Tibial Nonunion: Treatment Alternatives

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Abstract

Because the spectrum of injuries to the tibia is so great, no single method of treatment is applicable to all nonunions. Therefore, it is important for surgeons who treat tibial nonunions to be skilled in several different methods of treatment. In patients with significant deformities, electrical stimulation, isolated fibular osteotomy, and bone grafts alone are unsatisfactory treatment options. In aseptic nonunions, the use of intramedullary nailing or compression plating appears to have many advantages. In previously closed and selected grade I and grade II open fractures, reamed intramedullary nailing is a safe and effective method of treatment. Because of the risk of infection, reamed nailing is not recommended after external fixation of open fractures. In these cases as well as others, the authors prefer plate osteosynthesis. With few exceptions, the plate should be placed, under tension, on the convex side of the tibia. Used in this fashion, the plate can assist in correction of any deformity and can also provide stable internal fixation. Half-pin external fixation is used primarily in the management of infected fractures. Ilizarov and other small-wire circular fixators have proved effective in treating complex-composite deformities associated with sepsis, bone loss, shortening, angulation, or malrotation. Amputation may be warranted if a functional limb cannot be achieved.

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Nonunion of the tibia after high-energy trauma continues to be a common problem. Treatment is influenced by the location of the nonunion, the integrity of the soft tissues, the presence or absence of infection, the angular and rotational alignment of the limb, the degree of instability at the nonunion site, and the radiographic appearance. If rational treatment is to be instituted, the surgeon must have a clear understanding of the "personality" of the nonunion, since no single method of treatment is applicable in all situations. The approach to treatment may be nonoperative or surgical and can be broadly viewed as functional, electrical, mechanical, biological, or some combination thereof. Results are optimized when deformities are corrected and adequate stabilization of the fracture allows early range-of-motion and weight-bearing activities.

Despite the availability of improved surgical techniques, more potent antibiotics, and sophisticated soft-tissue coverage procedures, nonunion still occurs in many patients after high-energy tibial fractures. Recent advances in soft-tissue reconstruction with the use of muscle flaps or free-tissue transfer have been effective in decreasing the rate of infection after many severe injuries.[1] Unfortunately, the addition of vascularized soft tissue alone has a less dramatic effect on the promotion of fracture healing in complex-composite injuries. Failure to achieve union in a timely fashion is often associated with prolonged morbidity, inability to return to work, the need for multiple operative procedures, and emotional impairment. In virtually all cases of tibial nonunion, loss of limb function is common, with varying degrees of muscle atrophy, compromise of the soft tissues, osteopenia, and decreased range of motion of the knee, ankle, or subtalar joints.

The problems facing the orthopaedic surgeon are challenging. Treatment must be designed to correct axial or rotational malalignment, equalize leg lengths, prevent or treat established infection, and allow functional restoration of the limb. Finally, the surgeon must choose among many diverse treatment modalities, all of which, when correctly done, have high rates of success. These include cast or brace immobilization, electrical stimulation, fibular osteotomy, bone grafting, internal fixation with plates or intramedullary nails, and external

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fixation with either small-wire or conventional devices.

Etiology

Although there have been a large number of clinical studies, the definition of tibial nonunion remains arbitrary. Traditionally, a finite period of time was allowed to elapse before a fracture was defined as being characterized by delayed union or nonunion. If fracture stability or bridging callus was not present between 16 and 20 weeks, the fracture was described as "delayed union." The term "nonunion" was usually reserved for those fractures that had not healed after 9 months of adequate treatment. This passive approach undoubtedly prolonged morbidity in many patients with tibial fractures.

In the past two decades, orthopaedic surgeons have become increasingly aware that many high-energy tibial fractures are slow to consolidate despite adequate initial treatment. Rather than being limited by a definition of nonunion that involves a set time frame, they have come to realize that earlier and more aggressive treatment is warranted. Several authors have shown that surgical intervention is usually indicated 3 to 5 months after injury if the fracture fails to show progressive signs of healing on monthly radiographs.[2-4] In this environment, a nonunion or at least delayed union can be predicted, and a change in treatment is justified. Therefore, the designation of a delayed union or nonunion is currently made when the surgeon believes that the fracture has little or no potential for union and additional treatment is needed.

Although the etiology of tibial nonunion is diverse, the vast majority of these injuries fail to unite because the initial fracture displacement has damaged the surrounding soft tissues, leading to profound changes in the medullary and periosteal blood supply. Union is further delayed if the fracture becomes infected. Other factors that have been implicated in the etiology of nonunion include fracture comminution, segmental fracture patterns, bone loss, distraction, inadequate immobilization, the presence of an intact fibula, inadequate fixation, and delayed weight bearing. Smokers have also been shown to have significantly longer mean times to clinical union and a higher incidence of delayed union compared with nonsmokers.

