Feature Article
Exchange Nailing for Failure of Initially Rodded Tibial Shaft Fractures
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ABSTRACT
This retrospective study evaluated 32 patients who underwent exchange nailing for initially rodded nonunited tibial shaft fractures during a 5-year period. High-energy trauma accounted for 22 fractures; 19 fractures were open. An unreamed nail was initially used to stabilize all but 2 fractures. Implant failure occurred in 31% of fractures, mostly in distal-third fractures, with a failure rate of 34%. Average time from injury to exchange nailing was 36 weeks (range: 6-148 weeks) and consisted of closed reamed nailing and fibulectomy in 27 cases.

Healing occurred an average of 20 weeks (range: 6-47 weeks) after postexchange nailing in 27 (84%) fractures. Four (12.5%) fractures healed after additional procedures. There was 1 persistent nonunion. Factors leading to delay in union time included comminution, healed fibula, and proximal location. Multiple regression analysis using survival data at P<.05 showed a significant correlation between fracture configuration and fixation method (locked, dynamic, and unlocked) on time to union.

Exchange nailing with closed reaming and fibulectomy is a viable option for treating failures of primarily nailed tibial fractures. Increased stability and stimulation of arrested bone healing may account for the good outcome. The advantages of repeat reamed nailing should be weighed against the possible adverse effect of reaming on bone vascularity.

Over the past 20 years, management of tibial shaft fractures has become increasingly more aggressive. Surgical stabilization options include external fixation, plating, intramedullary devices, or sequential combinations. However, surgeons have been relying more on intramedullary fixation because of the predictable outcome in regard to fracture union and alignment.

Recent advances in the design of intramedullary nails have led to the development of interlocking devices, which can be fluoroscopically inserted with negligible disruption of the soft-tissue sleeve. The indications for insertion have been extended to include comminuted fractures as well as more proximal and distal fractures, which otherwise would have been treated by other modalities associated with increased complications.

Interlocking nails afford excellent rotational control, prevent nail migration and fracture collapse, stabilize the soft-tissue envelope, and thus allow early mobilization and weight bearing. Immediate nailing of grade I-III open tibial fractures has been advocated by some authors who report an infection rate (3%-14%) comparable to more conservative treatments. However, reaming does increase the incidence of infection and is not recommended during the initial treatment of grade II and III open fractures.

When nonunion occurs, secondary intramedullary nailing with reaming has been reported to have a 94%-100% success rate in noninfected cases. The procedure may be performed closed or open with or without bone grafting—studies report no difference in union with either approach.

Court-Brown et al defined exchange nailing in tibial nonunions as removal of

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the intramedullary nail, reaming of the intramedullary canal by at least one additional millimeter, and the insertion of a larger nail. Several series of tibial nonunion, initially treated by various methods and undergoing secondary nailing, have been reported. Templeman et al² reported on a large series of exchange nailing to treat aseptic nonunions that occurred after unreamed nailing. Correlation of time to union with multivariate factors was not performed.

This article analyzes the factors affecting development of a nonunion and successful treatment outcome.

**MATERIALS AND METHODS**

The charts and radiographs of 34 patients (23 men and 9 women) treated during a 5-year period for failed union of tibial fractures initially treated with intramedullary rods were reviewed. Two patients subsequently were lost to follow-up, leaving 32 patients available for evaluation. Union was defined as pain-free weight bearing without immobilization and radiographic cortical bridging in at least two perpendicular planes. Failure was defined as delayed union (absence of union 4 months after the initial nailing), nonunion (absence of union 6 months after the initial nailing), and implant failure or gross instability within the initial weight-bearing period of 4 months, which would most likely result in nonunion.

Average follow-up from the time of injury was 24.5 months (range: 0-60 months), and follow-up from the time of exchange nailing averaged 20 months (range: 6-54 months). Average patient age at the time of injury was 35 years (range: 18-86 years). Fractures were evenly distributed between right and left legs.

Mechanisms of injury were motor vehicle/pedestrian accidents (10), falls (8), motorcycle accidents (6), motor vehicle driver/passerenger accidents (5), motor vehicle/bicycle accidents (1), sports injuries (1), and impact by falling object (1). Fourteen (44%) patients had associated musculoskeletal injuries, and 4 (12.5%) patients had multisystemic injuries.

