Ilizarov Compression Over a Nail for Aseptic Femoral Nonunions That Have Failed Exchange Nailing: A Report of Five Cases

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Objective: To evaluate a new operative treatment of femoral nonunion following failed exchange nailing.

Design: Retrospective review, consecutive series.

Setting: Office-based orthopaedic practice.

Patients: Five consecutive patients (ages 31–67 years) were referred in with a femoral nonunion following exchange nailing an average of 28 months (range 11–55) after the initial traumatic injury. The patients had undergone an average of 5 (range 2–8) previous surgeries on the femur. No patient had signs or history of bone infection or segmental bone loss at presentation. All patients had diaphyseal or diaphyseal-metaphyseal oligotrophic nonunions and had failed an average of 2 (range 1–3) previous exchange nailings.

Intervention: Slow compression (0.25 to 0.50 mm per day) of the nonunion site over a new, smaller diameter nail using an Ilizarov external fixator.

Main Outcomes Measurements: Clinical and radiographic evidence of bone union, ambulation, pain, residual deformity, or shortening.

Results: All nonunions healed without the need for further nonunion surgery. The external fixator was removed at an average of 133 days (range 86–238 days). No deep infections occurred in any patient. All patients experienced some degree of pin site irritation. At the most recent follow-up (average 45 months; range 12–75 months), all patients had improved their functional ambulatory status and had discontinued or decreased the use of assistive devices to walk. All patients were full weight bearing. Average pain, as rated on a 0 to 10 Visual Analogue Scale, decreased from 8 of 10 before treatment to 1 of 10 after treatment. No patient experienced a clinically significant worsening of leg length discrepancy.

Conclusions: Slow compression over an intramedullary nail using external fixation successfully promotes the healing of problematic femoral nonunions that have failed one or more prior exchange nailings.

Key Words: femur, nonunion, external fixation, Ilizarov, intramedullary nail, compression, exchange nailing

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Nonunion following intramedullary nailing of a femur fracture is uncommon. The rate of nonunion following intramedullary nail fixation for a femur fracture is generally believed to be 2% or less.[1–3] Currently, the standard treatment of a femoral nonunion that has failed initial intramedullary nail fixation is exchange nailing.[4–7] Although repeat exchange nailing of the femur is effective in certain patients,[5,7] this strategy is not always successful.[8] For example, Koval et al have reported very poor results among a series of patients who underwent exchange nailing of the supracondylar femoral region.[9] Treatment options are limited for patients with femoral nonunions that have failed exchange nailing and no consensus exists regarding the optimal treatment of this uncommon and difficult clinical entity.

The current report presents a consecutive series of five patients with femoral nonunion who had failed one or more prior exchange nailings. We describe the application of slow compression over an intramedullary nail using Ilizarov external fixation to successfully heal recalcitrant femoral nonunions that have failed prior exchange nailing.

MATERIALS AND METHODS

The patients included in this study had aseptic oligotrophic nonunions of the femoral diaphysis or of the diaphyseal-metaphyseal junction that had failed one or more prior exchange nailings. The study group was selected from a larger

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series of patients with femoral nonunions who were referred in to our center between 1995 and 2001.

During this period, 16 consecutive patients with aseptic femoral nonunions of the diaphysis or diaphyseal-metaphyseal junction who had previously been treated with intramedullary nail fixation were referred in. Eleven patients who had received only one intramedullary nail for treatment of the index fracture underwent exchange nailing.

Five of the 16 patients had failed one or more prior exchange nailings. These patients were treated at our facility using slow compression over a nail using external fixation and comprise the study group of the current investigation. The average age of the 5 patients at the time of presentation was 49 years (age range 31–67 years). These patients were referred in to our center at an average of 28 months (range 11–55 months) after the initial traumatic injury. This study was exempt from institutional review and informed consent requirements because it involved only surveys and study of existing data and records. All patients were informed that the survey data were for use in a study and that their responses would remain confidential.

The study group included two women and three men (Table 1). Two of the five original injuries had been open femur fractures (Patient 1, Gustilo-Anderson Type IIIA; and Patient 3, Gustilo-Anderson Type IIIB), and three had been closed femur fractures.

