Osteomyelitis

21

Levent Eralp

The fact is, infection is not a cause of nonunion. If nonunion is allowed to occur, it is due not to infection, but to inadequate immobilization permitted by reason of infection.

Reginald Watson-Jones

21.1 Introduction

In the twenty-first century, although the technology for orthopedic implants, surgical techniques, and drugs has improved immensely, the prevalence of posttraumatic osteomyelitis continues to rise. Many patients survive high-energy traumas, including car accidents, work mishaps, gunshot injuries and battlefield trauma, but they still suffer from life-threatening infections that complicate the trauma and its surgical treatment. The offending bacterial organisms, such as *Staphylococcus aureus* and *Enterococcus faecalis*, are becoming harder to treat as antibiotic-resistant strains develop [1]. Posttraumatic osteomyelitis will continue to be a challenging pathology for surgeons treating and reconstructing the extremities due to the presence of these resistant bacterial strains.

Patients with an infected nonunion usually have had numerous previous surgical interventions, resulting in bone defects and soft tissue compromise. Beginning with Papineau, many treatment modalities have been described [21, 22]. All studies report a common problem of delayed bone healing. Several issues have been blamed for this delayed bone healing, the most important being the unsuccessful eradication of infection. Infection itself has been reported to be the main cause of delayed union or nonunion. Thus, complete cure of the infection is the mainstay of treatment in cases of infected nonunions [32].

Bone necrosis, damage to adjacent soft tissue, and penetration of bacteria are the prominent etiological features associated with the onset of osteomyelitis. The distribution of bone necrosis depends mainly on the severity of trauma, traumatic manipulations by the surgeon, and the associated type of primary osteosynthesis. Remodeling of bone necrosis from living bone is slow and depends on many factors. New bone formation is mainly subperiosteal, embedding osteomyelitic areas if the periosteum is not destroyed [19].

Today, thanks to changing concepts and advanced reconstruction techniques, chronic osteomyelitis can be cured. The concept of "to burn infection in the fire of Ilizarov device," as described by Ilizarov [13], has changed to the current philosophy of "the only cure for osteomyelitis is radical debridement until reaching live and bleeding bone," as described by Cierny et al. [32]. The extent of necessary debridement to obtain live and uninfected bone usually results in bone and soft tissue defects, which require complex reconstructions.

21.2 Clinical Evaluation

Any initial questioning should aim at recording the patient's medical history and, in particular, any events and interventions that may have precipitated osteomyelitis. All systemic and local factors that compromise wound and bone healing capacity should be investigated [7] (Table 21.1).

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Table 21.1 List of systemic and local factors that may compromise wound healing [6]

Systemic factors	Local factors
Malnutrition	Chronic lymphedema
Renal/liver failure	Venous stasis
Alcoholism	Major vessel compromise
Immunodeficiency	Arteritis
Chronic hypoxia	Extensive scarring
Malignancy	Radiation fibrosis
Extremes of age	–
Steroid therapy	–
Diabetes mellitus	–
Tobacco abuse	–

In 1985, Cierny and Mader developed a staging system for adult patients with osteomyelitis based on the anatomical type of osteomyelitis and physiological class [7]. The framework is called the University of Texas Medical Branch Staging System for Adult Osteomyelitis (Table 21.2). Host factors can be modified with medical or adjuvant surgical treatment, such as soft tissue flaps, and such alterations may positively influence the prognosis for the extremity.

During any initial clinical examination, certain important findings should be investigated. The vascularity of the affected extremity is imperative, as it explains the wound and bone healing problems and also suggests the technique to be used in future reconstructions, such as an impossible vascularized bone graft and even a possible amputation. In addition to distal pulse palpation, an arterial duplex ultrasound, even an angiography, should be conducted [8].

Previous incisions, scars, and applied flaps dictate the surgical approach to be used in a given operation. The need to drain sinuses may also present particular problems. Preoperatively, a fistulography can be conducted to identify the path between the infection focus and the skin. If in the resection field, they should be included in the resection specimen; otherwise, a sinus tract will close following adequate debridement. The skin around chronically draining sinuses may be prone to squamous cell carcinoma and should be biopsied preoperatively.

Bone deformities and defects frequently accompany infected nonunions. These bony pathologies should be evaluated by long-standing orthoroentgenography in both the anteroposterior and lateral planes. The main purpose of radiologic examination is to determine the extent of infection in all musculoskeletal tissues. Bone scans and gadolinium-enhanced MRI scans are used for this reason (Fig. 21.1).

From a clinical point of view, six main questions arise with regard to radiology:

1. Does infection or inflammation in the posttraumatic course help to determine whether conservative or surgical therapy would be most suitable?
2. Is the infection acute or chronic?
3. Where is the main focus of the infection? Are there septic metastases?
4. Which tissues and neighboring organs/articulations are involved?
5. What is the local quality and vitality of the bone and surrounding tissues?
6. What about the postoperative anatomy and stability (including orthopedic devices)?

Conventional radiographs are essential for the diagnosis, staging, and evaluation of posttraumatic osteomyelitis. The use of more sophisticated modalities, such as cross-sectional imaging and specific bone scans, may be indicated in selected complicated patients for preoperative planning [10].

