

8.1 Introduction

Soft-tissue injuries of wounds in a war zone represent perhaps the greatest challenge in limb reconstruction [8, 45]. The major factor determining the outcomes in high-energy injuries to the limbs is the severity of the soft-tissue damage, and surgical treatment is the most important prophylactic measure to prevent infection [17]. The first surgical procedure determines the long-term outcome [36].

After stabilization of the patient's general condition, a thorough head-to-toe examination must be performed, checking the blood supply to the limbs, their neurological status, bone stability, and soft-tissue condition. Early evaluation of the severely injured extremity and primary radical debridement is a crucial phase in the management of patients after open high-energy injuries [41]. It is essential to examine more than just the wound area; the entire extremity must be evaluated and radiographs of the adjacent joints must be obtained [4]. Fracture patterns in radiographs help determine the energy of the injury, although the soft-tissue damage is usually greater than that which is visually evident [65].

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Each wound should be evaluated completely and treated appropriately. The extent of soft-tissue damage frequently dictates treatment protocol [26].

The essential basic principles of contemporary surgical débridement were well delineated in the classic treatise of Joseph Trueta, *The Principles and Practice of War Surgery* [58], which includes the following elements: (1) enlargement of the wound to permit adequate visualization of the injured tissue, (2) assessment of injured tissue for viability, (3) excision of all contaminants and all non-viable tissue, (4) stabilization of the fracture, and (5) establishment of appropriate drainage. The same principles are appropriate today, and aggressive tumor-like débridement of all necrotic and nonviable tissue, including muscles and bone, is considered the most important single step in the management of soft-tissue injuries related to trauma [28, 66]. The timing of definitive osseous stabilization varies and is dependent on the quality and integrity of the soft-tissue envelope (Fig. 8.1).

8.2 Tissue Damage Evaluation

Soft-tissue evaluation in patients suffering from severe high-energy trauma, especially penetrating blast limb injury, is a challenge. According to the study by Weil [63], no unique classification exists for this type of injury. The Red Cross EXCVFM wound classification, originally designed for gunshot injuries, can be applied with some modifications [18]. Bowyer et al. [6] used this classification for the evaluation of injured patients during the Gulf War and suggested that it should be revised to include an assessment of neurological injuries.

Brumback [11] reported a study in which orthopedic surgeons had been asked to classify open fractures of the tibia on the basis of videotaped case presentations;



Fig. 8.1 Clinical appearance of patient suffering from crush injury to both lower limbs. Note severe extensive soft-tissue damage and skin degloving injury around right knee joint

the average agreement among the observers was only 60% overall, which was deemed to be moderate to poor. According to Zalavras [68], classification of an open fracture should be made only in the operating room, after performing thorough wound exploration and débridement. Dougherty [22] claimed that we do not have a precise scoring system for determining the amount of soft-tissue injury present, much less an ability to predict outcome. According to the results of their 2005 review study, Rosell and Clasper [49] were also unable to identify any useful clinical classification that could adequately guide all necessary aspects of management. They recommended that high-energy injuries should be treated according to the individual ‘personality’ of the damage, taking into account the soft-tissue injury, the bone involved, any associated joint involvement or bone defect, and the energy transferred to the wound. The degree of contamination and soft-tissue damage are important factors in the classification of an open fracture, but they may be mistakenly overlooked in the preoperative examination, sometimes due to the relative small size of the traumatic wound.

8.3 Goals of Debridement

Open fractures communicate with the outside environment and the resulting contamination of the wound with microorganisms, coupled with the compromised

vascular supply to the region, leads to an increased risk of infection as well as to complications in healing [54, 67]. The incidence of infection appears to be greater in high-energy wounds, especially combat blast injuries, than in low-energy wounds. Thus, emphasis should be placed on radical excision of nonviable tissue and contaminants, including utilizing a thorough and effective débridement technique [36].

The aim of initial irrigation and débridement of open fracture wounds is to decrease the bacterial load present in the wound as much as possible [42]. Lin et al. [37] stated that debridement and irrigation was the most commonly performed procedure due to the contaminated nature of combat injuries sustained in Operation Enduring Freedom, and reported an almost threefold lower incidence of repeat orthopedic procedures in patients undergoing adequate initial wound treatment before arriving at the tertiary military facility. The goal is a clean wound with viable tissues and no infection. The importance of timely performed thorough wound débridement and radical excision of necrotic tissue cannot be overstated. After irrigation of the wound, surgical débridement is the most important principle in open fracture management because nonviable tissues and foreign material enhance bacterial growth and hinder the host’s defense mechanisms [67].

8.3.1 Timing of Debridement

Débridement and wound excision should be performed as soon as possible; early débridement significantly reduces the infection rate in war injured limbs [31, 35, 46]. In his study, Tian [57] showed elevation of the number of bacteria in devitalized muscle tissue after missile wounding. Bacterial cultures were always positive if the specimens were taken immediately after injury. In a retrospective analysis of open fractures sustained by U.S. military personnel during Operation Just Cause, Jacob [31] reported a threefold (66%) increase in infection rate in patients who did not undergo débridement until their arrival at a tertiary medical facility, compared with those who underwent early débridement (22%). However, according to a study by Webb [62], the timing of débridement (less than 6 h after the injury, compared to 6–24 h after the injury) and the timing of soft-tissue coverage (3 days or less after the injury as compared to more than 3 days after the injury) had no apparent effect on clinical or functional outcome in the

treatment of severe type-III open tibial diaphyseal fractures. These data are consistent with the report by Harley et al. [30], in that there was no change in outcome or the percentage of patients having a major complication when fractures that were débrided within 6 h after the injury were compared with those that were débrided between 6 and 24 h after the injury.

8.4 Wound Irrigation

Copious irrigation is an essential part of wound management; however, the timing, the optimal fluid volume, the delivery method, and the kind of irrigation solution have not been determined [1]. In 2007, Owens [42] evaluated the effect of different delays in irrigation on bacterial removal in an animal model. The results were as follows: earlier wound irrigation resulted in superior bacterial removal and a $70\% \pm 2\%$, $52\% \pm 3\%$, and $37\% \pm 4\%$ reduction in bacterial counts from the preirrigation level at 3, 6, and 12 h, respectively. The clearance ratios were significantly different at all time points ($p < 0.004$).

Thorough and copious irrigation of contaminated wounds will lower the risk of infection [41]. Most surgeons use sterile saline for the irrigation of wounds [1, 20]. Different active solutions have been added to a saline medium with the aim of improving wound healing and preventing infection. The most popular additives are antiseptics, antibiotics, and soap, according to publications by Anglen [2], Brennan and Leaper [9], Conroy et al. [14], Gilmore and Sanderson [27], Lineaweaver et al. [38], Rogers et al. [47], Rosenstein et al. [48], Stevenson et al. [52], and Vilijanto [60].

8.4.1 Local Antiseptics

According to Crowley [20], the most commonly used local antiseptics are povidone-iodine (Betadine; Seton Scholl Healthcare Pty Ltd, Terrey Hills, UK) and chlorhexidine gluconate (Hibitane; (Bioglan) Bradley Pharmaceuticals Inc., West Fairfield NJ). These products are active against a broad spectrum of bacteria, fungi, and viruses, eliminating wound pathogens. Rogers [47] and Vilijanto [60] believe that, by reducing the bacterial load, the use of local antiseptics will lead to less pressure on the host defense system.

In 1975, Gilmore and Sanderson [27] showed a statistically significant reduction in wound infection with the prophylactic use of povidone-iodine.

At the same time, Vilijanto [60] also noted that the disadvantages of local antiseptics included toxicity toward host cells and cell function, which may cause delayed wound healing. In 1985, Brennen and Leaper [9] and Lineaweaver [38] showed their negative effect on microvascular flow and endothelial integrity, and their toxic effect on tissues, especially from undiluted forms of local antiseptic solutions. Recent studies have shown that some commonly used antibiotic and antiseptic solutions are also toxic to osteoblasts when applied as topical irrigants and may even cause delayed bone consolidation [15, 33]. However, no difference was found in infection rates between operative wounds treated with normal saline and those treated with povidone-iodine in the large series of Rogers et al. [47]. According to Norris [41], the use of topical antibiotic irrigation in orthopedic surgery requires further evaluation.

