Nonreamed Intramedullary Nailing of Open Tibial Fractures

Melbourne D. Boynton, MD, and Gregory J. Schmeling, MD

Abstract

The development of small-diameter interlocking intramedullary nails that can be inserted without reaming provides a fixation option for open tibial-shaft fractures. Nonreamed intramedullary nailing of these injuries facilitates soft-tissue management without an increase in infection or nonunion rates relative to external fixation. Reaming is not required, which means less injury to the tibial endosteal blood supply. Proximal and distal interlocking maintains better bone alignment than is possible with semirigid or noninterlocking intramedullary nails. The technique of using these devices with static interlocking is described, as are some suggested techniques for avoiding complications.

J Am Acad Orthop Surg 1994;2:107-114

Open tibial-shaft fractures remain a difficult challenge for the orthopaedic surgeon. The primary goal of treatment is to obtain a functional extremity, which usually necessitates removal of devitalized tissue, stabilization of the bone, and reconstruction of the soft-tissue envelope. A healed, noninfected soft-tissue envelope is required to provide the optimal environment for vascular ingrowth and subsequent bone healing.

At the time of injury, both the endosteal and the periosteal blood supply are damaged.[1] The endosteal vessels supply the inner two thirds of the cortex, and the periosteal vessels supply the outer third. The extent of damage and the length of the vascular recovery phase determine the time to bone union and the resistance to infection. Accordingly, further disruption of the blood supply should be avoided during fracture management.

Nonreamed intramedullary nailing of open tibial fractures has received a great deal of interest recently because it appears to meet the objectives required to optimize treatment. The indications, technique, and complications will be discussed, with special attention to the advantages of this method over other methods that have been reported.

Fracture Grading

An understanding of the extent of the injury, to both the bone and the soft tissues, is essential to the formulation of a treatment plan for open tibial fractures. Alternatives for bone stabilization, soft-tissue reconstruction, and adjunctive antibiotic therapy are all based on classification schemes that predict complications based on the extent of injury. The most widely used classification scheme in North America is the Gustilo-Anderson open-fracture grading system (Table 1).[2] Tscherne developed a similar grading system for open fractures based on the severity of the soft-tissue damage but extended it to include closed fractures as well (Table 2).[3] The AO / ASIF group has proposed a grading system for soft-tissue injuries associated with open and closed fractures that is an expansion of both of those systems. A fourth classification system is the one proposed by Trafton[4] (Table 3). This system has the benefit of simplicity and is relatively easy to remember. The system incorporates five factors defining the extent of the injury; the injury characteristic of the highest severity is used to grade the extent of the bone and soft-tissue injury. Although this classification system is useful in guiding initial treatment, it may lump some dissimilar injuries together because it has only three groups. The AO / ASIF classification and the one proposed by Trafton have yet to be clinically tested as predictors of outcome.

There are two major problems with the application of any of these classification systems. The first problem is when to grade the fracture. The grading may be done in the emergency room, at the time of initial debridement, or after the final debridement just before wound closure. There is no way to determine when other authors graded the frac-

Dr. Boynton is Assistant Professor of Orthopaedics, Medical College of Wisconsin, Milwaukee. Dr. Schmeling is Assistant Professor of Orthopaedics, Medical College of Wisconsin, Milwaukee.

Reprint requests: Dr. Boynton, Department of Orthopaedics, Medical College of Wisconsin, Box 149, 8700 W. Wisconsin Avenue, Milwaukee, WI 53226.