Scarring of postoperative and postinjury bone defects may lead to false-positive diagnoses up to

Table 21.2 The University of Texas Medical Branch Staging System for Adult Osteomyelitis

Anatomic type	Physiologic class
Type I: Medullary osteomyelitis	A host: Good immune system and delivery
Type II: Superficial osteomyelitis	B host: Compromised locally (B^L) or systemically (B^S)
Type III: Localized osteomyelitis	C host: Requires suppressive or no treatment; treatment would cause more damage than the disease itself
Type IV: Diffuse osteomyelitis	–

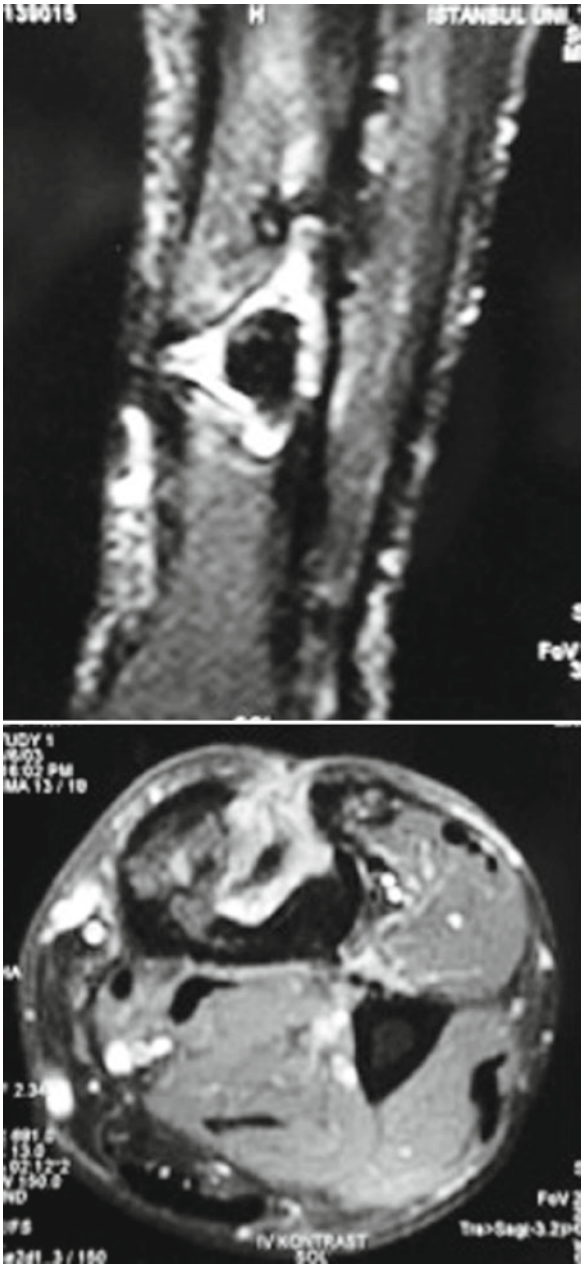

Fig. 21.1 MRI from a patient with chronic posttraumatic osteomyelitis, displaying a sequestrum and fistula tract

13 months postoperatively. Positive MRI results in this time period must be correlated with clinical findings and laboratory results, as well as with other imaging modalities, such as scintigraphy or PET. An additional CT scan may be necessary for the preoperative evaluation of patients who have had multiple surgical interventions to analyze bone alterations (cortical fistula, cortical bone remodeling, and disuse osteoporosis). If MRI discloses a possible fistula in severely thickened and remodeled bone after intramedullary reaming, a CT should be performed to confirm or refute its presence. Metal artifacts are apparent in most patients who undergo multiple operations and may render complete evaluation of the traumatized limb impossible or may lead to underestimation or overestimation of infection [14, 15]. Scintigraphy errors in the later course, due to ectopic, peripheral, and hematopoietic bone marrow, can often be corrected by MRI [14].

21.3 Principles of Therapy

As with the treatment of malignant tumors, one has to decide between specific local and systemic therapies [16]. In general, the treatment protocol should lead to:

1. Local and systemic eradication of the infection (or at least to an enduring non-symptomatic stage)
2. A stable limb with a normal mechanical axis
3. Normal muscle action
4. Normal joint function

Treatment options are based on the Cierny–Mader Staging System for osteomyelitis. Management of chronic osteomyelitis with a limb-salvage protocol consists of debridement, systemic and local antibiotic therapy, skeletal stabilization, soft tissue coverage, and reconstructive procedures for the treatment of bone defects [39]. These principles can be incorporated in a staged protocol, often implemented by a multidisciplinary team consisting of an orthopedic surgeon, an infectious disease specialist, a plastic/microvascular surgeon, and preferably a hyperbaric oxygen treatment specialist. From a practical point of view, as this chapter deals with the complications of severe limb trauma, we shall focus on bone defects that are >5 cm or that become >5 cm as a result of radical debridement (Cierny–Mader Type IV lesions).

When there is an infection, several factors must be carefully evaluated to develop a detailed management plan. Imaging studies should be reviewed to assess the status of bone healing, the location and extent of cortical and medullary bone involvement and defects, the extent of soft tissue compromise, and the status and integrity of existing implants. The quality and integrity of the soft tissue envelope and the need for flap coverage should be evaluated. The neurovascular status of the extremity should be determined. Cultures and sensitivity tests allow for the selection of appropriate antibiotics for local delivery with antibiotic beads and for systemic therapy. Subsequent cultures of intraoperative specimens should be performed, as the results may indicate that a different antibiotic is required. The medical status of the patient should be assessed to ensure the safe execution of a complex reconstructive plan. Interventions, such as nutritional support and smoking cessation programs, may help to optimize the patient's condition before surgery.

21.3.1 Debridement

Radical debridement of all dead tissue, including skin, soft tissue, and bone, is necessary. An intraoperative methylene blue injection of a fistula will dye all the infection area and identify the debridement arena. Debridement proceeds until bleeding, living tissue is observed at the resection margins to ensure that all foci of infection are removed [24, 32]. Viable bone is characterized by punctate bleeding, known as the "paprika sign" (Fig. 21.2). When possible, a high-speed burr with continuous cooling irrigation to prevent heat necrosis is preferred to achieve a thorough debridement. This procedure should not be limited by concerns about any osseous and soft tissue defects. Specimens of purulent fluid, soft tissue, and bone from the infected area should be sent for aerobic and anaerobic cultures; it is also important to perform cultures for fungi and granulomatous infections in immunocompromised patients. The wound should be irrigated with a copious amount of saline solution, and antibiotics may be added to the terminal liter of the irrigation fluid [32]. After irrigation, all gowns, gloves, drapes, and instruments should be exchanged for a new, clean setup (double setup) [8].