The patients had undergone an average of 5 (range 2–8) previous trips to the operating room to receive an average of 6 (range 3–9) surgical procedures (Table 1). These patients had failed an average of 2 (range 1–3) previous exchange nailings.

At the time of presentation, laboratory results, imaging studies (plain radiographs and computed tomography [CT]), and clinical examination results were not consistent with infection. No patient had a history of bone infection associated with the injury. Radiographs showed an oligotrophic nonunion in all five patients. There was very little callus formation and no evidence of bridging at any of the cortices.

Table 1 lists the comorbidities that were observed among these patients. None of the patients had been injured at work. None of the patients had pending litigation regarding their injury. Patient 4 was divorced and living with her two teenage children (ages 14 and 18 years). She had many family members who lived near her home and who provided assistance for her as necessary. All of the other patients were married and living with their spouses and had other adult family members living in the immediate area.

Several of the patients had a leg length discrepancy upon presentation. All patients elected to undergo treatment with slow compression over a nail using external fixation without any attempt to correct leg length discrepancy. The average preoperative leg length discrepancy was 13 mm (range 0–30 mm) as measured from the center of the femoral head to the center of

TABLE 1. Clinical Profile of Five Patients With Oligotrophic Femoral Nonunions Treated With Slow Compression Over a Nail Using External Fixation

Patient No.	Gender	Age at Presentation (yrs)	Time from Injury to Presentation (mos)	Location of Femoral Nonunion	Previous Trips to Operating Room	No. and Type of Previous Surgical Procedures	Comorbidities
1	Female	51	55	Distal diaphysis	8	9 (A_R, B, B, B, C, D, E, E, G)	Hypothyroidism, smoking (60 pack-yrs), major depression
2	Male	67	30	Middle diaphysis	6	7 (A_A, B, B, C, C, D, H)	Hypertension, emphysema, history of bladder cancer, previous smoking (70 pack-yrs)
3	Male	57	18	Distal diaphyseal-metaphyseal junction	5	9 (A_R, B, B, C, D, D, E, F, F)	Type II diabetes mellitus, chronic hepatitis, coronary artery disease
4	Female	38	11	Distal diaphyseal-metaphyseal junction	3	3 (A_R, B, C)	Hypertension, anemia, bipolar psychiatric disorder
5	Male	31	24	Middle diaphysis	2	3 (A_A, B, C)	None
Averages		49	28		5	6	

A_A, statically locked antegrade intramedullary nail (initial fracture stabilization); A_R, statically locked retrograde intramedullary nail (initial fracture stabilization); B, statically locked exchange nail; C, dynamization of nail; D, open bone graft (allograft or autograft); E, incision and drainage, debridement; F, soft-tissue reconstruction; G, replace broken distal interlocking screws; H, placement of internal bone stimulator.

the ankle joint on a standing bilateral anteroposterior 51-inch alignment view.[10]

At the time of presentation, one patient was unable to bear weight on the affected lower extremity and was confined to a wheelchair. Four patients were able to bear partial body weight and required crutches or a walker to ambulate.

The indications for slow compression over a nail using external fixation for the treatment of these patients with femoral nonunion were as follows. First, all patients had a nonunion of the femoral diaphysis or diaphyseal-metaphyseal junction that had failed treatment with one or more prior exchange nailings. Second, no patient had any evidence or history of bone infection. Third, no patient had a segmental bone defect associated with the nonunion. Fourth, the nonunion pattern in all patients was such that clinically significant femoral shortening was not likely to occur during compression. Standard exclusion criteria for surgical treatment or general anesthesia also applied, such as an unstable medical status or existence of comorbidities that were contraindications for operative treatment. None of the original 16 patients presenting with femoral nonunion following intramedullary nailing had been excluded from treatment with slow compression over a nail using external fixation based on social or medical criteria.