Classification

Two important factors in the classification of nonunions are the expected vascularity at the fracture site and the presence or absence of infection. One method of classifying nonunions is to indirectly assess the vascularity at the fracture site on radiographs or radionuclide scans. With a hypertrophic nonunion, there has been an obvious attempt at bone healing, with the production of callus leading to flared, often dense bone ends. As a general rule, hypertrophic nonunions are well vascularized. In contrast, in an atrophic nonunion, there has been little or no effort to heal. Callus is scanty or absent, the bone ends are tapered and osteopenic, and bone vascularity may be deficient. Nonunions characterized by bone loss or congenital pseudarthrosis are unique types that do not fit well into a classification based on vascularity alone.

Nonunion can also be classified on the basis of infection. The fracture may be noninfected, previously infected, or currently infected.

Rationale for Treatment

The treatment of a tibial nonunion is influenced by its location, the integrity of the soft tissues, the presence or absence of infection, the angular and rotational alignment of the limb, the degree of instability at the nonunion site, and the radiographic appearance. If rational treatment is to be instituted, the surgeon must have a clear understanding of the individual characteristics of the nonunion, since no single method of treatment is optimal in all cases. The patient's nutritional status, weight, associated medical problems, smoking history, neurovascular status, and soft-tissue envelope must be carefully assessed. After a detailed examination of the extremity and a careful review of imaging studies, the surgeon must choose the method of treatment that appears most likely to lead to fracture union. The approach to treatment may be nonoperative or surgical, and the options can be broadly viewed as functional, electrical, mechanical, biological, or some combination thereof. It is the surgeon's role to identify the proper "stimulus" that will lead to uneventful fracture healing.

For example, in the case of patients with hypertrophic tibial nonunions, several authors have shown that the failure to unite is primarily a mechanical problem. In this environment, the proper stimulus is stable fixation of the fracture, which reduces micromotion at the nonunion site, allowing capillary ingrowth with endochondral ossification. The addition of a biological stimulus in the form of a bone graft is not necessary or indicated. If the fracture fragments are well aligned, it is not necessary to "take down" the nonunion because the mesenchymal tissue between the bone ends retains the capacity to form osseous tissue in the proper environment. However, atrophic nonunions, with their restricted blood supply, require the additional stimulation provided by shingling or augmentation at the fracture site with bone graft.

Diagnostic Workup

When evaluating a patient with a tibial nonunion, it is essential to carefully review pertinent prior medical records and imaging studies before initiating additional treatment. The vast majority of patients with a long and complicated history of tibial nonunion are unable to provide accurate information about such factors as previous open wounds, degrees of contamination, culture reports, and antibiotic sensitivities. Unlike acute injuries, tibial nonunions rarely require immediate intervention. The urge to operate should be tempered by the knowledge that these injuries can be extremely challenging and fraught with the potential for multiple complications.

An anteroposterior and a lateral radiograph will generally allow adequate assessment of the nonunion site. However, in some cases, the obliquity of the nonunion may be "out of plane" on these two views, giving the false impression of adequate healing. If the fracture morphology is not clear or there is persistent pain at the fracture site, 40-degree internal- and external-rotation oblique views may be very informative. Occasionally, examination of the limb under fluoroscopy, with or without stress views, may help to identify subtle motion at the fracture site. Linear tomography can also be useful in the evaluation of fracture healing, particularly in the presence of fixation hardware. In the absence of fixation devices, computed tomography and magnetic resonance imaging have supplanted linear tomography in the assessment of fracture healing.

The role of radionuclide scanning in the assessment of delayed union and nonunion remains poorly defined. It has been used primarily to investigate the possibility of infection. Subclinical, undetected infection remains a significant therapeutic problem in the management of tibial nonunions.[5] Knowledge of the presence or absence of infection is of vital importance to the surgeon weighing multiple treatment alternatives. Except in moderate to advanced cases, plain radiographs usually do not reveal signs of osteomyelitis at the nonunion site. Although the localized uptake of technetium-99m diphosphonate reflects a reparative bone process, it is not specific for infection. Gallium-67 citrate accumulates at the site of inflammation, but it too is not specific for active infection. Even with sequential technetium or gallium scintigraphy, most studies report accuracy rates of only 50% to 60% in defining subclinical osteomyelitis. Indium-111–labeled leukocyte scans have been shown to have high sensitivity, specificity, and accuracy in acute osteomyelitis, but they are much less effective in the diagnosis of chronic, subacute, and indolent bone infections.[6-9]