8.4.2 Local Antibiotics

According to studies by Anglen [1], Conroy et al. [14], and Rosenstein et al. [48], the most commonly studied antibiotics have been neomycin, whose mode of action is unknown, bacitracin, which interferes with cell wall synthesis, and polymyxin, which directly alters the permeability of the cell membrane and can reduce the rate of infection compared with the use of saline solution. The use of antibiotics as additives has also been investigated, but the results are inconclusive; their use is not without risk of anaphylaxis and the promotion of antibiotic resistance will always be a source of concern [20].

8.4.3 Surfactants

The purpose of the widely used soap solutions to clean open wounds is to lower the bacterial load in the wound by removing the bacteria, rather than killing them. In 1999, Conroy [14] found that soap appeared to be at least as effective as many antiseptics and antibiotics. In 2005, Anglen [2] compared soap and antibiotic solutions for the irrigation of wounds in open fractures of the lower limb and showed that neither method had a particular advantage. However, there is no consensus

regarding optimal volume, pressure, and the desirable additives to the irrigation fluid [32].

8.4.4 High-Pressure Pulsatile Lavage (HPPL)

According to a study performed by Draeger [23], suction and sharp debridement, as practiced by most surgeons, may remove foreign bodies well without the use of high-pressure pulsatile lavage (HPPL). Moreover, HPPL may drive some contaminants deeper into tissue already compromised by trauma, rather than removing them. Furthermore, this study supports the conclusion that pulsatile lavage may further damage soft tissue more than low-pressure irrigation with bulb syringe and suction irrigation. Also, according to Zalavras and Patzakis [50], pulsatile flow *per se* does not add to the effectiveness of irrigation. However, the 2008 study by Keeling [26] recommends that copious irrigation of at least 9 liters of normal saline solution per wound should be delivered throughout the wound by pulsatile lavage.

Based on current evidence, Crowley [17] made the following treatment recommendations for the local irrigation of wounds in the management of high-energy open fractures:

1. Normal saline should be used routinely for the irrigation of fractures.
2. The use of antibiotics and antiseptics as additives should be limited because of inconclusive evidence and potential risks.
3. Low-pressure irrigation methods should be used routinely.
4. Surgeons who continue to use high-pressure pulsed lavage systems should limit the pressure to 50 psi.

8.5 Debridement Technique

Thorough débridement is critical; it is the most important step in preventing complications, especially infection [34, 35, 59]. Aggressive extensive debridement of all damaged tissue surrounding bullet tracts from high-velocity military weapons has been standard military surgical practice. Inadequate debridement remains the major cause of chronic infection after severe extremity trauma [55]. In 2003, Bartlett wrote: “The evaluation and treatment of damaged muscle remains one of surgeon’s greatest challenges” [4]. Inadequate debridement of open fractures is often the rule rather than the exception, because tissue devitalization is usually not appreciated immediately [16, 29, 46, 55]. Inadequate excision of missile wounds of the extremities will leave necrotic tissue in the wound, predisposing to infection and to possible later amputation [69]. No principle is more important in the care of an open fracture than copious irrigation and meticulous wound debridement, including necrotic muscles [64] (Fig. 8.2).

Before the patient is anesthetized, a thorough neurological examination of the injured limb should be conducted, unless the patient is unconscious, or a

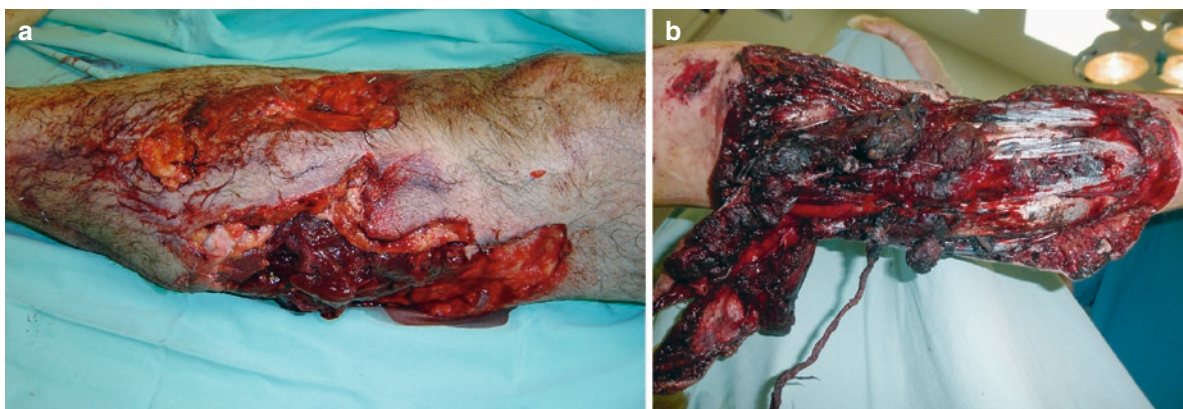


Fig. 8.2 (a, b) Clinical pictures of the lower limbs after blast injury demonstrate severe, extensive wide-spread damage to skin and soft tissue with post-traumatic skin and soft-tissue loss

proximally placed tourniquet is in place, creating limb numbness.

In performing a primary debridement procedure, the involved limb is prepared circumferentially and draped free so as to leave all important skeletal landmarks visible. A tourniquet is applied to the proximal part of the extremity, to be used only when necessary (active bleeding); otherwise, the debridement procedure is completed without inflating the tourniquet. This prevents additional ischemic damage to already severely traumatized tissues during the operative procedure. In addition, there may have been prolonged tourniquet time from the injury event until hospital admission, especially in the treatment of war trauma patients with prolonged time of evacuation from the battlefield due to severe combat conditions. Even when a tourniquet is obligatory, the tourniquet time should be kept to a minimum, since using a tourniquet in treating lower extremity trauma has been shown to increase the incidence of wound infection, presumably by increasing tissue hypoxia and acidosis [51, 67].

Generally, the operation is performed with repeated thorough washing of the post-traumatic wound and skin on all surfaces of the injured extremity with a chlorhexidine soapy scrub followed by normal saline and/or Ringer's solution. An additional flushing with hydrogen peroxide solution is also recommended [28]. All visible and palpated foreign bodies must be removed from the wound. All devitalized soft tissues in the wound bed must be thoroughly removed during the debridement procedure. Denuded and comminuted bone fragments with questionable viability must also be removed. Wound excision is performed usually by making a longitudinal incision, which allows decompression of the wound, avoiding crossing joints longitudinally [50]. Wounds are surgically extended into the adjacent "normal" tissues along the lines of described surgical exposure to allow for complete visualization and adequate exposure of the tissues in the trauma zone. Primary surgical debridement of the wound must be radical and aggressive, with excision of all devitalized tissues which can be a source of tissue necrosis and infection in the future. The margins of the entrance and exit wounds should be excised and the track thoroughly irrigated [3]. Excision of the wound skin edges not only removes devitalized tissues but also improves the exposure of the depth of the wound. At the same time, peripheral nerves and tendons, unless detached, should not be debrided radically during the primary debridement procedure [13].

The borders of the tissue damaged area with the normal tissues in cases of high-energy trauma are usually contused and cannot be precisely distinguished. The classic symptoms of the "four Cs" – color (red, not pale or brown), consistency (not waxy or "stewed"), contractility on being pinched, and capillary bleeding when cut – must be checked and detected during surgical debridement of muscle [3, 7]. According to Volgas et al. [61], these four Cs of muscle viability used to assess what needs to be excised are very subjective and highly dependent on the experience of the surgeon. We fully agree with Bartlett that the surgeon's experience in interpreting all these important physical findings is the most influential factor ultimately.

When the borders have been defined, all nonviable skin, subcutaneous fat, and muscle should be removed sharply. All intact segmental muscular vascular branches must be preserved to avert further local muscle ischemia. All nonviable tissue must be removed, while as much functional tissue of the tendons, joint capsule, and ligaments as possible are spared during extensive debridement unless they are extremely contaminated or macerated. The surgeon should observe the wound cavity and the tissues for any foreign material that may have been carried into the wound. Injured nerves or tendon should be marked with sutures during the primary debridement procedure for later elective repair surgery [50] (Fig. 8.3).