The dead space that results from debridement is filled with physician-made polymethylmethacrylate antibiotic-impregnated beads (explained in detail in "the combined technique"). The pathogen must be susceptible to the eluted antibiotic. If wound closure is not possible, the wound containing antibiotic beads is sealed with a semipermeable membrane so that the eluted antibiotic will remain in the involved area to guarantee a high local concentration [40].

When a nonunion or bone defect is associated with infection, subsequent procedures for wound management and bone defect bridging are planned, and the beads can be removed at the time of final reconstruction.

The decision to retain or remove implants from the site of an infected fracture should be taken on a case-by-case basis. It depends on the time since fracture fixation, bone healing status, hardware-induced stability, and fracture location [24]. If the fracture has healed, the internal fixation device should be removed. When the fracture has not healed, the internal fixation device should be left in place as long as it stabilizes the fracture. Loose hardware that does not contribute to stability should be removed. If the fracture has not healed and if the hardware is removed, the fracture should be stabilized with another device; preferably, an external fixator should be utilized for nonunions in the tibia and for nonunions with a bone defect.

In cases with an adequate soft tissue envelope, delayed or primary closure may be advisable depending on the extent of infection. If soft tissues are compromised, coverage should be achieved with local or free muscle flaps. A new approach is to utilize negative pressure wound coverage techniques (NPWT) with a VAC device (KCI, San Antonio TX, USA). NPWT is often used because of its ability to reduce excess moisture in the wound, reducing the bioburden and exposure to associated toxins. The technique also increases cell proliferation (including proliferation of

Fig. 21.2 Severe crush injury of the foot and ankle (**a**, **b**). VAC treatment allowed for skin graft coverage in 14 days (**c**)

granulation tissue) and perfusion in the wound bed. In addition, NPWT aids in contraction of the wound edges by gently stretching the skin [4]. This adjuvant in wound treatment aims to carry the soft tissue reconstruction procedure one step down in the reconstructive ladder, thus allowing for a simpler technique, such as a local muscle flap instead of a free flap (Fig. 21.2). The VAC Instill (KCI, San Antonio, TX, USA) differs from traditional VAC therapy because it allows the clinician to add solutions to the wound, as well as to apply negative pressure. A wound culture may be obtained prior to starting the VAC Instill process to select an optimal solution for a specific local antibiotic irrigation [37].

Another valuable adjuvant is hyperbaric oxygen treatment (HOT) [34]. HOT can be applied preoperatively in some cases, along with systemic antibiotics when there is severe inflammation and acute infection flare-up for 2–3 weeks. The operation can be delayed until a considerable drop has been achieved in elevated white blood cell count, C-RP (C-reactive protein) and ESR (erythrocyte sedimentation rate) levels. HOT should be continued for 30–40 sessions postoperatively in patients who have been heavy smokers and who have a history of radiation treatment to the infection area, or in patients with macro- or microangiopathies.

Basic science studies have underlined the value of a vascular muscle envelope around the bone to promote healing of a chronically infected bone segment in the mangled extremity [18]. Improvement of the local blood supply and the elimination of all dead space to provide a well-vascularized environment for bone grafts or to regenerate bone can promote healing. Surgical removal of all dead bone segments is not sufficient to cure osteomyelitis. Radical surgical debridement to remove all dead tissue and orthopedic implants around dead bone followed by coverage of the remaining bone with vascularized and healthy soft tissue are the only way to cure chronic bone infection [27].

21.3.2 Local and Systemic Antibiotherapy

Local antibiotic therapy is a well-documented method. Poly(methyl methacrylate) (PMMA) is the standard delivery medium for antibiotics [40]. A randomized controlled trial by Calhoun et al. compared 4 weeks of intravenous antibiotics with Septopal beads in 52 patients with infected nonunions in the context of debridement and reconstructive surgery. The success rate in treating the infection was 83% in the systemic antibiotic group and 89% in the antibiotic bead group [6]. Local antibiotic therapy can be used as an alternative to long-term systemic antibiotherapy. Drawbacks include the need for secondary debridement, lack of osteoconductivity, and foreign body reaction. During a second operative session, the need for bone reconstruction following eradication of the infection allows for early removal of the PMMA beads.

A new option for achieving local antibiotic elution combined with bone stability has been reported and technically validated by Thonse and Conway [33]. The antibiotic cement-coated intramedullary locking nails are very effective for treating infected bone unions and segmental bone defects. This technique is associated with a 27% risk that a supplementary procedure will be needed to take care of the infection or nonunion.

The type of systemic antibiotic treatment is chosen on the basis of the results of the preoperative cultures, but it can be modified on the basis of the results of the intraoperative culture and sensitivity tests. Administration of antibiotics is a key part of the management protocol, but it will fail without adequate debridement. Intravenous antibiotics are usually continued for 4–6 weeks [23]. While antibiotic-resistant organisms are a problem, vancomycin is useful for methicilline-resistant *Staphylococcus aureus* infections, and the recently introduced antibiotic, linezolid, has been used for vancomycin-resistant *Enterococcus* infections [25].

21.3.3 Bone and Soft Tissue (Temporary) Stabilization

Bone stabilization is commonly achieved by external fixators. They are simple to apply, provide good stability, and do not further compromise the soft tissue envelope [35]. The type of external fixator to be used (monolateral or circular) depends on the anatomical site, the size of the defect, and the condition of the soft tissues.

Depending on the size of the defect subsequent to radical debridement, the type of soft tissue reconstruction is determined – ranging from a split skin graft to free vascularized myocutaneous flaps. According to Heppert, soft tissue coverage options will depend on the following criteria [12]:

1. The type of osteosynthesis
2. The position and size of the soft tissue defect
3. The local vascular status
4. Patient compliance

21.3.4 Final Bone (Defect) Reconstruction

Bone reconstruction should be delayed until a healthy degree of soft tissue coverage has been achieved and the infection has been eradicated [39]. At the time of the final bone operation, the decision as to how to bridge the bone defect depends on the anatomical location and the length of the defect. Gaps result from the primary (i.e., high-energy, in this context) trauma, primary osteosynthesis, and radical debridement to treat the infection. Severe limb injuries may exhibit bone defects that exceed 5–6 cm. These scenarios need specialized procedures, such as vascularized bone grafts, distraction osteogenesis procedures, and titanium cages.