The surgical procedure involved removing the retained intramedullary nail and inserting a smaller diameter nail (typically 2 to 3 mm smaller) so that the bone fragments would be able to slide over the nail without interference during slow, gradual compression. The medullary canal was not reamed in any of these cases. The new nail was dynamically locked. A retrograde intramedullary nail was inserted and locked distally in three patients in whom the nonunion site was distal to the midshaft (Patients 1, 3, and 4). An antegrade intramedullary nail was inserted and locked proximally in the two patients whose nonunions were just proximal to the midshaft (Patients 2 and 5).

After placing the smaller diameter intramedullary nail, an Ilizarov external fixator (Smith & Nephew, Memphis, TN) that had been constructed to allow compression was applied to the femur. Placement of an Ilizarov external fixator over an intramedullary nail has been previously described in detail.[11,12] The technique varies depending on whether a retrograde intramedullary nail (nonunion at the distal diaphysis or the diaphyseal-metaphyseal junction; Fig. 1) or an antegrade intramedullary nail (nonunion mid-diaphysis or higher; Fig. 2) is used. In both situations, safe anatomic corridors for the Ilizarov implants (half-pins and thin wires) are determined using radiographs during preoperative planning.

For placement over a retrograde intramedullary nail, four Ilizarov rings are required. Two full rings are placed on the distal femur (distal to the nonunion site), one full ring is placed slightly proximal to the nonunion site, and a femoral arch is placed at the proximal femur. Thin wires are used at the two distal rings. The third ring holds no implants, but serves as a transmission ring linking the proximal and distal frame components. Partially threaded half-pins are used at the most proximal ring. The retrograde intramedullary nail is inserted first, followed by anchoring of the proximal and then the distal Ilizarov rings. The half-pins on the proximal ring are proximal to the retrograde intramedullary nail and are inserted in the usual manner. Thin wires in the two distal rings are inserted around the retrograde nail through the safe anatomic corridors

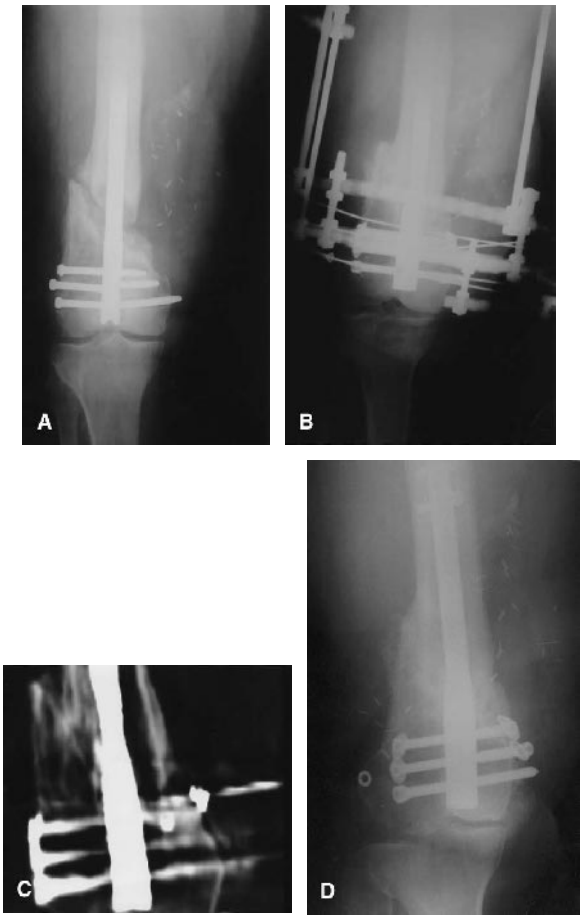

FIGURE 1. A, Presenting anteroposterior radiograph of a 57-year-old man (Patient 3) 18 months after sustaining an open fracture in an auto–pedestrian accident. This patient had undergone nine previous surgical procedures, including two previous exchange nailings, two open bone grafts, and two soft tissue flaps (vascular clips are visible). He was not able to bear full body weight, was using a walker to walk short distances at home, and reported an average pain level of 6 out of 10. B, Radiograph taken on postoperative day 90 showing that the contact between the fracture fragments has improved. Note the bending of the thin wires of the external fixator, indicating a compressive force at the nonunion site. C, CT scan taken on postoperative day 202 showing a cross-sectional area of bridging bone of approximately 25%. The Ilizarov external fixator was removed 36 days after this image was taken. D, Final radiograph 17 months after removal of the Ilizarov external fixator showing solid bony union.