Debridement of nonviable soft tissue and irrigation with normal saline are repeated during the operative procedure. All denuded bone fragments must be removed from the wound, avoiding devascularization of the fracture zone. In some cases, loop magnification during the debridement procedure may be useful. According to Brusov [12], a 5–5.5 cm degloving of the periosteum from the bone ends can be detected in most cases of high-energy trauma. According to current publications, the extensiveness and extent of the bony debridement is controversial, with recommendations varying from replacing large free contaminated cortical fragments to removing cortical bone until bleeding from the edges is seen [39]. The free bone fragments are most often saved to add to the mechanical integrity of fixation. According to McAndrew [39], deep wound infection occurred in 7–25% of patients in whom free and devascularized cortical fragments were saved, and these failures were common due to inadequate bone debridement. At the present time, the various possibilities of the Ilizarov method in providing not only stable



Fig. 8.3 Clinical appearance of the lower limb after gunshot wound (a) Appearance on admission, before debridement, (b) after surgical debridement

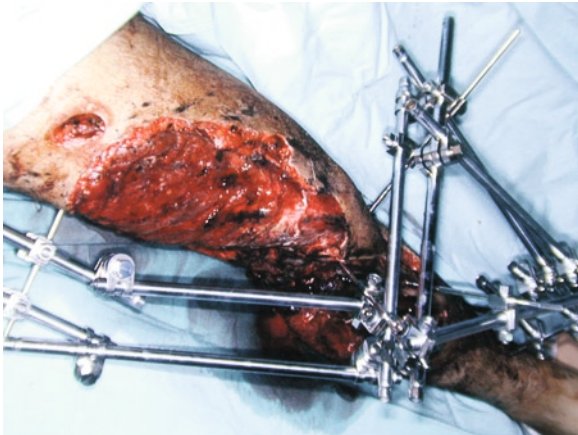


Fig. 8.4 Clinical picture of a patient suffering from open high-energy lower-limb fracture due to blast injury. An emergency procedure is carried out with stabilization of fracture with tubular AO external fixator. Note viable wound edges after performing primary radical débridement procedure

fracture fixation in patients who suffered from severe bone comminution and extensive post-traumatic bone loss, but also effective bridging of bone defects using later distraction osteogenesis, allows for optimal necessary aggressive debridement during the primary surgical procedure. This reduces the quantity of nonviable tissues in the depth of the wound, diminishing the risk of wound deterioration and avoiding multiple surgical procedures in the future. Finally, radical excision of necrotic tissue, as proposed by Godina [28] should be

performed so that all nonviable tissue, including bone, is removed (Fig. 8.4).

8.6 Fasciotomy

For patients with vascular injuries (Gustilo IIIC fractures) or when an open crush injury is significant, prophylactic fasciotomies should be performed to prevent compartment syndrome (Figs. 8.5 and 8.6).

Acute compartment syndrome may occur in massively traumatized limbs and must be considered as a real cause of limb ischemia. Swelling of muscle fibers to as much as five times normal size can be observed, and local edema may lead to compartment syndrome with further increase of the insult to the soft tissues of the injured segment [25]. While the presence of an open fracture wound does not prevent the extremity from the complication of compartment syndrome, an open fracture does not automatically relieve the compartment of the injured limb, and even these patients can go on to develop compartment syndrome [5].

The liberal use of fasciotomies not only releases compromised muscle compartments, but also facilitates thorough wound inspection in the deep levels of the injured limb. Fasciotomy must be performed if any question of compartment syndrome exists. According to Moed [40], prophylactic fasciotomy is indicated if there is the slightest indication that compartment

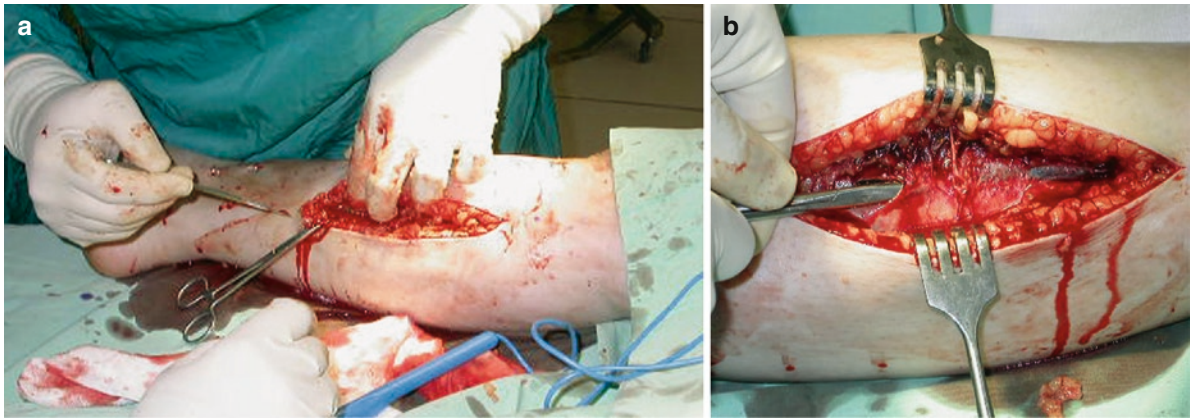


Fig. 8.5 Clinical pictures demonstrate operative procedure of fasciotomy in treatment of patient who suffered from acute compartment syndrome after high-energy lower-limb injury. (a) Skin incision, (b) opening of fascia

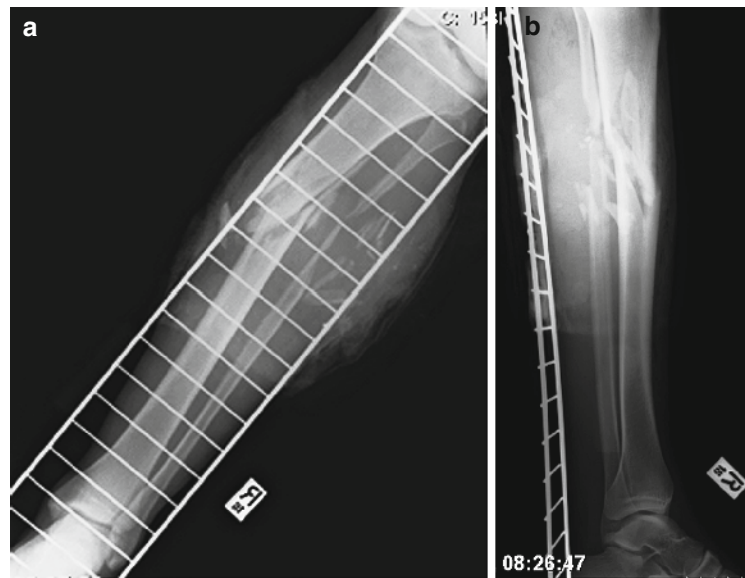


Fig. 8.6 Twenty-one-year old male suffering from open Gustilo-Andersen type IIIC right tibial fracture due to blast anti-tank rocket injury. Fasciotomy was performed during primary debridement due to acute compartment syndrome. (a, b) X-ray at time of injury. Note comminution and displacement of tibial and fibular bone fragments. (c) Immediate fasciotomy was performed to handle acute compartment syndrome, (d, e) Radiological pictures after primary stabilization of the fracture using hybrid external fixation. (f) Clinical appearance of the right lower limb fixed with unilateral tubular external fixation

frame. Note open post-fasciotomy wound, (g, h) Clinical appearance after skin grafting, good wound healing, (i, j) Conversion of tubular external fixator to Ilizarov circular frame is performed. Clinical appearance of the leg from medial and lateral side, (k, l) Radiological pictures after conversion to Ilizarov external fixation demonstrate stabilization of fracture in position of reduction, (m, n) After 6 months of external fixation, the Ilizarov frame was removed. X-rays 1 year later demonstrate bone healing of the fracture in good alignment