Soft-tissue injuries were classified according to Gustilo et al.¹,² Nineteen (60%) fractures were open and 13 (40%) were closed. There were 6 grade I, 10 grade II, and 3 grade III (2 type IIIA and 1 type IIIB) open fractures. Open fractures were treated by a protocol that included debridement in the first 6 hours and rod insertion. Delayed primary closure or soft-tissue coverage was performed when indicated. Three patients required a local muscle flap (1 grade III and 2 grade II). The remaining patients required delayed primary closure and skin grafting within 5 days of the injury. Indications for intramedullary nailing of closed fractures were instability due to comminution or proximity to metaphyseal ends (4), compartment syndrome (4), polytrauma (3), and failure of closed reduction (2).

Fracture configuration was classified radiographically using the AO system. There were 13 type A, 12 type B, and 7 type C. Subclassification for direct and indirect injury mechanism showed 9 class I, 14 class 2, and 9 class 3. There was a predominance of comminuted fractures (60%) and direct injury mechanism (72%). All had a fractured fibula, and 3 were plated because of lateral malleolar involvement.

The initial choice of nail depended on the surgeon’s preference and experience. Twenty (62%) fractures were treated with solid interlocking nails. Eleven were static, 4 dynamic, and 5 unlocked. Static nails were locked both proximally and distally. Dynamic nails had screws applied only on one end (proximal or distal). Unlocked nails had no transfixion screws. Eight patients had a Lottes nail, and 2 patients had Ender rods or a Broekers-Wills nail. Both Broekers-Wills nails had proximal interlocking screws and were considered dynamic nails. All but 2 nails were unreamed, and all open fractures were unreamed.

Twelve patients underwent additional procedure an average of 21 weeks after injury to promote union. These included dynamization by removal of distal or proximal interlocking screws (4); electrical stimulation (3); posterolateral bone grafting (2); fibulectomy with dynamization (2); and fibulectomy, dynamization, and electrical stimulation (1) (Figure 1).

Complications after initial rodding included four broken rods, two broken distal screws, one broken proximal and distal screw, and three bent rods. The overall implant failure rate was 34%. All screw failures, two of the broken rods and two of the bent rods occurred in distal-third fractures. Three broken rods and one bent rod were in middle-third fractures. All of the bent rods were Lottes nails.

Three patients had proximal implant migration with knee pain, three had postoperative compartment syndrome, and one developed a superficial infection controlled with dressing changes and antibiotics. There was one deep infection (Staphylococcus aureus and Enterobacter) that required debridement and intravenous antibiotics for 6 weeks. The infection was controlled but the fracture remained united. One patient had a deep vein thrombosis that responded to anticoagulation therapy.

Average time to exchange nailing was 36 weeks (range: 6-148 weeks). Four underwent exchange nailing <4 months after initial rodding. Of these, 2 had implant failures (1 broken rod at the distal screw hole and 1 bent rod), and 2 had instability on stress tests and weight bearing. Of the remaining 28 patients, 3 had delayed union and 25 had nonunion. There were no active infections at the time of reaming.

All patients had reaming of the intramedullary canal to a diameter 2-3 mm wider than the initial nail. All patients received a first-generation cephalosporin perioperatively, which was continued 48 hours postoperatively.

**RESULTS**

**Union**

Twenty-seven (84%) of 32 fractures united an average of 20 weeks (range: 6-47 weeks) after exchange nailing. Four
(12.5%) fractures eventually healed after additional procedures. One had a posterolateral bone grafting 30 weeks after exchange nailing and united 26 weeks later. Two underwent dynamization with removal of the distal interlocking screw an average of 24 weeks after secondary nailing, with healing 24 weeks later. The fourth patient had a closed fracture treated with two exchange nailings. The second exchange was performed 13 months after the first for a broken rod at the level of a hypertrophic union. The fracture united 23 months after the second exchange. One patient with a comminuted closed fracture initially treated with a reamed static nail had persistent nonunion. Despite dynamization, a nonunion developed 2 months postinjury. Exchange nailing with a dynamized nail was performed 22 weeks after the injury. At 34 weeks postexchange, the patient still had pain on weight bearing.