Magnetic resonance imaging can be useful in the diagnosis of acute and chronic bone and soft-tissue infections.[10-13] The multiplanar imaging capability and the high degree of contrast resolution allows accurate delineation of the limits of an infective process. It can be used to locate a small sequestrum in a patient with chronic drainage or to evaluate the quality of the interface with an avascular wedge or butterfly fragment. A study is considered to be consistent with osteomyelitis when an area of abnormal marrow showing increased signal intensity on T2-weighted images corresponds with an area of low signal on T1-weighted sequences. Sinus tracts can be followed as high-signal-intensity fluid areas on T2-weighted images that extend through the skin and subcutaneous tissues into defects in the bone and marrow.

Magnetic resonance imaging can also play a vital role in the assessment and planning of the surgical treatment of patients with acute or chronic osteomyelitis complicating fracture healing, because it can be used to define the intramedullary extent of the infection before surgical debridement. In one study,[13] bone infection was identified with a diagnostic sensitivity of 100%, a specificity of 63%, and an accuracy of 93%.

Tissue biopsy remains a useful technique for evaluating infection complicating fracture repair.[14] Antibiotic therapy should be discontinued for at least 72 hours before biopsy, and several representative biopsy specimens should be obtained for analysis. Cultures should be sent for aerobic, anaerobic, fungal, and acid-fast studies as indicated. Gristina et al[14] have reported that even open biopsy techniques may yield information that is less than complete because of the problem of analyzing bacteria protected by external glycocalyx.

Nonsurgical Treatment

Functional Casts or Braces

In a small number of cases, continued nonoperative treatment of a tibial nonunion may be appropriate. Occasionally, a fracture treated in a non-weight-bearing long-leg cast will heal after conversion to a weight-bearing cast or brace. The introduction of weight bearing provides a functional stimulus that alters the fracture environment, leading to callus formation and fracture consolidation.[15] The stimulus of weight bearing and intermittent loading can be sufficient to induce healing in a fracture not subjected previously to loading. This method of treatment allows mobilization of the knee, ankle, and subtalar joints. Fracture bracing improves muscle and skin quality and rarely is a "bridge-burning" procedure. Although disability may be extended, the costs are minimal, and the risks appear relatively low. If the fracture fails to unite, alternative methods of treatment are possible with little additional risk.

Electrical Stimulation

The use of electrical stimulation in the management of delayed union and nonunion continues to be controversial. To date, the exact mechanism of bone healing by electrical stimulation is not completely understood. While there is a large volume of literature advocating its use, there are few prospective, double-blind, randomized studies.[16,17] The technique is best indicated in a compliant patient with a stable hypertrophic nonunion with little or no clinical deformity.

The technique requires excellent patient compliance, is expensive, and generally requires immobilization. The major drawback is the inability to address the associated problems of angulation, malrotation, and limb shortening that often occur in patients with tibial nonunions. Furthermore, lack of compliance by many patients also limits its use. In our experience, electrical stimulation has often been recommended for patients with unstable, mobile, atrophic nonunions, in whom the technique has little or no chance of success. Although they are doubtless well intentioned, surgeons may prolong patient morbidity and increase costs attempting to avoid the more risky but successful approach of surgical management.

Surgical Treatment

Fibular Osteotomy

Osteotomy of the fibula in an attempt to encourage tibial union is based on the belief that the fibula acts as a distraction strut, preventing compressive forces on the tibial fracture site. When both the tibia and the fibula are fractured, the fibula almost always heals first, sometimes in as little as 6 to 8 weeks. Once healed, it may become load sharing and thus decrease actual loads across the tibial fracture site. When the fibula is not fractured, it may prevent close apposition of the tibial fragments and protect the tibia from its full axial load.

Fibular osteotomy is more commonly used as an adjunctive procedure to assist with deformity correction when combined with surgical stabilization of the tibia. The indications for isolated fibular osteotomy should be confined to stable hypertrophic nonunions with little or no deformity. The advantages of osteotomy of the fibula are its low morbidity and cost and the fact that it rarely precludes subsequent procedures.

Most investigators favor resection of a 1.5- to 2.5-cm segment of the fibula. Resection of larger amounts increases morbidity, provides no additional compressive force on the tibia, and may increase tibial fracture instability or jeopardize a posterolateral bone graft if the tibial fracture fails to unite. Additional disadvantages of isolated fibular osteotomy include a mixed record of success, the inability to overcome substantial degrees of deformity, and the necessity of additional prolonged casting or bracing of the tibial nonunion. Contraindications to the procedure include unstable atrophic nonunions, synovial pseudarthrosis, active infection at the tibial fracture site, unacceptable tibial angulation, and the inability of the patient to bear weight.