21.3.5 Distraction Osteogenesis Techniques

Today, callus distraction is the gold standard for reconstructing osseous defects, especially in defects larger than 4 cm [35]. Many different techniques for callus distraction have been described and classified according to fixator type (Fig. 21.3). The advantages of callus distraction are spontaneous bone formation in the distraction zone, a relatively low-risk procedure, synchronous deformity correction, and stable osteosynthesis that allows for early weight-bearing. Bone defects resulting from infection after high-energy traumas are often associated with deformity, leg-length discrepancy, joint stiffness, disuse osteoporosis, soft tissue atrophy, and sequelae of neurovascular damage. Distraction osteogenesis techniques make an effort to deal with all of these problems concurrently. Defects are reconstructed either by bone transport or acute compression with simultaneous lengthening at a different metaphyseal site.

Segmental bone transport is used for large bone defects of >6 cm. Smaller defects (<6 cm) are treated by acute compression at the defect site with gradual lengthening by metaphyseal corticotomy [26, 28, 29]. A delay in the formation of regenerate at the distracted gap prolongs the external fixation time. Healing at the target site does not begin until intercalary fragment lengthening is achieved. Instability of the frame may cause a delay in the regenerate formation and require additional procedures to maintain alignment, such as wire exchange and frame adjustment.

Malunion and malalignment at the docking site can occur because of improper application of the Ilizarov assembly. Soft tissue interposition at the docking site may impair good compression. The transported segment of bone may deviate as it passes through soft tissue; this may lead to translation at the docking site [17]. The transported bone end may become avascular, resulting in nonunion at the docking site. Secondary interventions often become necessary. Acute compression and simultaneous lengthening address both alignment and length in a single treatment with fewer complications. It also reduces complications associated with bone transport and is safe for larger long bone defects. The rate of severe pin-tract infection is lower, because stability is shared between the acute compression site and the fixator from early on during treatment. Moreover, during the whole treatment course, fewer secondary adjustments are performed on the frame.

21.3.6 Fibula Transport

An alternative use of external fixation to bridge large tibia defects is the transfer of the ipsilateral fibula transversely, using a circular external fixator and protecting its vascular pedicles. This technique should be applied with expertise during external fixation surgery. The technique is used in patients with massive defects of the tibia and an associated active infection. Complications are nonunion, shortening, an anterior bow, and a stiff ankle joint [30].

Fig. 21.3 A 40-year-old male patient with a C-M type IV-B_L lesion and with a 9-cm (total, after radical debridement) bone defect following Gustilo–Anderson GIIIB open tibia fracture after a work accident. (**a**) Several scars and a draining fistula on the tibial skin. (**b**) Radical bone debridement, insertion of antibiotic-loaded PMMA beads, and temporary external fixation. (**c**) Bone segment transfer with a monolateral external fixator (Tasarım Medikal LRS, Istanbul, Turkey). (**d**) End of segment transfer, compression, and grafting of the docking site with dynamization of the system using Schanz screw removal. (**e**, **f**) Anteroposterior and lateral x-rays after fixator removal. (**g**, **h**) Excellent knee and ankle motion 3 months after fixator removal

21.3.7 Vascularized Bone Grafts (VBGs)

Vascularized bone grafts are indicated when the skeletal defect is longer than 6 cm [36, 38]. Fibular osteocutaneous, composite rib and iliac osteocutaneous flaps are the most common clinically used VBGs. Vascularized bone fills a large dead space, overpasses considerable bone defects, enhances tissue healing with a living, biologic, infection-resistant composite tissue, and also serves to cover soft tissue defects. Reported success rates range from 80% to 95% [36, 38], and complications include anastomosis failure, nonunion, graft fracture, and donor site problems. This technique is preferred in patients with a healthy vascular tree who need both bone and soft tissue bridging – including, most importantly, an experienced microvascular team. Our experience involves two cases, one with tibial bone and soft tissue loss and the other with a femoral bone defect exceeding 12 cm (Fig. 21.4). Both patients healed uneventfully and the VFGs became hypertrophied after 14 and 8 months, respectively.

21.3.8 Titanium Cage

This technique has recently been reported in the literature with short-term results. The prerequisites are a sterile bone defect that exceeds 10 cm with a healthy soft tissue envelope. In the reported series, Attias et al. and Ostermann et al. comment on patients with excellent limb alignment, and bony healing, with a CT examination that revealed bony ingrowth through the cage at the final follow-up [5, 20]. This technique may be a reasonable alternative in the treatment of segmental bone loss in the context of long bones. Our experience is limited to two cases. One case displayed excellent bone formation on CT scans though the cage (Fig. 21.5). The other patient became reinfected, and the protocol was changed to a tandem bone transport with a circular external fixator.

21.3.9 The Combined Technique

Since the introduction of distraction osteogenesis by Ilizarov, this technique has been employed successfully to achieve union, correct deformity, reestablish limb-length equality, and reconstruct segmental defects. The time spent in an external fixator depends on the length of distraction required and is not free of complications. When the distraction phase is over, the consolidation phase, double the duration of the distraction phase, becomes difficult for the patient to tolerate. Removal of the fixator prior to sufficient consolidation is associated with re-fracture, deformity, and shortening of the callus. To decrease the total external fixator time, the combined technique, consisting of distraction with an external fixator over an intramedullary nail, has been introduced [9].