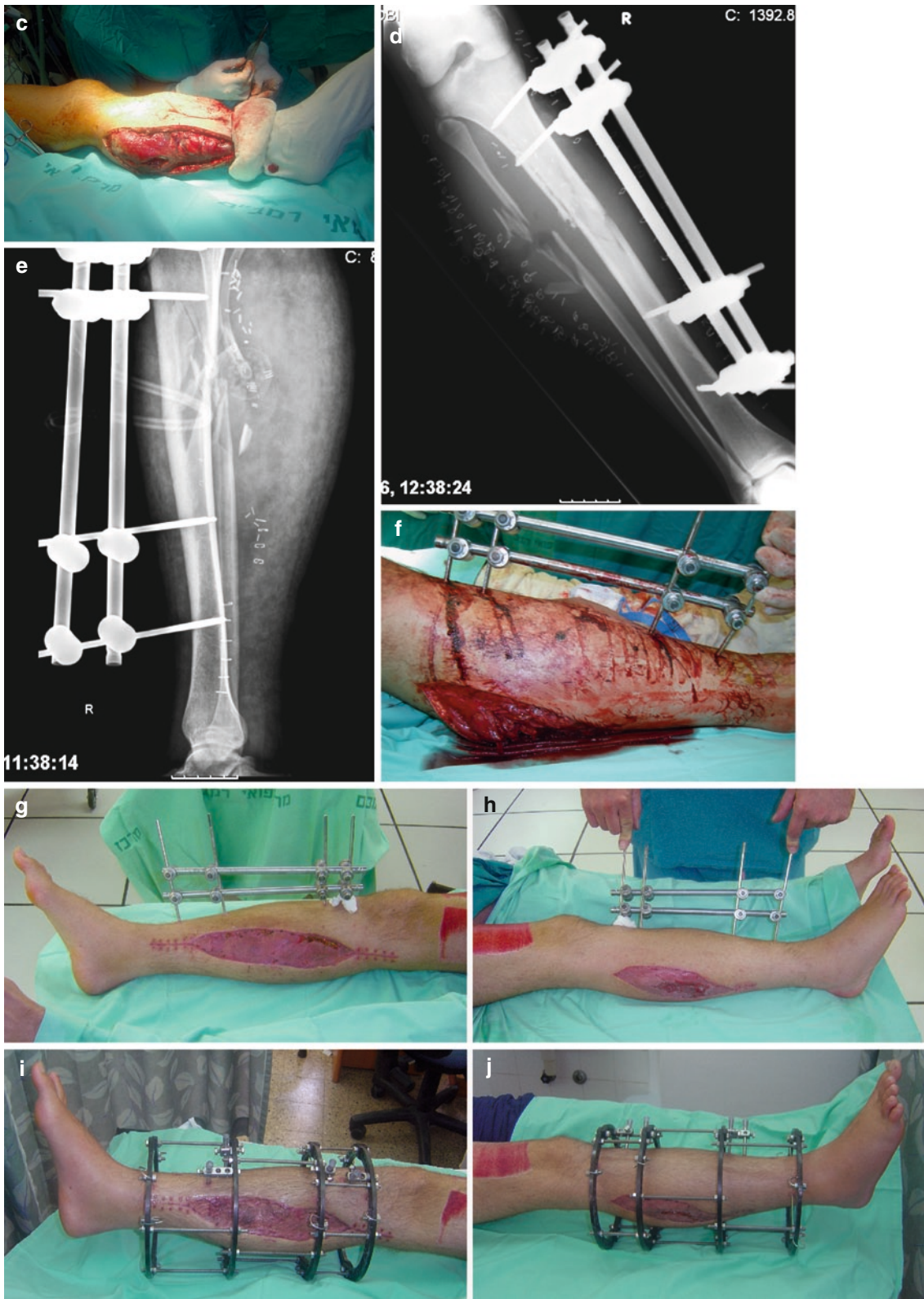


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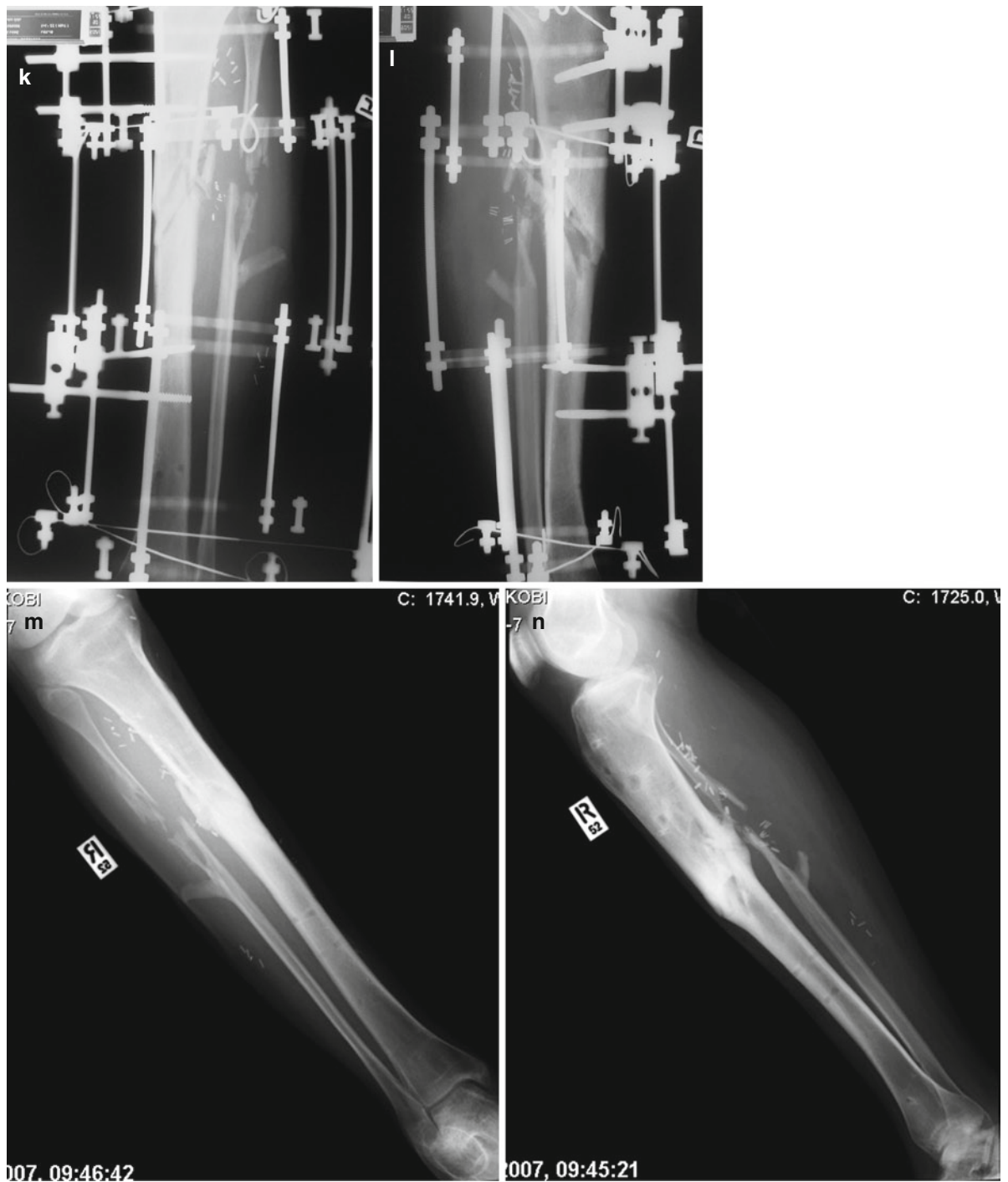


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Fig. 8.7 Clinical picture illustrates fasciotomy performed for treatment of acute compartment syndrome due to blast injury with tibial and fibular fractures and circular burns

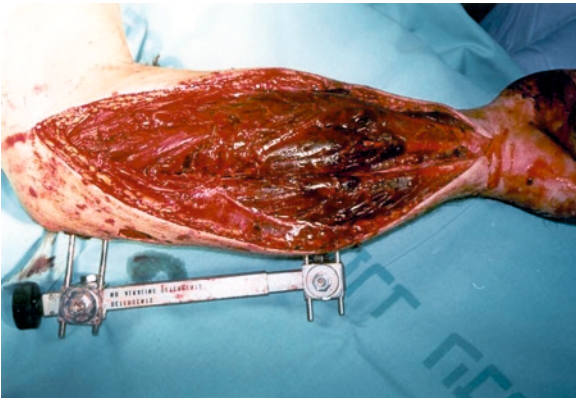


Fig. 8.8 Thirty-three-year old male with crush injury to the left forearm. Immediate fasciotomy was performed to handle acute compartment syndrome. The ulnar bone fracture was stabilized using Wagner external fixation frame

syndrome will occur. The development of this dangerous complication should not be overlooked (Fig. 8.7)!

In war injuries in particular, a low threshold of suspicion is recommended for the use of fasciotomy in the overall treatment of lower limb fractures (Fig. 8.8).

If the wound is heavily contaminated and the soft-tissue damage is deep and extensive, it is difficult to judge the extent of primary surgical tissue excision. When finishing primary debridement procedures in patients suffering from high-energy injuries, primary closure of wounds must be avoided because of contamination and retention of necrotic tissues. The widely accepted standard of care of soft-tissue injury associated



Fig. 8.9 Clinical picture taken five days after fasciotomy demonstrates good tissue condition in the open postdebridement wound



Fig. 8.10 Clinical appearance of the severely injured lower limb due to blast injury demonstrates tubular external fixation with open postdebridement wound

with open fractures is to leave the traumatic wound open after the initial surgical debridement [64]. Pollak [45] suggested that utilizing traditional wet-to-dry dressings is safe and sufficiently effective during medical transportation and on the first day of the treatment. In the Vietnam conflict, Brown [10] obtained very good clinical results and a low rate of infection with the open-wound technique; however, current concepts suggest that these wounds may be closed earlier when conditions are optimized (Figs. 8.9 and 8.10).