Bone Grafts

Autogenous bone transplantation, usually involving grafts from the iliac crest, remains the classic method of treatment of tibial nonunions in a variety of locations (Fig. 1). The most common use of bone grafts is as a biological stimulus in the management of atrophic tibial nonunions. The use of large cortical struts (either autograft or allograft), with their low surface-area vascularity and low porosity, requires more time for vascular ingrowth before incorporation and is not recommended.

Anterolateral grafting of the tibia has been used extensively in the past, but the proximity to traumatic anterior wounds increases the rate of wound complications. Furthermore, the amount of bone graft that can be inserted is relatively small.

The posterolateral approach is the preferred technique in the middle and distal thirds of the bone.[18] When the fracture site is exposed, care must be taken not to disturb the fibrous union or penetrate the interosseous membrane. The fibrous tissue helps stabilize the fracture fragments, has osteogenic potential, and may contribute to consolidation of the fracture. The posterolateral approach avoids open wounds, scars, and draining sinuses, which are often present in the anterior or anteromedial aspect of the leg when there has been extensive soft-tissue damage. The anterior compartment is not violated when the posterolateral approach to the tibia is employed. In the proximal third of the tibia, proximity to the neurovascular structures makes posterolateral grafting risky. In these cases, a posteromedial graft may be preferable.

Connolly et al[19] popularized the use of percutaneous bone marrow injections to treat delayed unions and nonunions of the tibia. These authors as well as others[20] have shown, both in vitro and in vivo, that healing of nonunions can be successfully stimulated by injecting autologous marrow into defects. The

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Fig. 1 **A,** Bone loss associated with a grade IIIB fracture of the tibia in association with a segmental fibular fracture affecting ankle stability. After irrigation and debridement, the tibia was stabilized with half-pin external fixation, and a plate was applied to the distal fibula. **B,** Five days after injury, the soft tissues were reconstructed with a rectus abdominis free-tissue transfer. At 6 weeks, the flap was elevated, and an iliac-crest bone graft was placed anteriorly into the tibial defect. **C,** At follow-up at 18 months, complete healing was seen, with maintenance of length and alignment.

amount of osteogenesis produced by the marrow is directly related to its cell density. The technique involves harvesting bone marrow percutaneously from the iliac crest and injecting it directly into the area of the tibial nonunion. This allows the marrow to be used much like an autologous bone graft, but without the attendant morbidity of open harvesting and surgical dissection at the fracture site. Under fluoroscopic control, a marrow needle is inserted into the site of the nonunion or delayed union. The preferred location is the well-vascularized posterior aspect of the fracture, where a standard posterolateral bone graft would be performed. It is important to remember that marrow injection is not a substitute for adequate stabilization of the fracture or correction of malalignment.

Bone grafts are also indicated to fill defects caused by cortical bone loss. They can be used successfully to treat as much as 6 cm of bone loss, usually in combination with external fixation. When there is more bone loss, alternative techniques, such as bone transport, may be more effective. The advantages of bone grafting include its status as a time-honored and well-tested technique, its success rate of 88% to 95%, and the fact that no specialized equipment is needed. Nevertheless, there are several disadvantages with this method of treatment. Donor-site morbidity is often underestimated; grafting provides little opportunity for deformity correction; bone-graft incorporation can be slow; and supplemental immobilization is usually necessary.

Plate Osteosynthesis

Although the use of plating techniques in the treatment of acute tibial fractures has decreased with the introduction of interlocking tibial nails, its use in posttraumatic reconstruction has increased in recent years.[21,22] The major advantage of compression plating in the management of nonunion is the ability to correct deformity, restore function, and promote healing (Fig. 2). It can be used in virtually any location along the tibia, from the knee to the

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Fig. 2 **A,** Fourteen weeks after multiple blunt trauma, this closed, displaced, angulated tibial shaft fracture remained painful and nonunited. **B,** Open reduction and internal fixation with plate osteosynthesis was performed without bone graft. A lag screw was used to increase interfragmental compression. **C,** Radiographs obtained at 15 months show uneventful fracture healing.

ankle; it obviates the need for a cast; and it allows the patient to begin mobilizing the knee, ankle, and subtalar joints.

There are several drawbacks with the use of plate osteosynthesis, however. Internal fixation with plates and screws involves a load-bearing device that requires a period of protected weight bearing. Its use in patients with a compromised soft-tissue envelope or scarred, atrophic skin increases the risk of wound breakdown and infection. Additionally, in elderly patients and patients with long-standing nonunions associated with severe osteopenia, plate osteosynthesis may not provide stable internal fixation. Furthermore, in the case of atrophic nonunions, adjunctive bone grafting is always necessary.