Table 1
Gustilo-Anderson Classification of Open Fractures[2]

Grade I	Clean wound <1 cm
Grade II	Laceration >1 cm without extensive soft-tissue damage, flaps, or avulsions
Grade IIIa	Extensive laceration (>10 cm) with adequate local soft-tissue coverage available or high-energy trauma regardless of wound size
Grade IIIb	Extensive soft-tissue loss requiring local or free flap coverage, usually associated with massive contamination
Grade IIIc	Vascular injury requiring repair

Table 2
Tscherne Classification of Open and Closed Fractures[3]

Open fractures	
Grade I	Low-energy puncture wound with no skin contusion and negligible contamination
Grade II	Moderate-energy small wound with small skin contusion and moderate contamination
Grade III	High-energy large wound with extensive skin contusion and severe contamination
Grade IV	Incomplete amputation
Closed fractures	
Grade 0	Indirect-force injury with negligible soft-tissue damage
Grade I	Low / moderate-energy injury with superficial abrasions and contusions
Grade II	High-energy injury with significant muscle contusion and deep contaminated skin abrasions
Grade III	High-energy injury with subcutaneous degloving and possible arterial injury or compartment syndrome

Table 3
Modified Tibial Fracture Classification[4]

	Extent of Injury		
Injury Characteristic	Minor	Moderate	Major
Fracture displacement	<50%	>50%	Tibial or fibular displacement
Comminution	Minimal	0 or 1 butterfly fragment	>2 free fragments or segmental
Wound grade			
Closed	0	I	II or III
Open	I	II	III or IV (Tscherne) or IIIa-IIIc (Gustilo-Anderson)
Energy	Low	Moderate	High
Fracture pattern	Spiral	Oblique or transverse	Transverse or fragmented

tures in their series. This may be one explanation for the widely differing results of treatment reported for open tibial fractures. The extent of the injury to the bone (in terms of comminution, energy of trauma, and fracture pattern) is usually determined radiographically in the emergency room. The extent of the soft-tissue injury (in terms of wound type, energy of trauma, and fracture displacement) may not be known until after the final debridement 5 to 7 days after injury.

Our initial approach is to radically debride all devitalized tissue. When such an approach is applied, the extent of the injury is usually known after the first debridement, and fracture grading is generally possible. Plans for initial bone stabilization and adjunctive antibiotic therapy are based on the grading of the injury after the first debridement. Should subsequent debridement reveal that more soft-tissue damage exists than was initially appreciated, the injury is upgraded.

The second problem with the application of these classification systems is the high degree of interobserver variability. One surgeon might consider an injury to be Gustilo-Anderson grade IIIa, while another might judge it to be grade II. In a report to the Orthopaedic Trauma Association in 1993, Brumback demonstrated the large interobserver variability obtainable with the Gustilo-Anderson grading system. Respondents were asked to grade 12 open tibial fractures based on what they saw on a narrated film. The number of respondents who agreed on the grade for each injury averaged 60% (range, 42% to 94%) for all 12 cases. When the respondents had trauma fellowship training, the number rose to 66% (range, 40% to 100%). Brumback concluded that treatment decisions in studies using this grading system may have been inadequate and comparisons of results from such studies may have been inaccurate.

Treatment Options

Reamed nailing has established success in the treatment of closed tibial fractures.[5] Intramedullary reaming is advocated to extend the bone-nail contact area (i.e., increase the nail working length) and to prepare the canal for placement of a large-diameter nail. However, reaming has also been shown to damage the endosteal circulation in several studies of tibial blood flow. In the canine tibia, intramedullary nailing with reaming reduces the diaphyseal cortical circulation by 70%, while insertion of a medullary nail without reaming reduces the cortical circulation by only 30%.[6] The endosteal circulation recovers with time. Temporary loss of endosteal circulation is of little importance in the treatment of closed, low-energy tibial fractures with mild soft-tissue damage because the periosteal vessels can increase their contribution to the cortical blood supply after a fracture or after endosteal reaming. In open fractures with periosteal stripping and closed fractures with severe soft-tissue damage, however, this response by the periosteal vessels does not occur. The importance of tibial blood flow and soft-tissue coverage in open fractures and closed fractures with severe soft-tissue damage cannot be overemphasized.

Nonreamed intramedullary nails (Lottes and Ender nails) have been advocated for the treatment of open tibial-shaft fractures with an axially stable fracture pattern. Several authors have reported acceptable results with low complication rates using these implants.[7-9] The problem with these nails is the lack of axial and rotational stability when they are used to treat comminuted fractures.