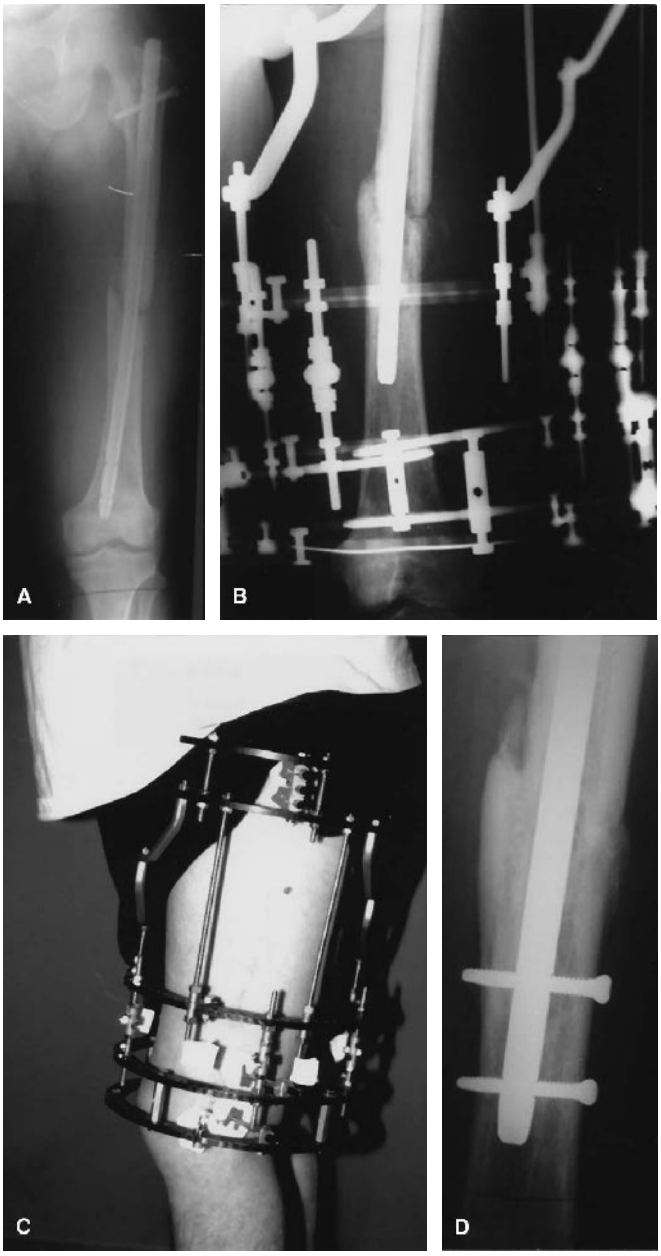

FIGURE 2. A, Presenting anteroposterior radiograph of a 67-year-old man (Patient 2) 30 months after sustaining an open fracture in an automobile accident. This patient had undergone seven previous surgical procedures, including two previous exchange nailings and an open bone graft. He was not able to bear full body weight, was using crutches to walk short distances at home, and reported an average pain level of 8 out of 10. B, Radiograph at postoperative day 75 showing compression over a smaller diameter antegrade intramedullary nail. C, Clinical photograph of the patient in the Ilizarov external fixator. D, Final radiograph 4 months after removal of the Ilizarov external fixator showing solid bony union. The duration of treatment with slow compression over an intramedullary nail using external fixation for this patient was 111 days.

that were identified during preoperative planning. If the nail is contacted during insertion of any of the thin wires, the wire is removed and reinserted at an angle that avoids contact.