21.3.9.1 Step I

Hardware removal and radical resection of dead bone with debridement of the infected scarred soft tissue are performed, and representative tissue cultures, including the sinus tract for all dead bone, are obtained. Cortical bleeding, described as the "paprika sign," is accepted as indication of vital tissue. The dead space is filled with custom-made antibiotic-impregnated PMMA beads (a combination of teicoplanin [2.4 g] and PMMA powder [40 g]). Patients who have an intramedullary implant are managed by implant removal. They receive an antibiotic-impregnated PMMA cement rod in place of the nail and are then immobilized with a custom-made brace. Stabilization is achieved with a temporary external fixator. Soft tissue defects may necessitate a local or free muscle flap for healthy coverage. Antibiotics are administered consistent with the culture and its sensitivity, for a minimum of 6 weeks or until the ESR and C-RP levels return to normal limits (Fig. 21.6).

21.3.9.2 Step II (IM Nail Insertion/Application of External Fixator and Osteotomy)

After a period of 6 weeks, or when the patient exhibits normal CRP and ESR levels, the surgeon removes the antibiotic beads or cement rods. A biopsy taken from the bone gap is sent for Gram stain and frozen section analysis. The absence of microorganisms on the Gram stain and fewer than five polymorphonuclear leucocytes per high-power field are taken as an indication of the resolution of infection. Antegrade nailing is used only

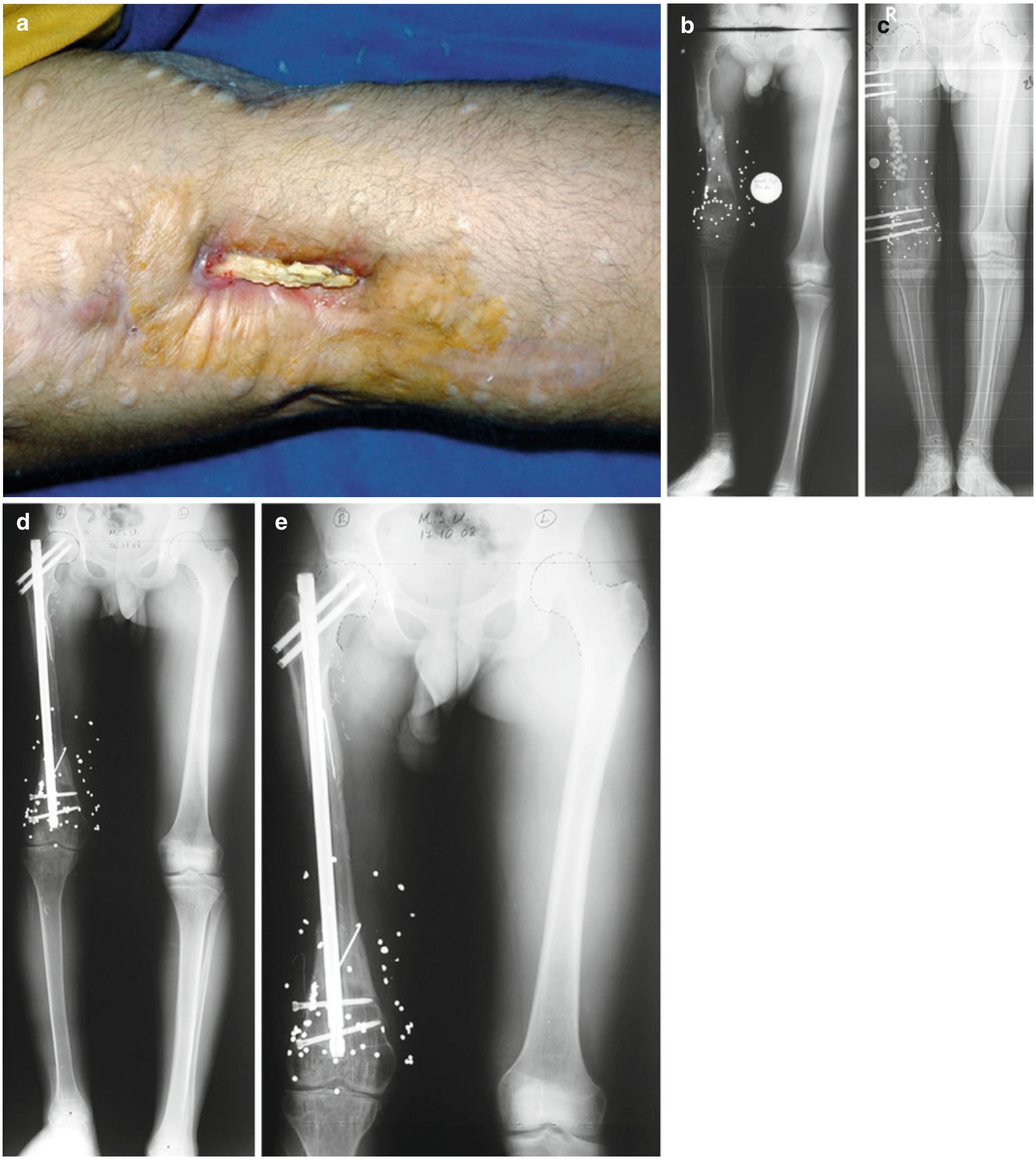

Fig. 21.4 A 21-year-old male patient with a C-M type IV-B_L lesion with an 8-cm shortening and a 4-cm bone defect, with a stiff knee and rigid soft tissue envelope due to gun injury. (**a**) The exposed bone. (**b**) Following radical debridement and antibiotic-loaded PMMA bead application, the soft tissues were distracted by 4×¼ mm/day to achieve equal femoral length. (**c**) Removal of the external fixator and insertion of an intramedullary nail and vascularized fibula graft. (**d**, **e**) Hypertrophy of the VFG after 18 months