External fixation has been advocated for the treatment of comminuted open tibial fractures for the past two decades. The incidences of infection (13% to 15%), nonunion (3% to 11%), malunion (9% to 36%), and pin-tract infection (21% to 30%) are significant.[8,10,11] Infection remains a problem when reamed intramedullary nailing is used for the treatment of delayed union or nonunion after external fixation, especially when there has been pin-site drainage from the external fixation device used initially.[12,13]

The complications associated with external fixation have heightened the search for alternative methods of fixation for open comminuted tibial fractures. The excellent results achieved with the nonreamed Ender and Lottes nails in stable fracture patterns and the excellent results with statically locked reamed nails in closed unstable fracture patterns have led to the development of the statically locked nonreamed tibial nail. Excellent results, with complication rates less than or equal to those for external fixation, have been reported with the use of the narrow-diameter, statically locked nonreamed nail for the treatment of severe, unstable, open tibial-shaft fractures (infection, 3% to 8%; malunion, 0% to 9%; nonunion, 0% to 4%).[14-19] Furthermore, there is no problem with pin-site drainage and the associated infection risk should reamed intramedullary nailing subsequently be required.

Indications

The indications for use of the statically locked nonreamed nail are based on the grading of the soft-tissue injury for each fracture. We use the nonreamed nail in closed tibial fractures with extensive soft-tissue injury and in all open tibial-shaft fractures. The use of a nonreamed nail in Gustilo-Anderson grade IIIb or IIIc injuries is still under investigation. Recent reports have found no difference in union or infection rates in grade IIIb tibial-shaft fractures when compared with treatment with an external fixator.[15,17]

Relative contraindications to the use of the nonreamed nail in tibial-shaft fractures include massive contamination and skeletal immaturity. An external fixator is recommended when contraindications are present. This technique requires a good deal of surgeon experience, particularly for grade IIIb and IIIc injuries.

Technique

Emergency Room

Sterile dressings are applied to the wound. A "one-look" policy of wound evaluation is strictly enforced. Delay in initial operative debridement greater than 6 to 8 hours is avoided. Cultures of the wound are not obtained in the emergency room.

Preoperative Plan

Radiographs of the injured tibia are evaluated for intramedullary canal diameter. Occasionally, the diameter will be too small to accommodate the nonreamed intramedullary nail, and an alternative method of fixation will be required.

Accurate determination of nail length is important because most manufacturers of nonreamed nailing systems package the nails separately. If there is severe comminution of the diaphysis, we estimate the nail length using a radiograph of the noninjured tibia. Nail length can also be determined intraoperatively by insertion of a guide wire.

Irrigation and Debridement

Irrigation and debridement of the open wound are carried out with the use of instruments that are kept separate from those used for nailing the tibia. Aggressive radical debridement is then performed. All foreign material and nonviable tissue, including bone, is removed. The open wound is extended as needed to completely debride the injury site. Care is taken when extending the wound to minimize further soft-tissue damage in the surrounding zone of injury.

Irrigation is then carried out with a high-flow pulsatile irrigating system. Ten liters of irrigating fluid is used for most injuries. The last bag of fluid contains bactericidal antibiotics. Routine wound cultures are not taken at the time of initial irrigation and debridement, as they have a low yield and do not alter the choice of adjunctive chemotherapy. After irrigation and debridement of the severely contaminated wound, the extremity is prepared with a bactericidal solution and draped again, and the operating personnel change their gowns and gloves.

Reduction

We perform the procedure on a radiolucent table. A surgical assistant holds the extremity in place for nailing, or a femoral distractor is used to maintain axial alignment of the fracture (Fig. 1, A). Alternatively, the patient is positioned on a fracture table with a padded rest under the distal thigh (Fig. 1, B). The hip and knee are flexed to 70 and 90 degrees, respectively. A calcaneal traction pin is used to maintain alignment with traction and to allow access for distal locking bolts.