When applied to the convex surface of the nonunited tibia as a tension band, the plate can assist in correction of the deformity while achieving stable internal fixation. Tibial nonunions with deformities that are correctable with a plate should not be disturbed. Operative mobilization of a nonunited tibia increases the instability at the fracture site, impairs vascularity, and prolongs healing time. Takedown of a nonunion is necessary only in patients who have excessive angulation or shortening, a true synovial pseudarthrosis, or an infected nonunion. In these difficult situations, alternative methods of treatment may be indicated.

In the middle three fifths of the tibia, a plate should be applied to the tension side of the bone, where it will act as a tension band. With varus deformities, the plate is applied laterally; with valgus deformities, the plate is applied medially. Through an anterior approach, the soft tissues are elevated only on the side of the tibia where the plate is to be applied. Circumferential stripping of the nonunion should be avoided, except in patients who require major deformity correction. In patients with stiff nonunions or substantial angulation, a fibular osteotomy often improves deformity correction.

Adjunctive measures, such as use of a femoral distractor or an articulated compression-distraction device, are extremely useful in minimizing soft-tissue dissection. It is important to contour the plate to the bone, rather than realigning the tibia to the plate. Whenever possible, an interfragmentary lag screw should be placed across the nonunion site, either separately or through the plate, which will increase the stability of the nonunion and decrease rotational shear at the nonunion site.

In the diaphysis, we prefer 4.5-mm titanium limited-contact dynamic-compression (LCDC) plates. However, in the distal tibial metaphyseal region, the use of 3.5-mm titanium LCDC implants may be preferable. In most hypertrophic nonunions, the mechanical stability provided by a plate alone usually leads to rapid consolidation of the fracture. In atrophic nonunions, the use of plate fixation together with autogenous bone graft is necessary.

If there is a history of infection, aspiration biopsy should be considered before plating. If the culture is positive, alternative methods of treatment may be indicated.

Intramedullary Nailing

Closed intramedullary nailing with reaming is perhaps the optimal method of management for tibial nonunions and delayed unions.[23-26] It provides enough mechanical strength to allow impaction without angular deformity during weight bearing. Reaming itself may act as a stimulus to healing. Nailing also allows early active rehabilitation of the muscles and joints of the lower extremity without the need for an external cast or brace (Fig. 3). Unfortunately, in many patients, the biological environment is not suitable for a reamed intramedullary nail.

The use of a reamed intramedullary nail in the management of a tibial nonunion is indicated in the treatment of closed fractures and in selected patients with prior grade I and grade II open tibial fractures in the middle three fifths of the bone. The technique is also useful when acute plating has failed and when conversion from use of a nonreamed tibial nail is necessary. Because of the high rates of infection, reamed intramedullary nails should be used with caution in patients with prior grade III open tibial fractures, particularly when initial management was with external fixation.[23] Patients with medullary canal malalignment that necessitates open intramedullary nailing are often better treated with alternative techniques. In patients with stiff hypertrophic nonunions and substantial deformity, closed intramedullary nailing may be technically difficult or impossible.

Intramedullary nailing of tibial nonunions can be a challenging surgical reconstruction. Previous experience in the management of acute fractures with reamed intramedullary nails is helpful. In nonunions of longstanding duration, the medullary canal is often occluded. In this situation, intramedullary pseudarthrosis chisels may be necessary to open the