For placement over an antegrade intramedullary nail, four Ilizarov rings are required in a construct similar to that used with retrograde nailing. Two full rings are placed on the distal femur (distal to the nonunion site), one ring is placed slightly proximal to the nonunion site, and a femoral arch is placed at the proximal femur. Thin wires are used at the two distal rings, the third ring is a transmission ring, and partially threaded half-pins are used at the most proximal ring. The half-pins for the proximal ring must be inserted around the proximal end of the antegrade nail. The half-pins on the proximal ring are inserted using the Lengthening Over a Nail (LON) device (Smith and Nephew Orthopaedics, Memphis, TN), which is a guide that attaches to the proximal interlocking screw guide. The LON device allows predrilling half-pin sites that are slightly offset to avoid the antegrade intramedullary nail. The thin wires at the two distal rings are distal to the shorter antegrade intramedullary nail and are inserted in the distal femur in the usual fashion.

Postoperative treatment included full weight bearing as tolerated, physical therapy for strength and range of motion exercises, and instruction in daily pin site hygiene. Immediate weight bearing is not only possible due to the stability of construct, but axial loading during ambulation is known to promote bony union using the Ilizarov method.[13]

All patients undergoing slow compression over a nail using external fixation were prescribed 750 mg of oral ciprofloxacin twice daily for the duration of treatment with the Ilizarov external fixator as broad-spectrum prophylactic treatment against infection. At our institution, all other patients undergoing Ilizarov external fixation are not routinely prescribed oral antibiotics. The decision to give prophylactic oral antibiotics for patients was made in consultation with the dedicated musculoskeletal infectious disease specialist because of the potential increased risk of seeding the medullary canal with bacteria when using intramedullary nail fixation and external fixation.[14]

The Ilizarov external fixator was initially used to apply slow, monofocal compression at a rate of 0.25 mm to 0.50 mm per day. Progress of bony contact and bony union was monitored using anteroposterior and lateral radiographs. CT scans were obtained every 45 to 90 days after surgery. The rhythm and rate of compression was gradually decreased during treatment and could be as little as 0.25 mm per week once bony contact had been made and progression of bony union was observed.[15] Compression was maintained until the intramedullary nail was statically locked and the Ilizarov external fixator was removed.

The criteria for bony union as described by Heckman et al[16] were not readily applicable to this patient population. Because these patients heal via direct osteonal healing without

visible callus and via medullary healing and because there is often a significant amount of external fixator apparatus overlying the nonunion site on radiographs, it is often impossible to assess healing on three of four cortices. Therefore, we find the use of CT scan invaluable in assessing these and similar patients. Computed tomography scans were obtained every 45 to 90 days, depending on the progression of bony healing observed. Bony union was defined as bridging of greater than 25% of the cross-sectional area of the nonunion site.[15] Following bridging of greater than 25% of the cross-sectional area of the nonunion site, the intramedullary nail was statically locked and the external fixator was removed in the operating room.

Patient Evaluation

Patients reported their current functional ambulatory status, use of assistive devices for ambulation, weightbearing status, and pain at the most recent follow-up. These were compared with pretreatment values that were obtained at the initial office visit. Pretreatment and posttreatment leg length discrepancies were also compared by measuring from the center of the femoral head to the center of the ankle joint on a standing bilateral anteroposterior 51-inch alignment view.[10]

Functional ambulatory status was classified as Community Ambulator, Household Ambulator, Nonfunctional Ambulator, or Nonambulator, as described by Hoffer et al.[17] A *Community Ambulator* is able to walk indoors and outdoors, with or without crutches or braces, but may use a wheelchair for long trips. A *Household Ambulator* is able to walk only indoors with the use of crutches or braces and uses a wheelchair for some indoor and all outdoor activities. A *Nonfunctional Ambulator* is able to walk in therapy sessions only and uses a wheelchair for transportation. A *Nonambulator* is wheelchair-bound, but is often able to transfer from a chair to a bed.

Weight bearing ability was classified as full weight bearing, partial weight bearing, or non-weight bearing. Weight bearing ability was rated according to a patient's usual function rather than the maximum weight bearing the patient was capable of achieving. Any assistive devices the patients used for walking during typical daily activities were recorded.