Multiple regression analysis using survival data showed statistically significant correlation of time to union with time between initial injury and exchange nailing, fracture configuration, and type of fixation (ie, static, dynamic, or unlocked) at \( P<0.05 \). Average time to union postexchange for delayed (3) and nonunion (25) cases was 18 and 19 weeks, respectively, with 4 failed cases. Four patients underwent the exchange <4 months after initial rodding with an average healing time of 36 weeks with 1 failure.

Thirteen AO type A fractures with simple noncomminuted configuration healed an average of 16 weeks postexchange with 1 failure. Twelve type B fractures united at 24 weeks with 3 failures, and seven type C fractures healed at 21 weeks with 1 failure. Both type B and C fractures had comminuted fracture configuration.

Patients with unlocked nails (17) healed an average of 19 weeks postexchange compared to 22 weeks for both statically (6) and dynamically (9) locked nails. Additional procedures were higher in static nailing (44%) compared to dynamic (12.5%) and unlocked (11%) nails.

For statistical analysis, closed and group I fractures were compared with grade II and III fractures with times to union of 20 weeks and 21 weeks postexchange, respectively. The two groups were not statistically significant.

Patients with a nonunited fibula (27), via fibulotomy or nonunion, were grouped together and compared with patients whose fibulas were healed and intact (3). Nonunited fibulas had an average union time of 20 weeks postexchange compared to intact fibulas, which healed 24 weeks postexchange. These groups also were not statistically significant.

Fifteen distal-third fractures healed an average of 21 weeks postexchange, and there were no nonunions. Three proximal-third fractures had an average time to union of 26 weeks with no failures. Ten middle-third fractures had an average union time of 20 weeks, but there were 4 reoperations in this subgroup. Four segmental fractures had an average time to union of 12 weeks, with 1 needing additional operations. Differences among these groups were not statistically significant.

**Malunion and Malrotation**

Malunion was defined as varus or valgus angulation >5°, anteroposterior angulation >10°, or shortening >1 cm. Malrotation was evaluated by comparing the amount of internal and external rotation with the uninjured extremity.

There were five cases of malunion before the exchange nailing. Two had a varus/valgus angulation of 5°-10°, two had an AP angulation of 10°-20°, and one had a posterior and valgus angulation of 15° and 10°, respectively. One exchange nailing underwent open osteotomy and freshening of the fracture line. The remaining cases were corrected by closed manipulation under fluoroscopic guidance while the new nail was inserted. Four fractures distracted 3-5 mm, and the remaining case was shortened <1 cm prior to exchange nailing. Patients with distracted fracture fragments underwent unlocked or dynamized nailing with good impaction of the fracture ends. On union, there was one malunited fracture in a distal fracture that was not locked and united in 15° of varus and 30° of posterior angulation.
With an intact fibula, there were no malunions.

**Postexchange Complications**

There was one deep infection (*S. aureus*), which resolved with debridement and intravenous antibiotics. One patient developed an anterior compartment syndrome necessitating fasciectomy. Another patient had persistent ankle pain secondary to a sacral injury causing peroneal and sciatic nerve dysfunction. The only case of implant failure was a broken rod that required a second exchange nailing. There was one malunion and no malrotation postexchange.

**DISCUSSION**

Many factors influence the treatment, prognosis, and outcome of tibial shaft fractures. Johner and Wruhs analyzed 291 tibial fractures treated by AO/ASIF rigid internal fixation. Four factors were considered for increased nonunion rates: 1) mechanism of injury, 2) degree of comminution, 3) soft-tissue injury, and 4) initial and final displacement. Nonunion is particularly problematic after open fracture. Adequate debridement and early soft-tissue coverage is necessary for uncomplicated secondary osseous reconstruction. In the present study, 60% of fractures were open and 72% were produced by high-energy impact. This may have contributed to the high rate of initial failure, delayed union, and nonunion.

Intramedullary nailing for tibial fractures has the advantage of closed application with fluoroscopic assistance plus the benefits of stable fixation allowing early weight bearing. Impaction along the fracture ends produces better control of the fragments since it acts as a stress-sharpening device. Stability is provided by elastic impingement on the endosteal surface of the tibia or by three-point fixation.