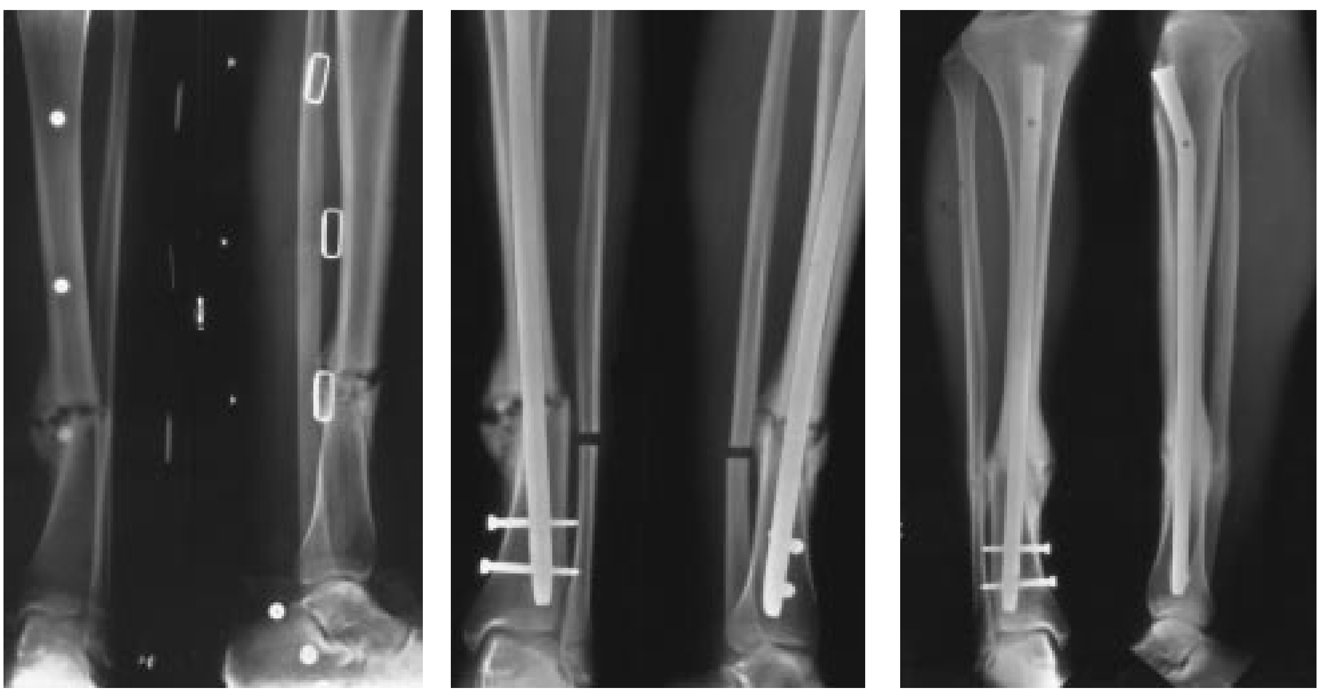

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Fig. 3 **A,** Nine months after a grade I open tibial fracture with an intact fibula, nonunion was seen, with a 12-degree varus deformity. **B,** Treatment consisted of placement of a reamed intramedullary interlocking nail and a fibular osteotomy. Despite the fibular resection, complete deformity correction was not achieved, leaving 7 degrees of residual varus angulation. **C,** At 1-year follow-up, the fracture had united with an excellent functional result.

canal before the guide wire can be successfully passed. Nailing can be done on a radiolucent table or on a fracture table. A tourniquet should not be used, to avoid thermal damage during reaming. The reamings should be cultured.

A nail with locking capabilities is strongly recommended. Unlike acute fractures, most tibial nonunions have begun to heal and are inherently stable after nailing without static locking. In very proximal and distal nonunions, the addition of locking screws to increase stability in the short fragment is often helpful. In nonunions in the middle third, locking is usually not necessary.

The role of nonreamed tibial nails in the management of established nonunions remains investigational.[27]

Conventional External Fixation

Half-pin external fixation is used primarily in the management of infected nonunions. Combined with radical and repeated debridements, soft-tissue reconstructive procedures, and adjunctive bone-grafting techniques, external fixation remains the mainstay of skeletal stabilization.

The use of a fixator that allows loading at the nonunion site during weight bearing may be mechanically and biologically attractive. Advantages include the simplicity of the unilateral half-pin technique and the ability to achieve limited axial deformity correction. With some fixators, segmental bone transport can be employed when indicated. The major disadvantage with external skeletal fixation is the need for prolonged use and the virtual inevitability of pin-tract infection.

The principal role of external fixation lies in the management of infected nonunions. The fixator allows stabilization of the injury and debridement as necessary and facilitates the reconstruction of soft tissues once infection is under control. Its use in aseptic nonunions is more limited. However, it can be helpful in proximal and distal nonunions, previously infected but quiescent nonunions, and nonunions with a scarred or worrisome soft-tissue envelope.

Small-Wire and Hybrid External Fixation

The use of small-wire circular fixators and hybrid external fixation in the management of tibial nonunions has grown in popularity.[28] Indications include the presence of a periarticular nonunion, a tibial fracture associated with bone loss, limb shortening, or an infected nonunion or the need for multiplanar deformity correction (Fig. 4).