Obtaining and maintaining correct mechanical alignment of the tibia during insertion of the nail are very important. Correction of some rotational malalignment is possible after nail insertion, but correction of sagittal or frontal malalignment is usually not possible. In most cases, axial traction alone will reduce the fracture and maintain alignment. Sometimes, adequate fixation of short proximal fragments with an intramedullary nail cannot be achieved.

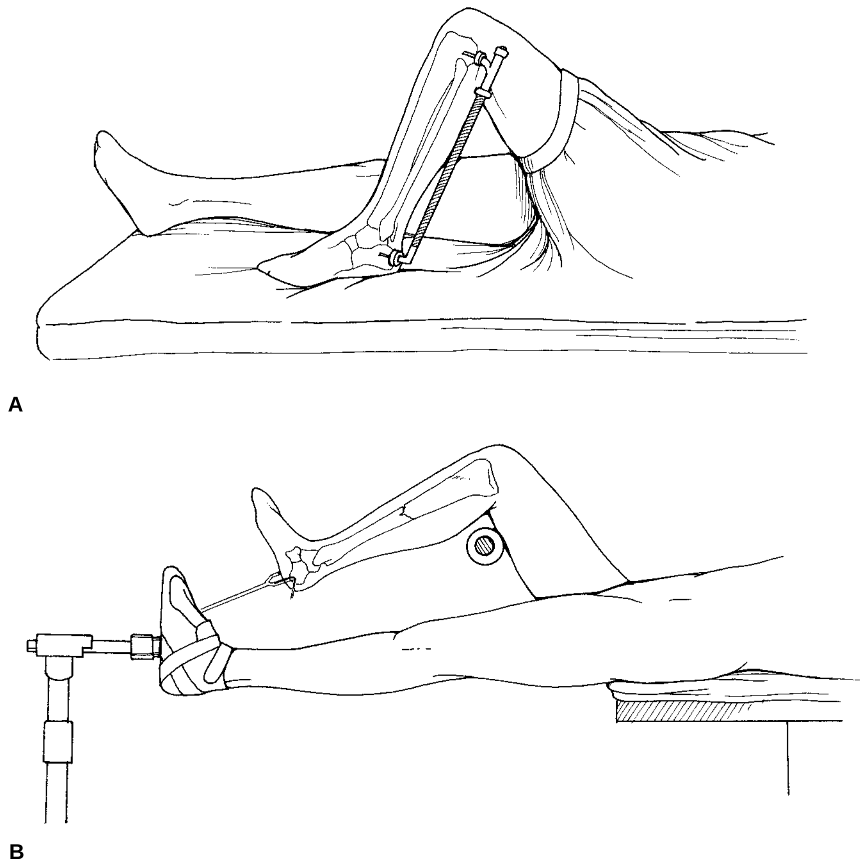

Fig. 1 **A,** With the patient on a radiolucent table, a femoral distractor is used to maintain fracture reduction for nailing after irrigation and debridement. This technique permits the knee to be flexed to 90 degrees for nail insertion. The knee is extended, and the leg is placed on a support for distal interlocking. **B,** Use of a fracture table and calcaneal pin traction to maintain alignment and allow positioning of the C arm for nailing and distal interlocking. Note that the thigh support is placed, not directly in the popliteal fossa, but just proximal to it. Irrigation and debridement of the leg are performed prior to placing the leg in traction.