Pain was rated on a numerical rating scale from 0 (no pain) to 10 (worst pain imaginable).[18,19] Two measures of pain were reported. Patients rated: 1) the average pain they experienced throughout a typical day; and 2) the maximum pain experienced at any time.

Wilcoxon rank sum tests were used to compare the posttreatment and pretreatment numerical variables. A P value of 0.05 was considered significant.

RESULTS

All five nonunions healed with treatment. All patients were very satisfied with their outcome. Removal of the external fixator occurred at an average of 133 days (range 86–238 days) following application. No unplanned surgical procedures were required; only the initial procedure and the planned procedure to remove the Ilizarov external fixator and statically lock the intramedullary nails were performed. None of the patients developed a deep infection during or after treatment with external fixation. Pin site irritation was noted in all patients. Pin site irritation resolved with several days of sterile whirlpool treatments and reinstruction with regard to pin site hygiene. The average follow up after removal of the external fixator was 45 months (range 12–75 months).

No clinically significant improvement or worsening of leg length discrepancy occurred in any patient. Compared with the average preoperative leg length discrepancy of 13 mm (range 0–30 mm), the leg length discrepancy at the most recent follow up averaged 16 mm (range 0–35 mm). This very small difference was neither a clinically nor a statistically significant change in leg length discrepancy ($P = 0.083$) (Table 2).

Preoperatively, four patients were Household Ambulators and one patient was a Nonambulator. At follow-up, all patients were Community Ambulators (Table 2).

All patients decreased the use of assistive devices to walk. Before treatment, none of the patients were walking without an assistive device and one patient had been confined to a wheelchair. At follow-up, all patients were walking without an assistance device (Table 2).

All patients increased their weight bearing ability after treatment. Before treatment, four patients were partial weight bearing and one patient was non-weight bearing. At follow-up, all patients were able to bear full body weight on their affected leg (Table 2).

Maximum and average pain both decreased significantly ($P = 0.042$). Maximum pain at any time decreased from 9 out of 10 before treatment to 1 out of 10 at follow up (Table 2). Average pain throughout a typical day decreased from 8 out of 10 before treatment to 1 out of 10 after treatment (Table 2). Three of the five patients were experiencing no pain whatsoever at follow-up.

DISCUSSION

Placement of an intramedullary nail is the current standard of care for treatment of fractures of the femoral diaphysis, with success rates greater than 98% in several large series.[1–3] Exchange nailing is often used to treat the uncommon event of femoral nonunion following fracture treatment with an intramedullary nail.[7,20] Several case series have reported union rates exceeding 90% for femoral nonunions treated with exchange nailing,[4,6,20,21] although others have reported lower rates of union.[5,7,8]

Repeat exchange nailing of the femur appears to be effective in promoting bony union among patients who show clinical and radiographic improvement after each successive exchange nailing. Those patients for whom repeat exchange nailing is most often ineffective tend to show little or no clinical or radiographic response to each of the nail exchanges. It is

TABLE 2. Results for Five Patients Treated With Slow Compression Over a Nail Using External Fixation

Patient No.	Ambulation Status		Assistive Device		Weight Bearing Status		Maximum Pain	
	Preop	Follow-up	Preop	Follow-up	Preop	Follow-up	Preop	Follow-up
1	NA	CA	Wheelchair	None	NWB	FWB	10	1
2	HA	CA	Crutches	None	PWB	FWB	8	4
3	HA	CA	Walker	None	PWB	FWB	7	0
4	HA	CA	Crutches	None	PWB	FWB	10	0
5	HA	CA	Crutches	None	PWB	FWB	9	0
Averages							9	1

Patient No.	Follow-up Average Pain		Foreshortening of Involved Leg (mm)		No. Days in External Fixator	No. Months Follow-up
	Preop	Follow-up	Preop	Follow-up		
1	10	0	30	35	127	46
2	8	4	25	30	111	71
3	6	0	0	5	238	24
4	10	0	10	10	105	12
5	7	0	0	0	86	75
Averages	8	1	13	16	133	45