Because the interference fit occurs mostly in the isthmus, reaming effectively enlarges the isthmus making more fractures amenable to this treatment. The theoretical possibility that interference with the blood supply by combined reaming and periosteal stripping would delay union has not materialized.

Hamza et al. reported 56 fractures (28 closed and 28 open) treated by open nailing with reaming and bone grafting with 98% fair to excellent results. Puno et al. compared reamed intramedullary nailing with closed reduction in casts. Union occurred in 98.3% with a 3.3% infection rate with no malunions for 60 closed and grade I fractures, while casting resulted in 90% union, 4.3% malunion, and 1.4% infection rates in 100 grade I and II fractures.

The introduction of interlocking nails broadened the indications for intramedullary fixation. Fractures from just below the tibial tubercle to 3 cm above the plafond are amenable to this treatment. The initial interlocking nails were inserted with reaming. In several series of treatment of closed and grade I-II open fractures, rates were reported to be 86%-98% for union, 2.4%-6.4% for malunion, and 2%-5.3% for infection. Average time to union was 15-16 weeks.

Rhinelander showed reaming of the diaphysis of long bones eliminates endosteal blood, which supplies the inner third of the cortex. In open fractures, there is additional devascularization from the stripping of the periosseous and soft tissues, aggravating the effects of reaming. Chapman stated that during this period of devascularization, the risk of infection is high. Delayed closed nailing with reaming for grade I and mild grade II fractures was recommended; reaming was not recommended for severe grade II and all grade III fractures.

Infections in fracture sites with reaming and interlocking nailing of grade II and III open fractures were reported by Bone et al. and Hamza et al. Reaming of severe open fractures also was discouraged.

In contrast, Court-Brown et al. recommended acute nailing with reaming in open grade II and III fractures. They evaluated 14 grade II and 27 grade III fractures; average time to union was 23.5 and 38.2 weeks, respectively.

The infection rate of 9.8% compared favorably to those of Bone et al. and Hamza et al.

Unreamed interlocking nailing is advocated to minimize the risk of infection from reaming. Length, alignment, and rotation are controlled; the soft-tissue sleeve is stabilized; and endosteal blood supply is maintained. Whittle et al. reported this technique in 50 cases, 68% of which were grade III fractures. At an average of 7 months, 96% of the fractures were united; 18 fractures needed additional procedures to promote union. The 8% infection rate was comparable to reports of nonlocking nailing without reaming for treatment of open fractures.

Reimer et al. reported 74 closed and open tibial fractures in blunt polytrauma patients treated with unreamed interlocking nails and analyzed outcomes in relation to additional procedures required to achieve union. They noted the number of reconstructive procedures to achieve union was a more sensitive indicator of the difficulty in achieving union than was time to union. Statistically significant factors determining reoperation rates include locking mode (static nails three to six times the relative risk for reoperation than dynamic nails), comminution (Winquist I and II had a reoperation rate of 24% versus 53% for grade II and III and segmental fractures), and type of nail alloy (titanium alloy nails had a 2% failure rate versus 25% for stainless steel). Twenty-six secondary operations were required to achieve union and alignment.

In the present study, 30 of 32 cases underwent unreamed nailing initially. Twelve patients had additional procedures (dynamization, fibulectomy, and bone exchange) before the exchange. The reoperation rate was 44% in static nailing compared to 12.5% and 11% for dynamic and unlocked nails, respectively. Average time to healing for AO type A fractures was 16 weeks compared to 24 and 21 weeks for type B and C fractures, respectively.

Intramedullary nailing for nonunion
of tibial fractures initially treated by various methods has been reported. Time to nailing varies from 2 months to 19 years after injury, resulting in union rates of 62.5%-100%. Lower rates were seen with infected pseudoarthrosis, but infection is not a contraindication to a successful outcome. Reaming with the insertion of bigger nails was done in all series; the added stability provided by the bigger nail was a key factor in achieving union. The use of open techniques was recommended by Johnson and Marder to permit correction of the deformity and freshening of fracture lines. Closed treatment, which preserves the soft-tissue sleeve and avoids devascularization, produced comparable union rates.

In the present study, the alignment of the fracture preexchage was maintained by the initial nail, and there was no difficulty in closed manipulation during the exchange nailing. Thus, this confirms the conclusion of Rosson and Simonis that open procedures should be performed only in cases where closed correction of the deformity is not possible.