8.7 Repeated Debridement

During primary inspection and debridement of the wounds of patients who suffered from high-energy injuries, especially after combat trauma, it is usually

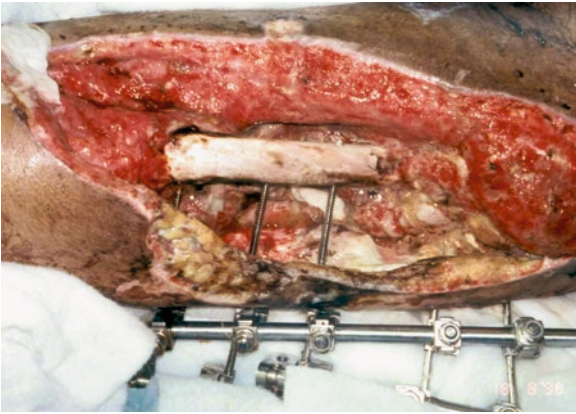


Fig. 8.11 Clinical appearance of the thigh after serial repeated debridement procedures (after crush injury lower limb, tubular external fixation) demonstrates deep soft-tissue and bone necrosis

not possible to assess the level and extent of the tissue damage precisely; as a general rule, meticulous repeated surgical debridements are required to achieve the best possible control of local infection. Repeated serial debridements are required for patients with high-velocity war injuries, especially those suffering from blast and crush injuries. There is usually a need for repeat debridement 24–48 h after the initial surgical procedure. A second-look procedure and repeated surgical debridement should be performed under general anesthesia. Serial inspection under anesthesia and debridement of necrotic tissue should be undertaken until final wound closure is deemed to be safe. According to Zalavras et al. [68], new techniques for debridement, such as the use of the Versajet Hydrosurgery device (Smith and Nephew, Memphis TN) have shown the benefit of reducing tissue loss during initial or second-look procedures (Figs. 8.11 and 8.12).

8.8 Management of Retained Bullets, Shells, and Shrapnel in the Limbs

In high-energy injuries, retained missile fragments encountered during debridement are removed during the procedure. Removing these fragments from the wound cavity causes little additional trauma and can significantly lower the potential for sepsis. A thorough search

should be made to remove not only radiographically detected metal fragments but also other incidental debris, including fragments of clothing, skin, and hair. In our experience in treating mine blast victims, we often find fragments of stones during surgical debridement.

The need to remove the foreign bodies depends primarily on the location of the retained missiles. Their continuous presence can lead to toxicity of the central nervous system, the peripheral nervous system, and the gastrointestinal, renal, and hematological systems. The literature suggests that patients with retained intra-articular lead bullets after gunshot wounds are at risk for the development of systemic lead poisoning [21, 70]. Aggressive surgical therapy may be needed for these patients [56]. Missiles retained in the joints or bursa can result in mechanical abrasion, mechanical obstruction, and destructive arthritis, leading to arthropathy. If possible, foreign materials should be removed arthroscopically. Arthrotomy is often necessary for adequate debridement, followed by surgical restoration of the articular surface. In uncomplicated cases, arthroscopy can provide valuable diagnostic information and definitive treatment [43]. In addition to avoiding the morbidity associated with arthrotomy, arthroscopy allows easier access to intra-articular areas, which are difficult to visualize, such as the posterior aspects of the knee joint. Removing the intra-articularly placed foreign bodies is best performed in the early stages of treatment but is not a life-saving procedure, especially in the management of multi-injured patients, and can be postponed if necessary. Open or arthroscopic removal of bullets or other foreign bodies is performed in these patients as an elective procedure [70] (Fig. 8.13).

Foreign bodies close to neurovascular formations and irritating them must be removed as soon as possible with great care. In later stages of treatment, there may be indications for removing foreign bodies that provoke septic complications.

Shrapnel injuries were once confined historically to wars and the battlefield, but today these wounds are seen more frequently in noncombatants because of the increase in world-wide acts of terror [44]. Specific wound care should be performed, depending on the amount of energy of the blast, the patient's general condition, anatomic site of the trauma, and related injuries. Eylon [24] suggests that nonsurgical treatment of shrapnel in soft tissue is the preferred option since, in most cases, it does not cause any short- or

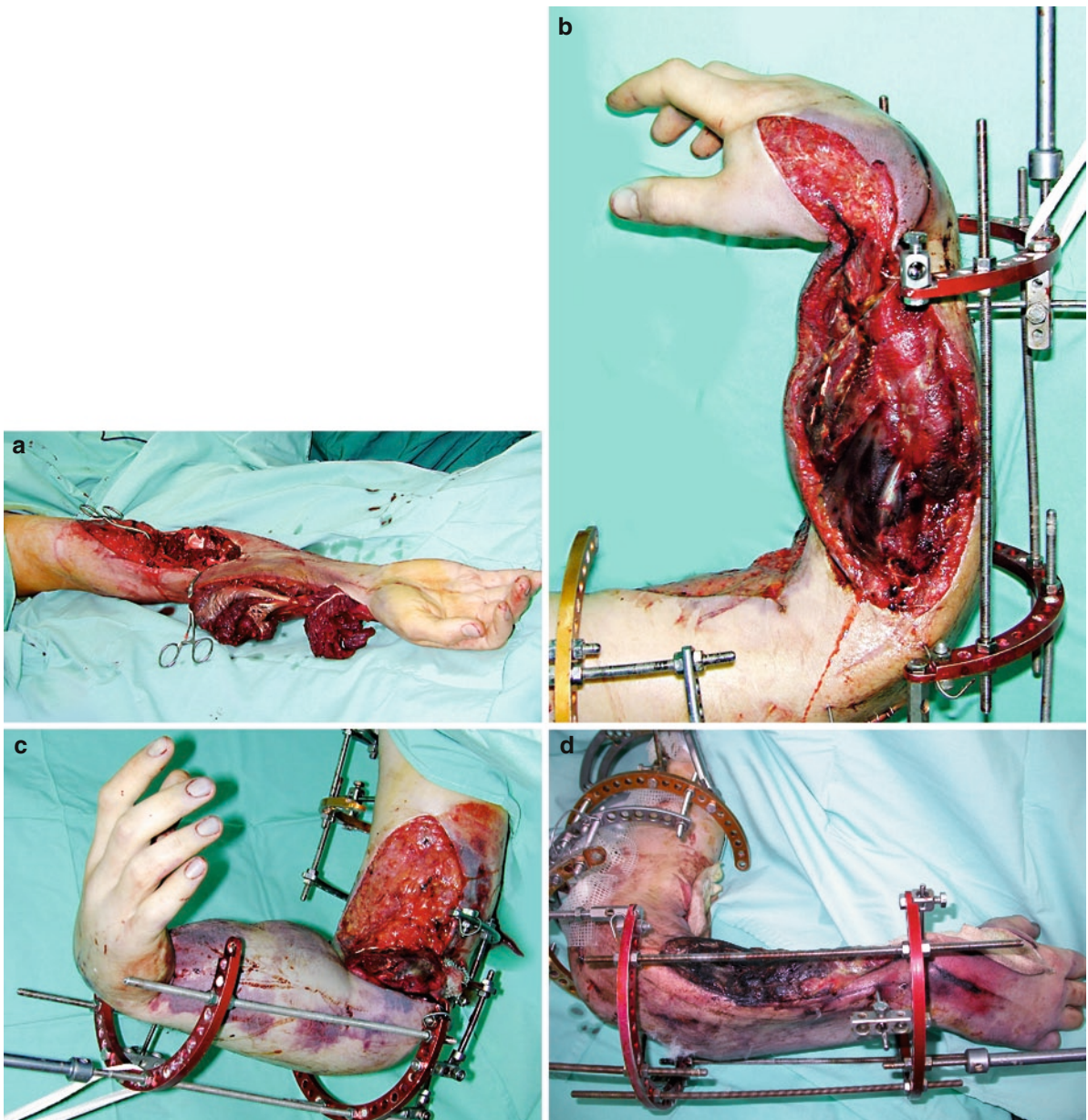


Fig. 8.12 Twenty-eight-year old male suffering from severe crush injury to right upper limb Gustilo-Anderson type IIIB. Primary treatment included debridement and trans-elbow bridging using minimally invasive Ilizarov half-rings external fixation frame. (a) Clinical picture demonstrates severe crush injury to right upper limb with extensive tissue destruction and exposed bone fragments, (b) Clinical appearance on second day after trauma. Trans-elbow external fixation right upper limb by Ilizarov device. Open postoperative wounds. Note swelling and

skin cyanosis without evident signs of soft-tissue necrosis, (c, d) Fifth day after trauma. Poor local condition with necrotic tissues dictates wounds revision and necrectomy. Repeated surgical debridement was performed, (e) Seventh day after trauma. Septic condition. Clinical appearance of extensive tissue necrosis of right forearm and around elbow joint. (f, g) Above-elbow amputation in the relatively healthy tissue borders was performed. Humeral shaft fracture fixed by Ilizarov external fixation frame with coverage of exposed bone fragment by local soft tissue