Nail Insertion

The entry hole must be in line with the tibial shaft on the anteroposterior view and should be directed down the center of the canal on the lateral view (Fig. 2). The patellar tendon is retracted laterally, and the entry hole is made with a curved awl just distal to the tibial plateau. If the hole is not parallel to the shaft, the nail may exit the posterior cortex of the tibia during insertion. An entry hole that is too proximal may damage the tibial plateau or the intermeniscal ligament. An entry hole that is too distal may result in injury to the attachment of the patellar tendon to the tibial tubercle or may lead to sagittal malalignment. Anterior translation of the proximal fragment, particularly in proximal-third tibial fractures, can be minimized by using a more proximal entry hole and by inserting the nail parallel to the anterior tibial cortex in the anterior portion of the bone.[20]

After the entry hole has been established, a guide wire is placed down the shaft of the tibia across the fracture to the distal physeal scar. The guide wire is then used to confirm the length required for the intramedullary nail. If there is concern about the diameter of the intramedullary canal, sounds can be placed down the canal to determine

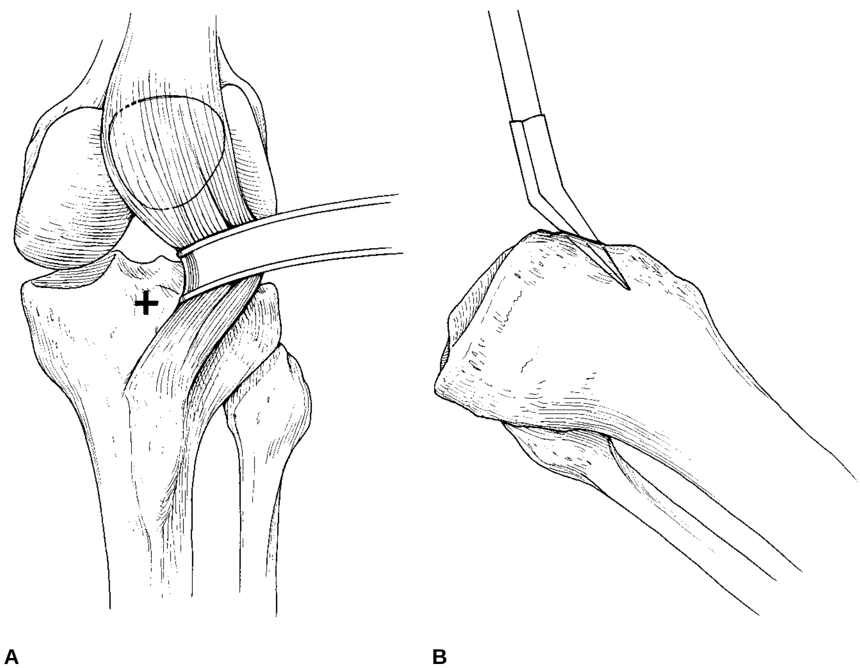

Fig. 2 **A,** The patellar tendon is retracted laterally to expose the entry site (cross), which is in line with the medullary canal of the tibia. **B,** The entry is started superior to the tibial tubercle and just distal to the tibial plateau.

the appropriate nail diameter. If the canal proves too small for the available nail, the surgeon may elect to undertake external fixation instead.

The intramedullary nail is then inserted. The progress of the insertion is checked with the use of an image intensifier. Care is taken to ensure that the nail remains centered in the intramedullary canal distally and that the fracture reduction is maintained. In distal fractures, failure to drive the nail into the center of the distal fragment will lead to malalignment in the frontal plane. After nail insertion, the tibia is examined fluoroscopically in both anteroposterior and lateral planes to check alignment and to make sure that it is not distracted or shortened at the fracture site.

Interlocking

Proximal interlocking is accomplished with the proximal locking-bolt guide and is usually straightforward. We prefer the freehand technique for the distal interlocks. The first step is to position the C arm so that each distal interlock hole is seen as a perfect circle. This ensures that the C-arm beam is parallel to the intended line for screw placement. Either a Kirschner wire or an awl can be used to establish a starter hole for the drill. The position of the point of the Kirschner wire over the interlocking hole is verified with the image intensifier. Alternatively, an awl can be placed in line with the center of the interlocking hole. The awl is then placed parallel to the beam of the C arm. The awl is tapped into the bone with a mallet to establish a starter hole for a drill. A hole of appropriate size is drilled through the medial cortex. The position of the drill in the interlock hole in the intramedullary rod is verified with the image intensifier before drilling through the opposite cortex. The distal interlocking bolt is then inserted.