The advantages of Ilizarov-type fixation include percutaneous application with minimal blood loss, wide application throughout the length of the tibia, the potential to achieve substantial deformity correction, and the ability to overcome bone defects without grafting. When properly applied, circular fixators provide stable fixation at multiple levels during distraction or compression. Axial alignment can be restored with the use of different combinations of frame designs that utilize hinges, beaded wires, and push or pull constructs on the rings. Stable fixation permits normaliza-

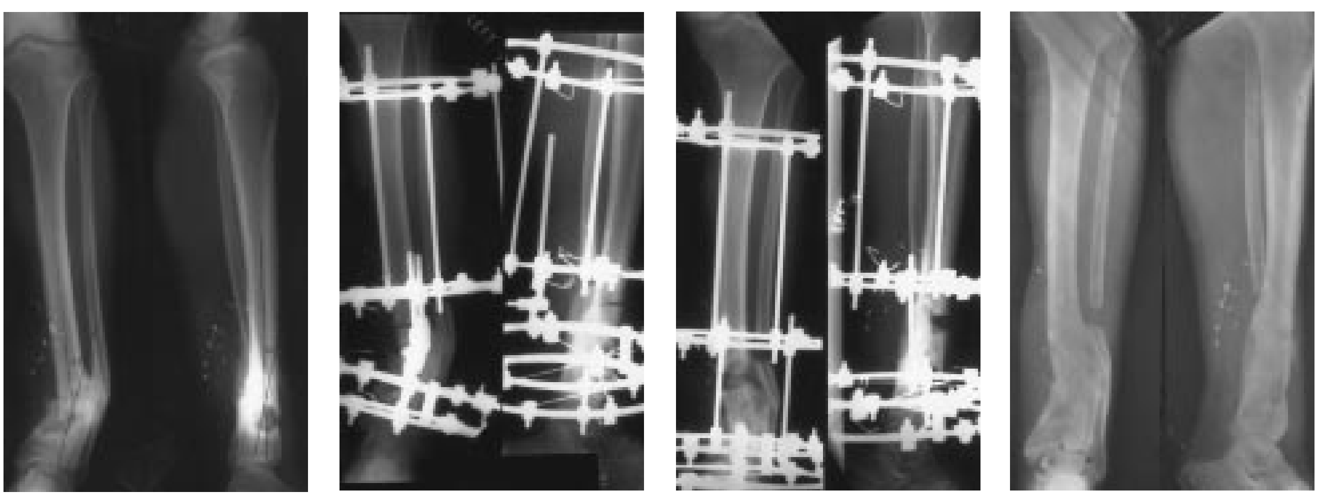

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Fig. 4 **A,** Treatment of a grade IIIB open tibial fracture that became infected involved multiple procedures, including a free flap. Thirteen months after injury, a complex-composite deformity remained, with 23 degrees of varus deformity and 3 cm of shortening. **B,** Treatment with an Ilizarov external-fixation device. **C,** A corticotomy was made just proximal to the apex of the deformity to allow correction and leg lengthening. **D,** Radiographs obtained at final follow-up at 19 months show restoration of length and alignment.

tion of function with early weight bearing and range-of-motion potential for adjacent joints. This, in turn, increases the vascularity of the entire limb, thereby promoting healing.

Nevertheless, there are several problems and disadvantages with the use of circular fixators. These include the necessity of maintaining an extensive inventory of equipment, the cost of the appliance, the relatively high incidence of pin-tract problems, the need for specialized training in the method, and the long learning curve. Furthermore, the technique is not indicated for many patients. Use of this method is relatively contraindicated in the treatment of patients who are psychologically impaired or emotionally fragile and patients for whom compliance or close follow-up is not possible. It should also not be attempted by a surgeon inexperienced in its use.

Summary

The management of severe open fractures of the tibia remains one of the more challenging problems facing the orthopaedic surgeon. Many of these fractures fail to unite because of the severity of the initial fracture displacement, the damage to the surrounding soft tissues, and the disruption of the microcirculation in the zone of injury. Failure to achieve union may lead to multiple surgical procedures, with months or years of disability before union is obtained or amputation is performed. Selecting a method of treatment is difficult, and activation of subclinical infection remains a hazard after surgical management.