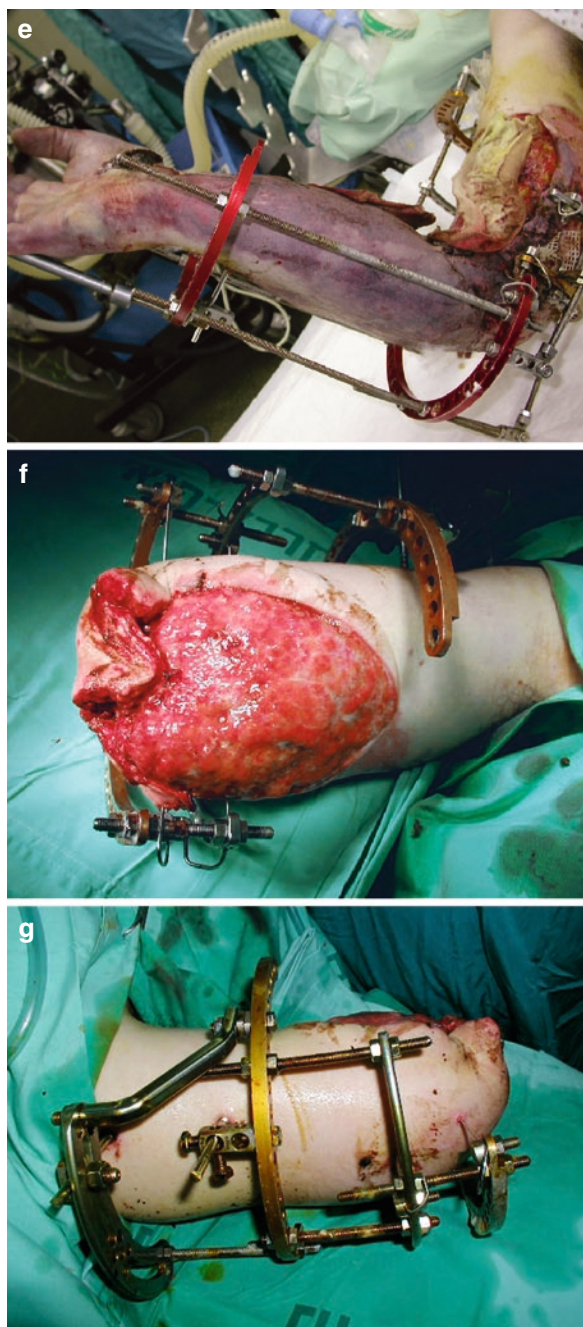


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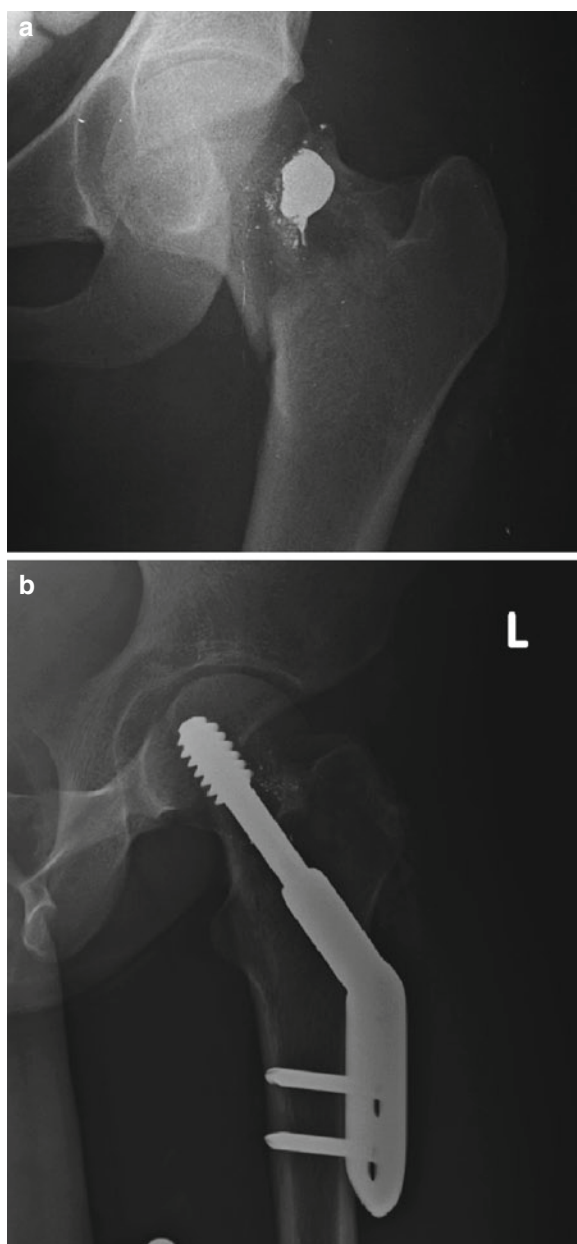


Fig. 8.13 Eighteen-year old female suffering from GSW to left lower limb. (a) Radiography on admission demonstrates subcapital fracture of left femur and presence of metal foreign body (bullet) in the intracapsular zone, (b) Surgical debridement of the wound, removal of the foreign body, and internal fixation using dynamic HIP screw were performed. Postoperative radiogram demonstrates anatomical reduction and internal fixation of the left subcapital femoral fracture (A. Lev El and H. Shehada, Sieff Medical Center, Safed, Israel)

long-term complications. However, they also think that delayed degradation of the shrapnel can occur in rare cases and cause complications that necessitate surgery. In general, according to Stromberg [53], shrapnel is left inert in the tissue and is removed at a later (sub-acute) stage of treatment only when absolutely necessary, such as in cases of systemic toxicity or local tissue complications (e.g., abscess, foreign body granuloma, etc) (Fig. 8.14).

According to Peyser et al. [44], the fundamental principles guiding shrapnel wound management are proper evaluation and excision of necrotic or contaminated tissue. Serial débridement is often necessary in high-risk injuries (e.g., excision of muscle that is merely questionable at first assessment but may become necrotic at a later stage). Shrapnel in the wound tract is usually removed during the acute stage; other shrapnel is either left for delayed removal or retained in the tissue for life. Factors that help the

surgeon determine whether the wound is high- or low-risk include time to treatment, path of the projectile, bone involvement, and the number of projectiles [61].