We statically interlock virtually all open tibial fractures that are treated with an intramedullary nail. Rotational alignment must be checked before completion of the static interlocking. If there is distraction of the fracture site, the proximal locks are placed and the heel is supported while the nail is driven in farther. This will close the gap at the fracture site. Alternatively, distal interlocking is done after the rod is overinserted. The tibia is supported, and the nail is hammered retrograde to close the gap at the fracture. If there is no distraction, we usually perform proximal interlocking before distal interlocking, so that the knee can be fully extended.

Most devices have two distal interlock holes. We prefer to use both. It is important to confirm that the bolts pass through the interlocking holes of the intramedullary rod. It is also important that the distal bolts completely penetrate the lateral cortex; this will make removal of the bolts simple if they break.

Early Postfixation Evaluation

After the nail has been inserted, compartment pressure measurements are taken if there is any clinical suspicion of elevated pressures. Open tibial fractures are as susceptible to compartment syndrome as closed tibial fractures are. A handheld pressure monitor is used to assess the compartment pressure of all four fascial compartments of the leg. If the pressures are elevated, a complete four-compartment fasciotomy is done through two incisions.

After the fracture has been stabilized, we obtain an intraoperative consultation with the microvascular or soft-tissue surgeon if soft-tissue coverage might be required. In severe open tibial fractures, soft-tissue coverage in the first 5 to 7 days after injury has been shown to result in a decreased rate of infection and nonunion.[21,22] Early consultation of the surgeon who will perform the tissue transfer facilitates surgical management.

The soft-tissue wounds from the injury are not closed. A synthetic, biologically inert membrane is applied to all wounds, and the limb is then placed in a sterile bulky dressing. Alternatively, antibiotic-impregnated polymethyl methacrylate beads are placed in the soft-tissue defect, and the wound is covered with an adhesive plastic film. The foot and ankle are splinted to avoid an equinus contracture and prevent motion of the injured soft tissues.

Adjunctive Antibiotic Therapy

Antibiotics are begun in the emergency room and are continued for 24 hours after initial surgical treatment. The patient's tetanus status is also determined in the emergency room, and the antibody level is supplemented as needed. Antibiotics are restarted preoperatively for each subsequent wound manipulation and continued for 24 hours.

Postoperative Management

The patient is returned to the operating room every 24 to 48 hours after the injury for a repeat evaluation and debridement until the wound is stable. At each evaluation, irrigation with 10 L of fluid is repeated. Dressings and splints are reapplied.

The wound is treated by delayed primary closure, covered with a split-thickness skin graft, or closed with a tissue transfer. We prefer to have the wound closed by 5 to 7 days after injury. We believe that initial aggressive debridement permits early closure or reconstruction of the soft tissues by day 5.

Once the swelling has diminished and the soft tissues are stable, the patient is mobilized. Protected toe-touch weight-bearing is permitted in most cases. Weight-bearing is increased when callus is noted on follow-up radiographs. Active early motion of the knee and ankle is encouraged, but muscle strengthening does not begin until bridging callus is observed.

Complications

Nonreamed tibial nails have a small diameter (8 to 10 mm). The locking bolts or screws, of necessity, are small as well. Consequently, the nails and locking bolts have a greater chance of failure than reamed nails and their larger bolts do. The reported rate of breakage for the nails is 0% to 6%, and that for the locking bolts is 4%.[14,18,19] Failure of the nails occurs most often with delayed union or nonunion of distal-third tibial fractures. This is particularly a problem with solid nonreamed nails because the distal nail fragment is difficult to remove. The solution to this problem is prevention. We recommend changing from a nonreamed nail to a larger nail early when the fracture does not show evidence of progression to union.

Failure of the locking bolts has not resulted in loss of reduction,[18,19] but broken locking bolts can make nail removal difficult. We make sure that both the proximal and the distal interlocking bolts penetrate the far cortex enough to facilitate removal in the future should the bolts break.