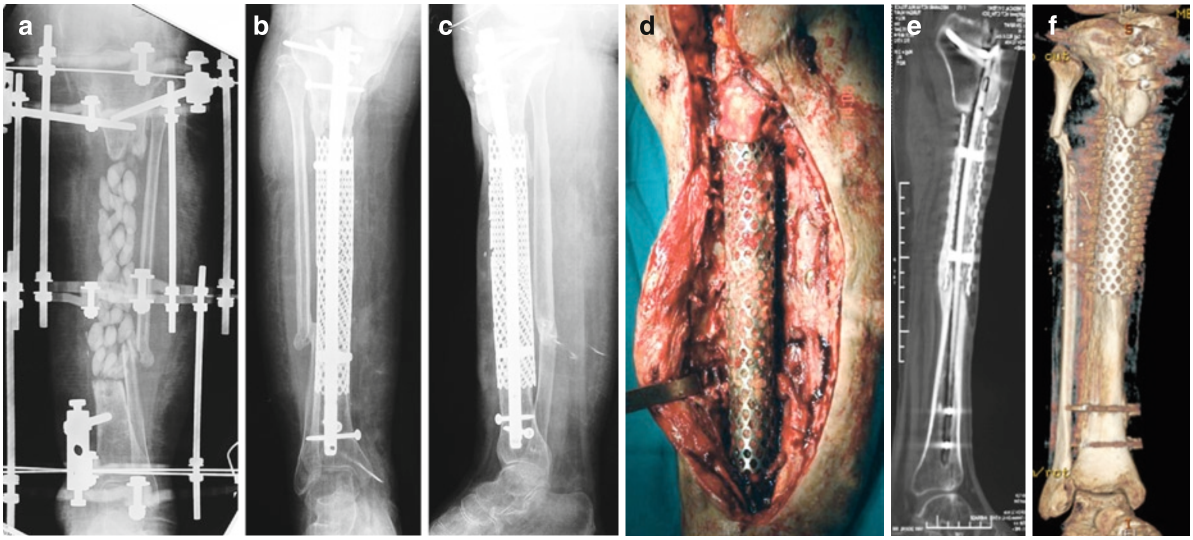

Fig. 21.5 A 33-year-old male patient with a C-M type IV-B_L lesion presented with a 14-cm bone defect following Gustilo–Anderson GIIIB open tibia fracture after a car accident. (**a**) Radical debridement, temporary external fixation, and antibiotic-loaded PMMA beads. (**b**) Insertion of a titanium cage filled with DBM and cancellous autograft, fixed by a locked intramedullary nail (AP view). (**c**) Insertion of titanium cage filled with DBM and cancellous autograft, fixed by a locked intramedullary nail (lateral view). (**d**) Intraoperative view. (**e**) Postoperative sagittal CT scan at 1 year, displaying new bone formation around the cage. (**f**) Postoperative three-dimensional CT scan at 1 year, displaying new bone formation around the cage

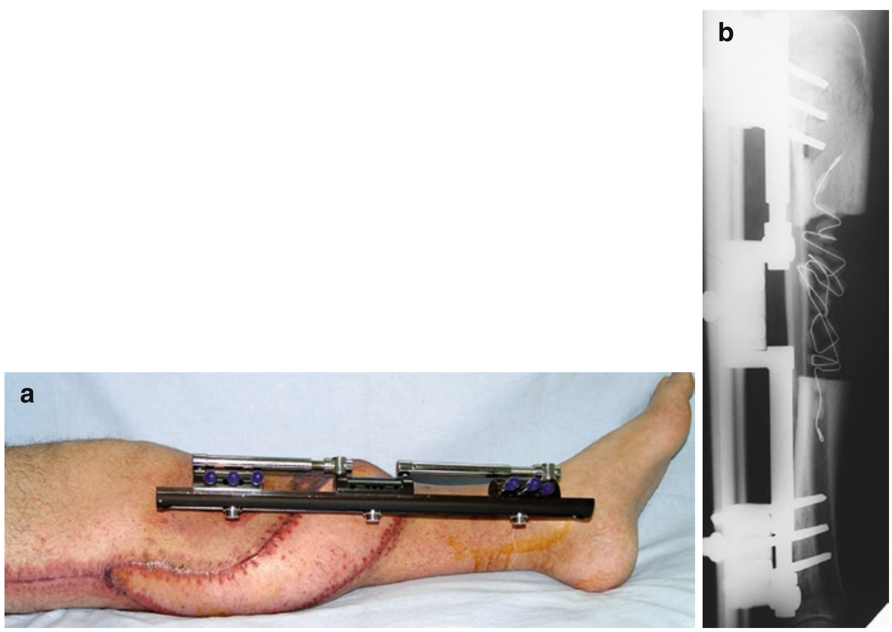

Fig. 21.6 Temporary external fixation with antibiotic-loaded PMMA beads inside (**a**) and a free latissimus dorsi flap to cover the soft tissue defect (**b**)

for patients with a segmental defect but without any leg-length discrepancy. Retrograde nailing is utilized to treat shortening combined with a segmental defect. With retrograde nailing, the nails are locked distally and the excessive length of the nail remains in the soft tissues proximally. With distraction, the nail glides distally until the correct length is achieved and is then locked at the completion of lengthening. For patients undergoing segmental transport to treat a bone defect without length discrepancy, antegrade nailing is performed. Additional holes are pre-drilled at the planned site of locking of the segment, at the completion of bone transport, to prevent recoil of the segment (Fig. 21.7).

21.3.9.3 Femur

The patient is placed in a supine position on a radiolucent table with the limbs in a scissors position and with a bolster below the pelvis on the involved side. Via a standard approach (through the piriformis fossa for antegrade nailing and through the parapatellar incision for retrograde nailing), the medullary canal is reamed over a guide wire to a diameter 1.5 mm larger than that of the intramedullary nail to be used. With lengthening procedures, the goal is to provide sufficient nail length on both sides of the regenerated bone at the end of distraction. This necessitates the use of an intramedullary