Fig. 8.14 Clinical appearance of injured lower limb after blast injury demonstrates multiple shrapnel entrance wounds

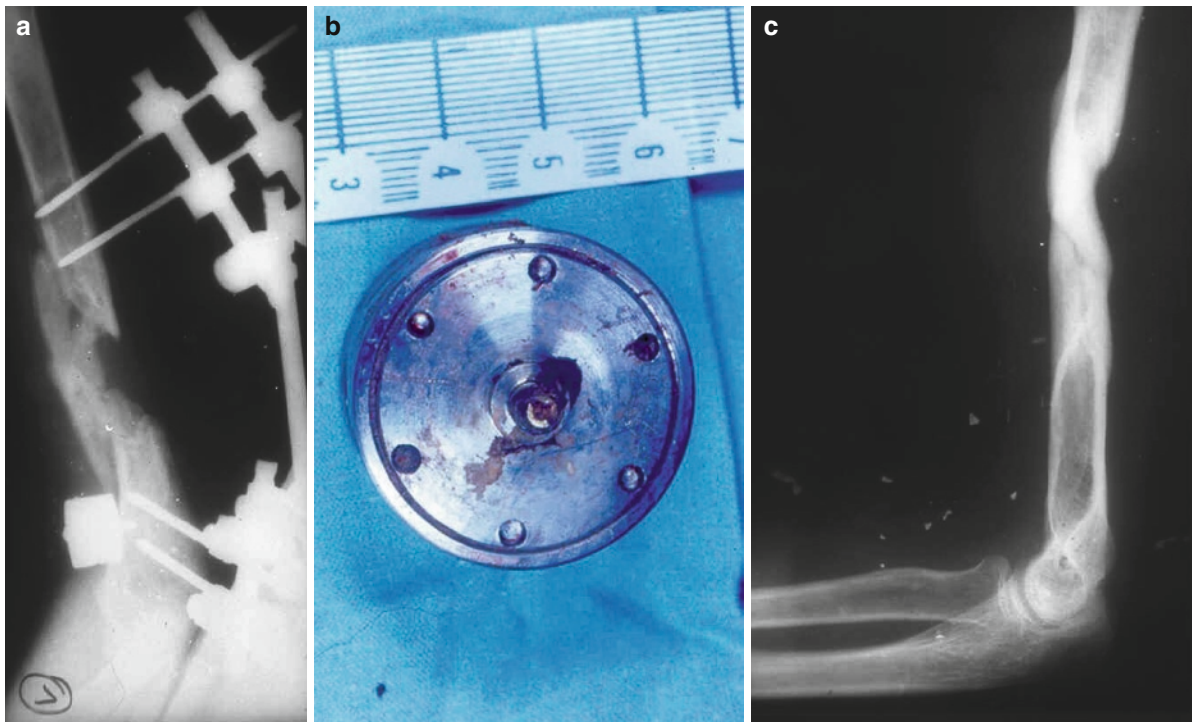


Fig. 8.15 Twenty-one-year-old-patient suffered from open comminuted fracture of the left humerus due to anti-tank rocket blast. Debridement of the wound and tubular unilateral external fixation were performed immediately on admission. (a) Radiograph after primary external fixation shows comminuted fracture of the humeral bone by a large metal foreign body and number of small foreign bodies in the elbow region, (b) The foreign body was

removed during conversion to Ilizarov external fixation frame. Clinical photo demonstrates complex foreign body (gyroscope of the anti-tank rocket), (c) Radiological picture at 1-year followup demonstrate solid bone consolidation of the humeral fracture by presence of number of small metal foreign bodies in soft tissue around elbow joint

Fig. 8.16 Twenty-one-year-old male was injured by anti-tank rocket blast. Debridement of the wound and tubular unilateral external fixation were performed immediately on admission. Final treatment of both lower-limb fractures was performed using the Ilizarov method. At 2-year follow-up, patient suffered from painful right leg and foot and restricted ankle joint motions. (a, b, c) Radiographs at 2-year follow-up demonstrate fracture consolidation with presence of multiple foreign bodies around ankle joint and in soft tissues of right foot. (d) Removal of intra-articular foreign bodies from the ankle joint and right foot was performed. Intra-operative radiogram demonstrates identification of intra-articular foreign body using thin wires, (e, f) X-ray pictures at 6 months followup



Fig. 8.16 (continued)

Nonsurgical treatment can be successful for noninfected small-fragment wounds (<2 cm) that are limited to soft tissue, do not involve viscera or vascular structures, and are not caused by a landmine [7]. Such wounds can be cleaned and dressed and patients given prophylactic antibiotics [19].

Foreign bodies that cause unpleasant and painful feelings upon movement, from wearing clothing and shoes, and foreign bodies that are easily palpated under the skin are usually removed at later stages. However, it is difficult, and sometimes impossible, to remove all missile fragments that are retained in the limbs. The morbidity of the removal procedure can be significant. Excellent long-term results can be achieved without the routine removal of missile fragments (Figs. 8.15 and 8.16).

References

1. Anglen, J.O.: Wound irrigation in musculoskeletal injury. *J. Am. Acad. Orthop. Surg.* **9**, 219–226 (2001)
2. Anglen, J.O.: Comparison of soap and antibiotic solutions for irrigation of lower-limb open fracture wounds: a prospective, randomized study. *J. Bone Joint Surg. Am.* **87**, 1415–1422 (2005)
3. Bartlett, C., Helfet, D., Hausman, M., Strauss, E.: Ballistics and gunshot wounds: effects on musculoskeletal tissues. *J. Am. Acad. Orthop. Surg.* **8**, 21–36 (2000)
4. Bartlett, C.: Clinical update: gunshot wound ballistics. *Clin. Orthop.* **408**, 28–57 (2003)
5. Blick, S.S., Brumback, R.J., Poka, A., et al.: Compartment syndrome in open tibial fractures. *J. Bone Joint Surg. Am.* **68**, 1348–1353 (1986)
6. Bowyer, G.W., Stewart, M.P., Ryan, J.M.: Gulf war wounds: application of the Red Cross wound classification. *Injury* **24**, 597–600 (1993)