Infection, malunion, delayed union, and nonunion are the complications that raise the greatest concern when treating severe open tibial-shaft fractures. Early superficial or deep infections are treated aggressively with surgical debridement and antibiotics to prevent progression of an early infection to chronic osteomyelitis or an infected nonunion.

Malunion is rare with a well-placed statically locked nail but occurs more often with dynamically locked or unlocked nails. The cortical interference fit with a nonreamed nail is often not stable enough to maintain reduction without interlocking bolts. For this reason, we recommend statically locking virtually all nonreamed intramedullary devices. Proximal-third shaft fractures are notorious for malunion. Rotational malunion is more common than one might expect. Anatomic reduction performed initially avoids both of these problems.

Fractures that demonstrate delay in union or nonunion are treated by replacing the nonreamed nail with a dynamically locked reamed nail or by using posterolateral bone grafting. After the soft-tissue envelope has stabilized and healed, reamed nailing seems reasonable. In our experience to date, dynamization of a statically locked nonreamed nail alone does not appear to promote progression to union and has the drawback that it may lead to loss of reduction and malunion.

Results

There are few reports on the use of the nonreamed interlocking nail for open tibial-shaft fractures.[14-19] In a study of 46 patients, Anglen et al[14] reported an infection rate of 4% (2 of 46, both with grade IIIb injuries), a nonunion rate of 2% (1/46), and a delayed union rate of 37% (17/46, 11 of whom required additional surgery). Agnew et al[16] found a screw breakage rate of 4% (8 of 200 screws). Reduction was lost as a result of hardware failure in 1 of their 50 patients (2%), and 15 additional procedures were required to achieve a union rate of 100%. In a prospective study comparing nonreamed nails with external fixation in grade IIIb tibial-shaft fractures, Tornetta et al[15] found one deep infection (incidence of 7%) in the nail group and one deep infection (7%) and three pin-tract infections (21%) in the external-fixator group. In a study of 31 patients, Boynton et al[19] found a union rate of 100%; a delayed union rate of 10% (3/31); loss of reduction in 2 patients (6%), both with unlocked nails; an infection rate of 6% (2 of 31 patients, both with grade IIIb injuries); nail breakage in 3% (1/31); and four screws that broke.

In a prospective study comparing nonreamed nails with external fixation in the treatment of open tibial fractures, Santoro et al[17] found a nonunion rate of 3% in the 33 patients in the nonreamed nail group, a malunion rate of 9%, an infection rate of 3%, nail breakage in 6%, and two screws that broke. In 50 fractures treated with nonreamed nails, Whittle et al[18] found a nonunion rate of 4%, an infection rate of 8% (four injuries, all grade III), nail breakage in 6%, and five screws that broke.

Based on these reports and our own experience, we believe that the use of a nonreamed nail for the stabilization of tibial fractures with severe soft-tissue injury can achieve results comparable with or better than those obtained with the use of an external fixator.

A word of caution is advisable, however. The results reported for the use of the statically locked nonreamed tibial nail depend not only on the nail as a method of biologic fixation but also on the soft-tissue management. Aggressive debridement and early soft-tissue reconstruction are as important to the end result as the method of fixation used to stabilize the bone.

Summary

Nonreamed interlocking tibial nails provide better fixation in comminuted fractures than flexible or noninterlocking intramedullary nails, such as Ender and Lottes nails. The use of nonreamed nails does not entail the possibility of the pin-site problems that can limit the useful life of an external fixator. Not having to ream the intramedullary canal to insert these nails is a theoretical advantage because less cortical blood flow is sacrificed.

Changing to a reamed nail or early posterolateral bone grafting when the fracture shows no progress toward union and the soft-tissue envelope has healed can prevent hardware failure.

Nonreamed interlocking intramedullary nailing has proved to be an excellent technique for the treatment of the vast majority of severe open tibial-shaft fractures in our hands. However, accurate comparison with the various treatment options reported in the literature is open to question because current fracture classification systems depend on subjective judgments.

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