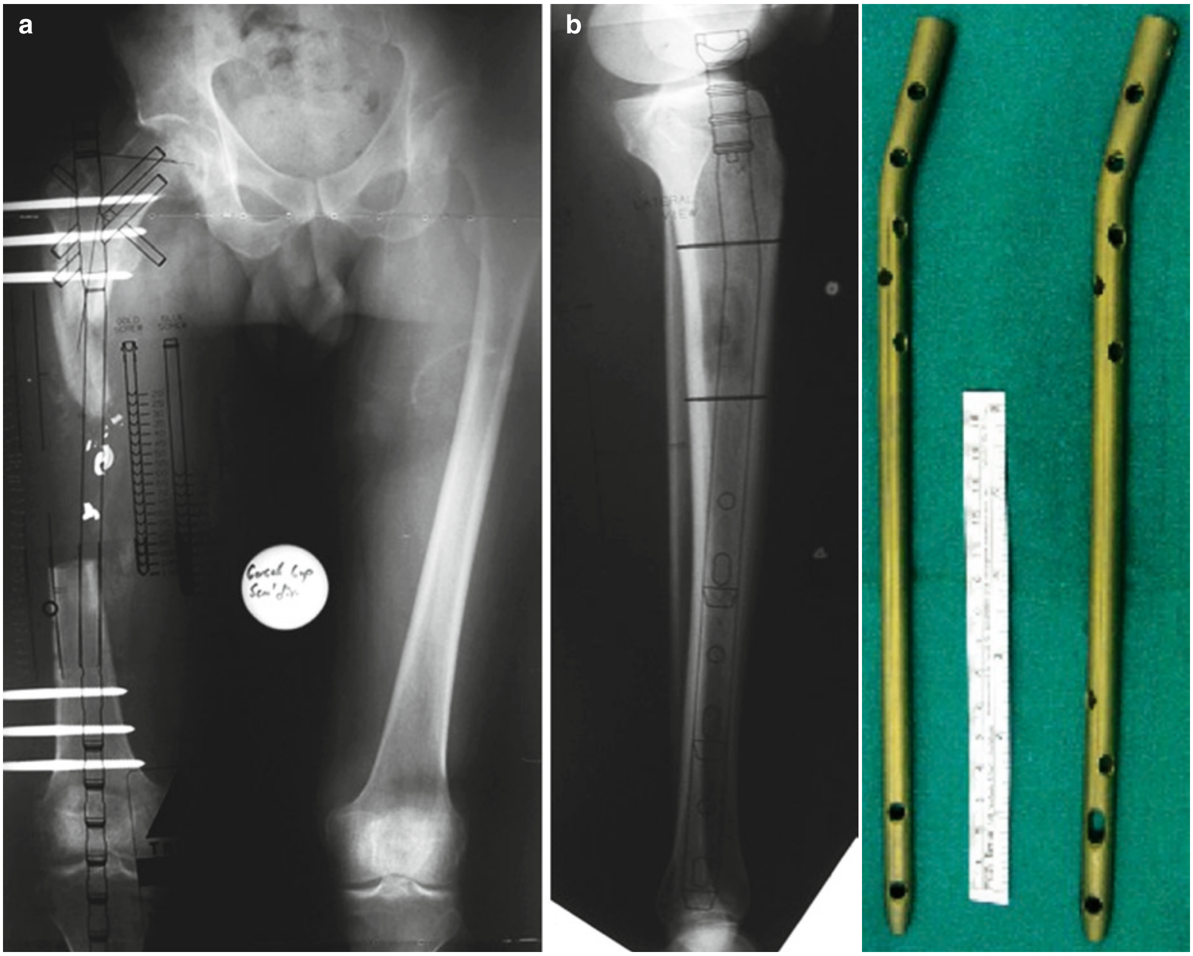

Fig. 21.7 Determination of appropriate intramedullary nail length, diameter, and site of additional locking screw holes on x-rays in the femur and tibia (**a**, **b**)

nail that is longer than the length of the femur, and retrograde nailing allows the excess nail length to protrude into the buttock until distraction is complete, by which time the nail should have glided gradually into the correct position. An appropriately placed corticotomy is then performed percutaneously with an osteotome. Finally, an intramedullary nail of the appropriate size is inserted and locked proximally or distally or on both sides according to the planned distraction.

Two to three Schanz screws proximal and two to three Schanz screws distal to the osteotomy level are then inserted without contacting an intramedullary nail. At least 1 mm of free space should be present between the Schanz screws and the intramedullary nail to prevent medullary infection triggered by pin site sepsis.

21.3.9.4 Tibia

After reaming the medullary canal 1.5 mm larger than the planned size of the nail, the nail is inserted and a three-ring circular external fixator is applied. A corticotomy is then performed at the appropriate level. For the patient with shortening and a segmental defect, an IM nail of the eventual desired length of the tibia is inserted and left protruding slightly from the surface so that it may slide distally during treatment (Fig. 21.8).

21.3.9.5 Postoperative Care

Distraction is started on the seventh postoperative day. The rate of the distraction is 1 mm/day, divided into four equal increments. An epidural catheter is placed for postoperative pain management, and range of motion exercises of the hip and knee are initiated as soon as the patient's comfort allows. In patients with a longer tibial intramedullary nail, knee exercises are postponed until the nail comes to lie inside the bone during lengthening. Full weight-bearing with two crutches commences as soon as possible.

21.3.9.6 Step III (Removal of External Fixator and Static Locking of the Nail)

After the distraction is complete, the nail is statically locked and the external fixator is removed. An autogenous cancellous bone graft is then added at the docking site.

21.4 Complications

Recurrence of infection is the most common complication that patients may experience after going through a number of interventions to cure their osteomyelitis [8]. The most common reason is inadequate debridement. When surgeons are further along their learning curve, the rate of this complication decreases. Following segmental resection, many patients experience a long and infection-free interval. Today, the microbiological features of bacteria are becoming more troublesome. Antibiotic-resistant and methicilline-resistant *S. aureus* are frequently diagnosed; these are known to hibernate intracellularly [2]. Thus, recurrence of the infection may occur if the patient becomes immunocompromised.

Conway has reported problems involving wound healing and bone healing as the second most common complication group [8]. The majority of patients are *B* hosts, who suffer from greater weaknesses in terms of wound healing and bone consolidation. Bone grafting, soft tissue grafts or flaps, external bone stimulation devices, and the use of hyperbaric oxygen treatment are adjuvant techniques to support bone and soft tissue healing.