7. Bowyer, G.W.: Management of small fragment wounds: experience from the Afghan border. *J. Trauma* **40**, S170–S172 (1996)
8. Bowyer, G.: Debridement of extremity war wounds. *J. Am. Acad. Orthop. Surg.* **14**, S52–S56 (2006)
9. Brennan, S.S., Leaper, D.J.: The effect of antiseptics on the healing wound: a study using the rabbit ear chamber. *Br. J. Surg.* **72**, 780–782 (1985)
10. Brown, P.W.: The fate of exposed bone. *Am. J. Surg.* **137**, 464–469 (1979)
11. Brumback, R.J., Jones, A.L.: Interobserver agreement in the classification of open fractures of the tibia. The results of a survey of two hundred and forty-five orthopaedic surgeons. *J. Bone Joint Surg. Am.* **76**, 1162–1166 (1994)
12. Brusov, P.G., Shapovalov, V.M., Artemiev, A.A., et al.: *Combat injuries to the limbs* [in Russian], p. 130. Geotar, Moscow (1996)
13. Bumbaširevic, M., Lesic, A., Mitkovic, M., Bumbaširevic, V.: Treatment of blast injuries of the extremity. *J. Am. Acad. Orthop. Surg.* **14**, S77–S81 (2006)
14. Conroy, B.P., Anglen, J.O., Simpson, W.A., et al.: Comparison of castile soap, benzalkonium chloride, and bacitracin as irrigation solutions for complex contaminated orthopaedic wounds. *J. Orthop. Trauma* **13**, 332–337 (1999)
15. Cooper, M.L., Boyce, S.T., Hansbrough, J.F., et al.: Cytotoxicity to cultured human keratinocytes of topical antimicrobial agents. *J. Surg. Res.* **48**, 190–195 (1990)
16. Coupland, R.M.: Technical aspects of war wounds excision. *Br. J. Surg.* **76**, 663–667 (1989)
17. Covey, D.C.: Blast and fragment injuries of the musculoskeletal system. *J. Bone Joint Surg. Am.* **84**, 1221–1234 (2002)
18. Covey, D.C.: Combat orthopaedics: a view from the trenches. *J. Am. Acad. Orthop. Surg.* **14**, S10–S17 (2006)
19. Covey, D.C., Lurate, R.B., Hatton, C.T.: Field hospital treatment of blast wounds of the musculoskeletal system during the Yugoslav civil war. *J. Orthop. Trauma* **14**, 278–286 (2000)
20. Crowley, D.J., Kanakaris, N.K., Giannoudis, P.V.: Irrigation of the wounds in open fractures. *J. Bone Joint Surg. Br.* **89**, 580–585 (2007)
21. Dillman, R., Crumb, C., Lidsky, M.: Lead poisoning from a gunshot wound. Report of a case and review of the literature. *Am. J. Med.* **66**, 509–514 (1979)
22. Dougherty, P.: Open tibia fracture. amputation versus limb salvage. opinion: below-the-knee amputation. *J. Orthop. Trauma* **21**, 67–68 (2007)
23. Draeger, R.W., Dahners, L.E.: Traumatic wound debridement. A comparison of irrigation methods. *J. Orthop. Trauma* **20**, 83–88 (2006)
24. Eylon, S., Mosheiff, R., Liebergall, M., et al.: Delayed reaction to shrapnel retained in soft tissue. *Injury* **36**, 275–281 (2005)
25. Fackler, M.L.: Wound ballistics and soft-tissue wound management. *Tech. Orthop.* **10**, 163–170 (1995)
26. Giannoudis, P.V., Harwood, P.J., Kontakis, G., et al.: Long-term quality of life in trauma patients following the full spectrum of tibial injury (fasciotomy, closed fracture, grade IIIB/IIIC open fracture and amputation). *Injury* **40**, 213–219 (2009)
27. Gilmore, O.J., Sanderson, P.J.: Prophylactic interparietal povidone-iodine in abdominal surgery. *Br. J. Surg.* **62**, 792–799 (1975)
28. Godina, M.: Early microsurgical reconstruction of complex trauma of the extremities. *Plast. Reconstr. Surg.* **78**, 285–292 (1986)
29. Gustilo, R.B.: Current concepts review: the management of open fractures. *J. Bone Joint Surg.* **72A**, 299–304 (1990)
30. Harley, B.J., Beaupre, L.A., Jones, C.A., et al.: The effect of time to definitive treatment on the rate of nonunion and infection in open fractures. *J. Orthop. Trauma* **16**, 484–490 (2002)
31. Jacob, E., Erpelding, J.M., Murphy, K.P.: A retrospective analysis of open fractures sustained by U.S. Military personnel during operation Just Cause. *Mil. Med.* **157**, 552–556 (1992)
32. Johnson, E., Strauss, E.: Recent advantages in the treatment of gunshot fractures of the humeral shaft. *Clin. Orthop.* **408**, 126–132 (2003)
33. Kaysinger, K.K., Nicholson, N.C., Ramp, W.K., Kellam, J.F.: Toxic effects of wound irrigation solutions on cultured tibiae and osteoblasts. *J. Orthop. Trauma* **9**, 303–311 (1995)
34. Keeling, J.J., Gwinn, D.E., Tintle, S.M., et al.: Short-term outcomes of severe open wartime tibial fractures treated with ring external fixation. *J. Bone Joint Surg. Am.* **90**, 2643–2651 (2008)
35. Lerner, A., Fodor, L., Soudry, M.: Is staged external fixation a valuable strategy for war injuries to the limbs? *Curr. Orthop. Relat. Res.* **448**, 217–224 (2006)
36. Lerner, A., Reis, D., Soudry, M.: *Severe injuries to the limbs. Staged treatment.* Springer, Berlin Heidelberg (2007)
37. Lin, D.L., Kirk, K.L., Murphy, K.P., et al.: Evaluation of orthopaedic injuries in Operation Enduring Freedom. *J. Orthop. Trauma* **18**, 300–305 (2004)
38. Lineaweaver, W., McMorris, S., Soucy, D., Howard, R.: Cellular and bacterial toxicities of topical antimicrobials. *Plast. Reconstr. Surg.* **75**, 394–396 (1985)
39. McAndrew, M.P., Lantz, B.A.: Initial care of massively traumatized lower extremities. *Clin. Orthop.* **243**, 20–29 (1989)
40. Moed, B.R., Fakhouri, A.J.: Compartment syndrome after low-velocity gunshot wounds to the forearm. *J. Orthop. Trauma* **5**, 134–137 (1991)
41. Norris, B.L., Kellam, J.F.: Soft-tissue injuries associated with high-energy extremity trauma: principles of management. *J. Am. Acad. Orthop. Surg.* **5**, 37–46 (1997)
42. Owens, B.D., Wenke, J.C.: Early wound irrigation improves the ability to remove bacteria. *J. Bone Joint Surg. Am.* **89**, 1723–1726 (2007)
43. Parisien, J.S., Esformes, I.: The role of arthroscopy in the management of low-velocity gunshot wounds of the knee joint. *Clin. Orthop.* **185**, 207–213 (1984)
44. Peyser, A., Khoury, A., Liebergall, M.: Shrapnel management. *J. Am. Acad. Orthop. Surg.* **14**, S66–S70 (2006)
45. Pollak, A.N., Ficke, J.R.: Extremity war injuries: challenges in definitive reconstruction. *J. Am. Acad. Orthop. Surg.* **16**, 628–634 (2008)
46. Reis, N.D., Zinman, C., Besser, M.J.B., et al.: A philosophy of a limb salvage in war: use of the fixateur externe. *Mil. Med.* **156**, 505–520 (1991)

47. Rogers, D.M., Blouin, G.S., O'Leary, J.P.: Povidone-iodine wound irrigation and wound sepsis. *Surg. Gynecol. Obstet.* **157**, 426–430 (1983)
48. Rosenstein, B.D., Wilson, F.C., Funderburk, C.H.: The use of bacitracin irrigation to prevent infection in postoperative skeletal wounds: an experimental study. *J. Bone Joint Surg. Am.* **71**, 427–430 (1989)
49. Rosell, P., Clasper, J.: Ballistic fractures – the limited value of existing classifications. *Injury* **36**, 369–372 (2005)
50. Sakorafas, G., Peros, G.: Principles of war surgery: current concepts and future perspectives. *Am. J. Emerg. Med.* **26**, 480–489 (2008)
51. Salam, A.A., Eyres, K.S., Cleary, J., et al.: The use of a tourniquet when plating tibial fractures. *J. Bone Joint Surg. Br.* **73**, 86–87 (1991)
52. Stevenson, J., McNaughton, G., Riley, J.: The use of prophylactic flucloxacillin in treatment of open fractures of the distal phalanx within an accident and emergency department: a double-blind randomized placebo-controlled trial. *J. Hand Surg. Br.* **28**, 388–394 (2003)
53. Stromberg, B.V.: Symptomatic lead toxicity secondary to retained shotgun pellets: case report. *J. Trauma* **30**, 356–357 (1990)
54. Swan, K.G., Swan, R.C.: *Gunshot wounds: pathophysiology and management.* Year Book Medical, Chicago (1989)
55. Swiontkowsky, M.: Criteria for bone debridement in massive lower limb trauma. *Clin. Orthop.* **243**, 41–47 (1989)
56. Switz, D., Elmorshidy, M., Deyerle, W.: Bullets, joints and lead intoxication. A remarkable and instructive case. *Arch. Intern. Med.* **136**, 939–941 (1976)
57. Tian, H.M., Deng, G.G., Huang, M.J., et al.: Quantitative bacteriological study of the wound track. *J. Trauma* **28**, S215–S216 (1988)
58. Trueta, J.: *The principles and practice of war surgery*, pp. 214–232. CV Mosby, St. Louis MO (1943)
59. Ullmann, Y., Fodor, L., Ramon, Y., et al.: The revised “reconstructive ladder” and its applications for high-energy injuries to the extremities. *Ann. Plast. Surg.* **56**, 401–405 (2006)
60. Vilijanto, J.: Disinfection of surgical wounds without inhibition of normal wound healing. *Arch. Surg.* **115**, 253–256 (1980)
61. Volgas, D., Stannard, J., Alonso, J.: Current orthopaedic treatment of ballistic injuries. *Injury* **36**, 380–386 (2005)
62. Webb, L.X., Bosse, M.G., Castillo, R.C., et al., and the LEAP Study Group: Analysis of surgeon-controlled variables in the treatment of limb-threatening type-III open tibial diaphyseal fractures. *J. Bone. Joint. Surg. Am.* **89**, 923–928 (2007)
63. Weil, Y.A., Mosheiff, R., Liebergall, M.: Blast and penetrating fragment injuries to the extremities. *J. Am. Acad. Orthop. Surg.* **14**, S136–S139 (2006)
64. Weitz-Marshall, A., Bosse, M.: Timing of closure of open fractures. *J. Am. Acad. Orthop. Surg.* **10**, 379–384 (2002)
65. Wilson, R.: Gunshots to the hand and upper extremity. *Clin. Orthop.* **408**, 133–144 (2003)
66. Wolf, J.M., Athwal, G.S., Shin, A.Y., Dennison, D.G.: Acute trauma to the upper extremity: what to do and when to do it. *J. Bone Joint Surg. Am.* **91**, 1240–1252 (2009)
67. Zalavras, C.G., Patzakis, M.J.: Open fractures: evaluation and management. *J. Am. Acad. Orthop. Surg.* **11**, 212–219 (2003)
68. Zalavras, C.G., Marcus, R.E., Levin, L.S., Patzakis, M.J.: Management of open fractures and subsequent complications. *J. Bone Joint Surg. Am.* **89**, 883–895 (2007)
69. Ziperman, H.H.: The management of soft tissue missile wounds in war and peace. *J. Trauma* **1**, 361–367 (1961)
70. Zura, R., Bosse, M.: Current treatment of gunshot wounds to the hip and pelvis. *Clin. Orthop.* **408**, 110–114 (2003)