References

1. Wiss DA, Sherman R, Oechsel M: External skeletal fixation and rectus abdominis free-tissue transfer in the management of severe open fractures of the tibia. *Orthop Clin North Am* 1993;24:549-556.
2. Fischer MD, Gustilo RB, Varecka TF: The timing of flap coverage, bone-grafting, and intramedullary nailing in patients who have a fracture of the tibial shaft with extensive soft-tissue injury. *J Bone Joint Surg Am* 1991;73:1316-1322.
3. Bach AW, Hansen ST Jr: Delayed union, nonunion, and malunion of the tibial shaft, in Evarts CM (ed): *Surgery of the Musculoskeletal System*, vol 3. New York: Churchill Livingstone, 1983, pp 8:63-8:86.
4. Gustilo RB, Mendoza RM, Williams DN: Problems in the management of type III (severe) open fractures: A new classification of type III open fractures. *J Trauma* 1984;24:742-746.
5. Marsh J, Nepola J, Seabold J: Subclinical infection in delayed nonunion of fractures [abstract]. *J Orthop Trauma* 1989;3:169.
6. Esterhai J, Alavi A, Mandell GA, et al: Sequential technetium-99m / gallium-67 scintigraphic evaluation of subclinical osteomyelitis complicating fracture nonunion. *J Orthop Res* 1985;3:219-225.
7. Smith MA, Jones EA, Strachan RK, et al: Prediction of fracture healing in the tibia by quantitative radionuclide imaging. *J Bone Joint Surg Br* 1987;69:441-447.
8. Merkel KD, Brown ML, Dewanjee MK, et al: Comparison of indium-labeled-leukocyte imaging with sequential technetium-gallium scanning in the diagnosis of low-grade musculoskeletal sepsis: A prospective study. *J Bone Joint Surg Am* 1985;67:465-476.
9. Nepola JV, Seabold JE, Marsh JL, et al: Diagnosis of infection in ununited fractures: Combined imaging with indium 111-labelled leukocytes and technetium-99m methylene diphosphonate. *J Bone Joint Surg Am* 1993;75:1816-1822.
10. Beltran J, Noto AM, McGhee RB, et al: Infections of the musculoskeletal system: High-field-strength MR imaging. *Radiology* 1987;164:449-454.
11. Berquist TH, Brown ML, Fitzgerald RH Jr, et al: Magnetic resonance imaging: Application in musculoskeletal infection. *Magn Reson Imaging* 1985;3:219-230.
12. Modic MT, Pflanze W, Feiglin DHI, et al: Magnetic resonance imaging of musculoskeletal infections. *Radiol Clin North Am* 1986;24:247-258.
13. Mason MD, Zlatkin MB, Esterhai JL, et al: Chronic complicated osteomyelitis of the lower extremity: Evaluation with MR imaging. *Radiology* 1989;173:355-359.
14. Gristina AG, Naylor PT, Webb LX: Molecular mechanisms in musculoskeletal sepsis: The race for the surface. *Instr Course Lect* 1990;39:471-482.
15. Sarmiento A, Latta LL: *Closed Functional Treatment of Fractures.* Berlin: Springer-Verlag, 1981, pp 1-58.
16. Sharrard WJW: A double-blind trial of pulsed electromagnetic fields for delayed union of tibial fractures. *J Bone Joint Surg Br* 1990;72:347-355.
17. Scott G, King JB: A prospective, double blind trial of electrical capacitive coupling in the treatment of non-union of long bones. *J Bone Joint Surg Am* 1994;76:820-826.
18. Simpson JM, Ebraheim NA, An HS, et al: Posterolateral bone graft of the tibia. *Clin Orthop* 1990;251:200-206.
19. Connolly JF, Guse R, Tiedeman J, et al: Autologous marrow injection as a substitute for operative grafting of tibial nonunions. *Clin Orthop* 1991;266:259-270.
20. Garg NK, Gaur S, Sharma S: Percutaneous autogenous bone marrow grafting in 20 cases of ununited fracture. *Acta Orthop Scand* 1993;64:671-672.
21. Wiss DA, Johnson DL, Miao M: Compression plating for non-union after failed external fixation of open tibial fractures. *J Bone Joint Surg Am* 1992;74:1279-1285.
22. Helfet DL, Jupiter JB, Gasser S: Indirect reduction and tension-band plating of tibial non-union with deformity. *J Bone Joint Surg Am* 1992;74:1286-1297.
23. Wiss DA, Stetson WB: Nonunion of the tibia treated with a reamed intramedullary nail. *J Orthop Trauma* 1994;8:189-194.
24. Johnson KD: Management of malunion and nonunion of the tibia. *Orthop Clin North Am* 1987;18:157-171.
25. Mayo KA, Benirschke SK: Treatment of tibial malunions and nonunions with reamed intramedullary nails. *Orthop Clin North Am* 1990;21:715-724.
26. Sledge SL, Johnson KD, Henley MB, et al: Intramedullary nailing with reaming to treat non-union of the tibia. *J Bone Joint Surg Am* 1989;71:1004-1019.
27. Riemer BL, Butterfield SL: Comparison of reamed and nonreamed solid core nailing of the tibial diaphysis after external fixation: A preliminary report. *J Orthop Trauma* 1993;7:279-285.
28. Schwartsman V, Choi SH, Schwartsman R: Tibial nonunions: Treatment tactics with the Ilizarov method. *Orthop Clin North Am* 1990;21:639-653.