surgery and plastic surgery). Basic principles must be carefully followed, but ingenuity is required to deal with the complexity of each individual case. Compartment syndrome is a significant risk even in open fracture, and careful monitoring of the patient is essential. Experience, technical skill, and significant resources are required, which often means transferring the patient to a specialist center.

The pitfalls are numerous. Infection remains the major risk and can lead to delayed union, nonunion, malunion, and loss of function. Delayed union and nonunion more often occur after open fractures than in closed fractures, the frequency also increases with the severity of injury. In severe injuries—particularly those with major bone loss—nonunion can be predicted. Surgical intervention to reconstruct bone defects and stimulate fracture healing should be performed early. Bone grafting—when used—is usually delayed for about 6 weeks after injury when the soft tissues have soundly healed. Autogenous cancellous bone grafting is the usual strategy for managing bone defects. Complex defects may require specialized techniques including fibular transfer, free composite graft, or distraction osteogenesis. A plan to avoid delayed union and nonunion must be conceived early. Finally, there seems to be evidence that application of recombinant human bone morphogenic protein to the fracture site at the time of
4.2 Open fractures

delayed wound coverage in open tibial shaft fractures reduces the risk of delayed union [29].

The patient must realize that a series of surgical procedures is frequently necessary to achieve the desired outcome. Prolonged immobilization must be avoided and the patient must receive appropriate rehabilitation in order to maximize the functional outcome.

16 Special situations

16.1 Open fractures with vascular injuries

Open fractures associated with major arterial injuries that require repair are classified as Gustilo type IIIC injuries. The principles of management of open fractures have to be combined with the principles of management of vascular injuries. Gustilo type IIIC open fractures are frequently associated with devastating damage to bone and soft tissues. Despite strict adherence to principles and techniques, poor functional outcomes are frequent sequelae of these severe injuries. Gustilo type IIIC open tibia fractures have a particularly poor prognosis because of the large zone of injury and the relatively fragile soft-tissue envelope.

Gustilo type IIIC open fractures require extremely careful assessment. The decision to either salvage or amputate depends on the consensus judgment of experienced orthopedic, plastic, and vascular surgeons. Salvage is technically possible in most cases. However, salvage is not always the correct choice, particularly for IIIC open tibia fractures. Vascular surgeons can usually revascularize the distal portion of the limb with a bypass graft. The limb can be realigned and stabilized by the techniques described in this chapter. Plastic surgery techniques can provide soft-tissue coverage. However, in the tibia, the severity of the injury to the soft-tissue envelope and bone may result in an infected nonunion. If salvage is chosen, the patient may be subject to a long course of repeated painful and psychologically distressing surgical procedures. The functional outcome may be poor and no better than amputation [30]. The problem lies in determining which limbs can be salvaged and which are better amputated (Fig 4.2-10). Several authors have attempted to address this issue [31]. Factors important in decision making include:

- the general condition of the patient (the presence of shock);
- the warm ischemia time (more than 6 hours);
- the age of the patient (over 30 years);
- the cut to crush ratio (blunt injuries have a large zone of crush).

Fig 4.2-10a–b Mangled lower leg in a 19-year-old female with polytrauma after a motorcycle accident. There was no circulation or sensory/motor activity distal to the injury (IOS-MT5-NV5). Primary amputation was performed.
In cases suited for an attempt at salvage, urgent revascularization is the immediate goal. In the lower limb, angiography is necessary in situations where the level of vascular injury is unclear. Whenever possible, this should be performed on the operating table to avoid delays in the angiography suite. Generally, revascularization is done prior to fracture stabilization, but in some situations, rapid temporary fracture fixation is applied prior to vascular repair. A temporary vascular shunt can be very useful.

- Fasciotomy is mandatory following arterial repair as reperfusion will result in swelling and can cause compartment syndrome.

16.2 Gunshot injuries

The severity of damage resulting from a gunshot injury is related to the amount of energy dissipated at the time of impact (E=m×v²/2). High-velocity rifles and close-range shotguns may cause devastating injuries because of the high energy of the impact, the secondary cavitation produced, and the secondary missile effects of shattered bone fragments. But, most gunshot wounds encountered in civilian practice are caused by low-velocity handguns and are less severe unless neuro-vascular structures are damaged. Cavitation is not significant and although bone fragmentation may be considerable, the secondary missile effects are minimal and bone fragments are rarely stripped of their soft-tissue attachments and blood supply.

High velocity weapons, close-range shotguns, and blast injuries produce severely contaminated Gustilo type III open fractures, which should be managed aggressively. Low-velocity weapons may produce significant fracture comminution but, since soft-tissue attachments are not disrupted, these fractures behave in a relatively benign way. Soft-tissue injuries are not severe and skin wounds are small. Widespread experience in violent communities has shown that these wounds can be managed by debridement and the fracture treated on its individual merits (Fig 4.2-11). Bullets lodged in joints should be removed to avoid lead arthropathy and systemic lead poisoning.

17 Summary

An open fracture is defined as one which communicates with the surrounding external environment. Open fractures represent about 3% of all limb fractures and most frequently occur as a result of high-energy trauma. Coexisting multiple injuries are common. The severity of injury can be classified and is the most important factor in predicting outcome. The ultimate goal is the early return of normal function of the limb and is dependent on adherence to the basic principles of prevention of infection, early soft-tissue and fracture healing, restoration of the anatomy, and functional recovery. Management protocols should follow the sequential steps of careful initial assessment, staged meticulous wound debridement, fracture stabilization, soft-tissue and bone reconstruction, and rehabilitation. The surgical techniques are demanding and are dependent on the availability of the appropriate resources, including orthopedic, plastic, and microvascular surgical expertise. There are many possible pitfalls that may lead to disastrous complications. However, in the majority of cases, these pitfalls can be avoided by careful attention to detail and the application of rational and mature clinical judgment.
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Fig 4.2-11a–f

a–b Entrance and exit wounds of a high-velocity gunshot wound to the thigh.

c–f Proximal femoral fracture treated with statically locked intramedullary nailing.
18 Bibliography