21.5 Conclusion

In his pioneer book, Gustilo reports that a long-standing infected nonunion may be a real challenge due to the following reasons [11]:

1. Usually, the patient has been operated on at least two or three times, with resultant scarring of the surrounding soft tissue, rendering the environment around the trauma site avascular
2. A sinus tract has usually formed, leading into the fracture site and indicating a sequestrum
3. Osteomyelitis involves a considerable length of bone, with thrombotic vessels of the Haversian canals
4. Limited joint motion with consequent scarring of the muscles involved leads to a dystrophic extremity
5. Mixed and drug-resistant infecting organisms develop after the patient has been administered antibiotics for an extended period

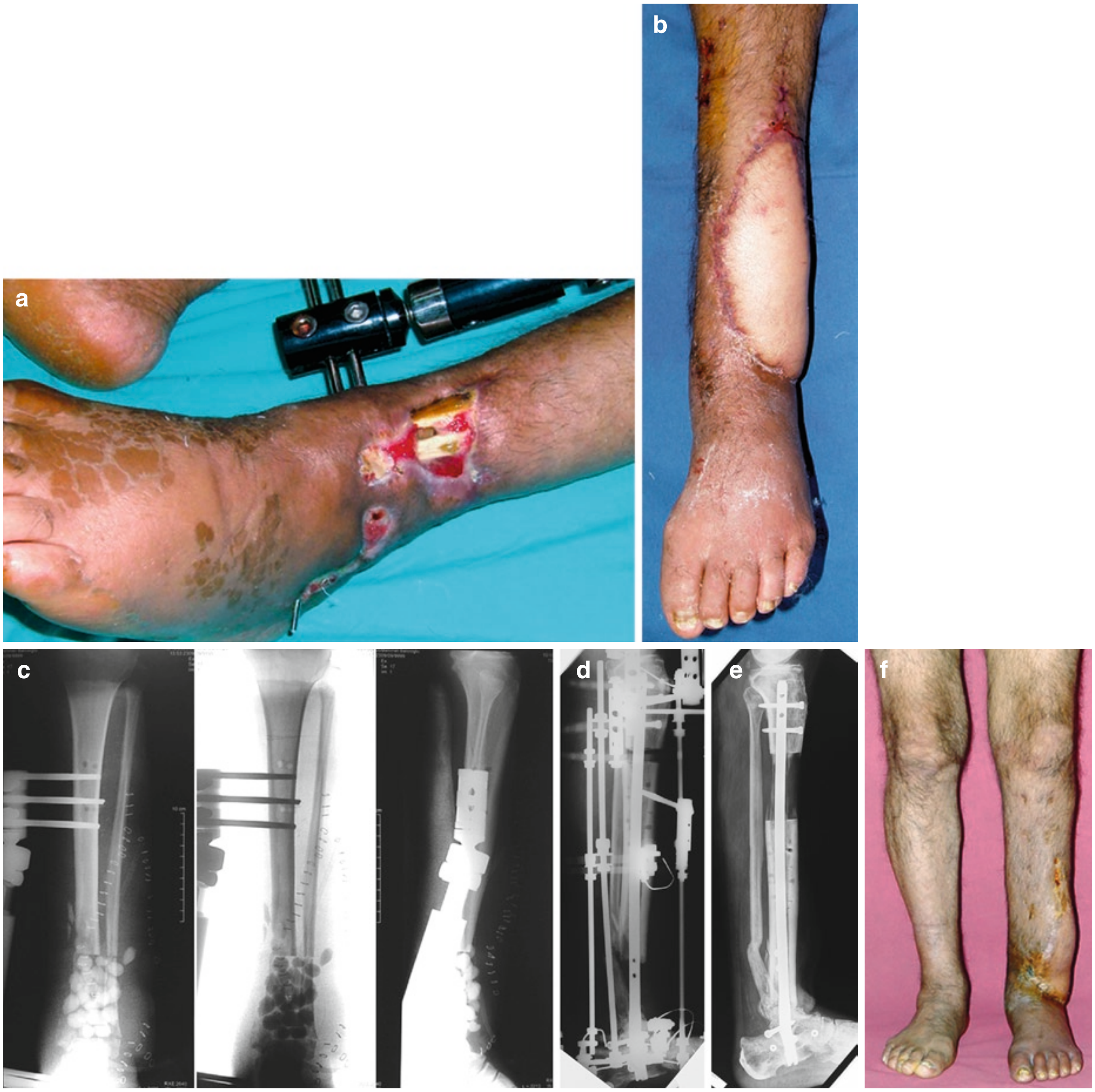

Fig. 21.8 A 68-year-old male patient with a C-M type IV-B_L lesion with an 8-cm bone loss and soft tissue loss (resulting from radical debridement) treated using the combined technique. (**a**) Distal tibial soft tissue defect with necrotic bone segment. (**b**) Radical debridement with antibiotic-loaded PMMA insertion. (**c**) Soft tissue coverage with latissimus dorsi free flap coverage. (**d**) Bone segment transfer in the context of ankle arthrodesis with a circular external fixator and intramedullary nail. (**e**) Lateral x-ray following locking custom holes, dock site grafting, and external fixator removal. (**f**) Clinical picture at the time of external fixator removal

Limb salvage, based on the principles described above, can be achieved with eradication of the infection and osseous union in 67–100% of cases [3, 32]. Siegel et al. reported that, at a mean of 5.1 years postoperatively, limb salvage was accomplished in all of 46 patients with chronic tibial osteomyelitis, and all but 2 exhibited clinical and radiographic evidence of union [31]. Smoking, advanced age, and intra-articular involvement were found to adversely affect the outcome.

Management of chronic posttraumatic osteomyelitis and infected nonunion of long bones is challenging; however, infection control, osseous union, and a satisfactory functional outcome can be achieved with use of the aforementioned principles.

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