Closed exchange nailing without fibulectomy for aseptic nonunions following unreamed tibial nailing has been reported by Templeman et al. Of 78 unreamed nailing, 27 fractures went on to nonunion or delayed union. On exchange nailing an average of 5 months after initial injury, 25 of the 27 fractures united. However, exchange nailing was not recommended for fractures with >30% bone loss or in prior grade III-B open fractures.

The routine use of bone grafting also was advocated by Johnson and Marder. Recent studies have shown bone grafting is essential only for fractures with bone loss >25%. Only two fractures in this study had open correction of angulation and bone grafting. Although they united earlier than cases treated closed and without bone graft, the numbers are too small for statistical comparison (Figure 2).

In the presence of an unstable fracture configuration, static nailing is needed to maintain length. Static nailing also is indicated for distal- and proximal-third fractures. In a series of 28 grade IIIB fractures treated by static interlocking nails without dynamization, all but 4 fractures healed at an average 5.8 months. Rosson and Simonis advocated the use of the statically locked nail when indicated with dynamization in 2-3 months.

In the present study, four cases of distraction in statically locked nails were changed to dynamic nails on exchange. Two of the six statically locked exchange nailing had to be dynamized to achieve union. We recommend the use of unlocked or dynamic nails on exchange nailing for diaphyseal fractures with stable lengths. Metaphyseal and comminuted fractures that require static nailing can be dynamized once callus formation is evident at 16-20 weeks. In no case of secondarily dynamized nail was malunion noted because the larger diameter nail has more contact with the endosteal cortex.

The presence of an intact fibula has been shown to lead to a higher incidence of nonunion and malunion both biomechanically and clinically. Fibulectomy during secondary nailing is routine unless shortening is anticipated. Fibulectomy also allows for correction of angulation and translation by closed manipulation. The present study showed a longer healing time for cases with a healed fibula (24 weeks) compared to those with a nonunited fibula (20 weeks). Log rank testing, however, did not show statistical significance (P=.062).

Once properly reconstructed and free of infection, open fractures have the same union rates as closed fractures on secondary nailing. Closed nailing may be instrumental in maintaining good vascularity of the fracture sites. Six months were allowed for the flaps to heal before another procedure was performed on open fractures with soft-tissue loss. Closed and grade I fractures are grouped together to compare previous studies. The union time and rate for this group is not significantly different from grade II and III fractures (P=.77). The single case of infection in this series occurred in a closed fracture that had two exchange nailing.
Almost half of the cases were distal-third fractures, and an additional four cases were segmental fractures with nonunion of the distal fracture site. Sixty percent of initial implant failures were in distal-third fractures. Following exchange nailing, all distal-third fractures healed compared with 40% of middle-third and 25% of segmental fractures requiring additional procedures. All proximal-third fractures healed after the exchange. Distal fractures healed at an average of 21 weeks, middle-third fractures at 20 weeks, segmental fractures at 12 weeks, and proximal-third fractures at 26 weeks.

Several mechanisms have been proposed to account for the high union rates in patients treated by secondary nailing. The intramedullary nail is a load-sharing device that allows impaction on weight bearing without angular stress. The latent osteogenic potential of the fibrous callus will then be stimulated by the stability afforded by a larger nail. The reamings also serve as autogenous bone grafts. On the other hand, Alho et al.16,17 believe osteogenic stimulation is caused by the trauma of reaming rather than the graft. Miller et al.18 proposed the reinjury of reaming reestablished medullary vascular continuity during repair. We believe the added stability of the larger nail and the renewed cortical revascularization from ingrowth of periosteal vessels, as seen from the study of Rhinelander,8 are responsible for providing a more suitable environment for fracture repair.

CONCLUSION
Closed exchange nailing with fibulocutomy is a reasonable option for the treatment of failed initially nailed tibial fractures. Bone grafting is reserved for fractures with significant bone loss, and open nailing is performed when closed manipulation and angulatory correction is not possible. Dynamization of statically locked nails should be considered once there is relative stability. Although there was a predominance of distal third fractures, this location did not preclude a successful treatment outcome.

REFERENCES