NA, Nonambulator; CA, Community Anbulator; HA, Household Ambulator; NWB, non-weight bearing; FWB, full weight bearing; PWB, partial weight bearing.

unlikely that such patients will ever heal with this technique.[15] All five patients in the present series had undergone at least one exchange nailing and subsequent dynamization. All had oligotrophic nonunions that had not produced any clinical or radiographic evidence of bony healing. For patients who have failed to produce any evidence of bony healing following exchange nailing and dynamization, the placement of additional exchange nails may not be appropriate. Slow compression over a nail using external fixation may be indicated for such patients.

Patients 1, 2, and 3 in the current series demonstrated failed repeat exchange nailing. There had been no evidence of bony healing following the first exchange nail and dynamization in these three patients. The subsequent exchange nails also failed to produce bony union and had resulted in an oligotrophic nonunion. By contrast, Patients 4 and 5 had only received one exchange nail and dynamization, which had also failed to produce evidence of bony union and had resulted in an oligotrophic nonunion.

We prefer to use the Ilizarov external fixator because of its mechanical stability, versatility, and use of tensioned wires, which simplifies implant passage around an intramedullary device. It is possible that this technique might yield equally good results with other types of external fixators, although the authors have no experience with this and therefore cannot recommend it. It is also possible that the in situ nail can be retained rather than inserting a smaller diameter nail if the retained nail permits compression (axial motion of the bone segments).

In the present series, however, there was no evidence of loosening or instability of the exchange nail (such as radiolucency around the nail). To the contrary, the nails appeared to be maintaining the nonunion in distraction in these patients. For instance, Figure 1A shows that two of the three distal interlocking screws of the dynamized exchange nail are broken as a result of weight bearing forces being transmitted through the nail, but the nonunion site clearly remains distracted. Thus, it was felt that a smaller diameter nail was necessary to reliably allow effective Ilizarov compression in these patients.

Others have described various procedures that may be used to treat femoral nonunion following failed exchange nailing. The alternatives include dynamization of the exchange nail, open reduction and internal fixation with plates and screws, and use of various modalities that augment bony healing. Each of these has distinct advantages and disadvantages relative to slow compression over a nail using external fixation.

Dynamization of a statically locked exchange nail can be used to treat femoral nonunion.[7,8,20] In a series of papers, however, Wu, and Wu and Chen, reported that nail dynamization failed to promote bony union in over 40% of their patients.[22,23] Wu concluded that nail dynamization can be used as a first effort to promote bony union, but that high success rates

should not be expected.[22] Slow compression over a nail using the Ilizarov external fixator includes some of the advantages of nail dynamization. The thin wires of the Ilizarov external fixator over a dynamically locked nail allow axial micromotion that stimulates the nonunion site during compression. An important advantage of slow compression over a nail using external fixation is that compression is under the direct control of the treating physician. Nail dynamization does not allow specific and continued control of compression at the nonunion site, which may explain its relatively high failure rate. When it is successful, nail dynamization offers several advantages relative to slow compression over a nail using external fixation. For example, nail dynamization is far less technically demanding and does not require a second trip to the operating room (as is required for frame removal). Also, nail dynamization does not involve wearing an external fixator for several months. All five patients in the present series, however, had failed to produce bony healing after undergoing one or more nail dynamization procedures.

High rates of bony union have been reported for open reduction and internal fixation with plates and screws for femoral nonunions following failure of intramedullary nailing.[24,25] The intramedullary nail may either be removed or retained and autogenous bone grafting can be performed for patients with bony defects or poor bone stock at the nonunion site.[24,25] In contrast to slow compression over a nail using external fixation, plating with or without bone grafting requires surgical exposure of the nonunion site. Also, all patients undergoing plating are required to remain non-weight bearing for at least several weeks.[24,25] Last, plates and screws do not allow modification of the treatment plan without requiring subsequent trips to the operating room, whereas Ilizarov external fixation allows modification as needed during treatment. An advantage of plating relative to slow compression over a nail using external fixation is that the patient is not required to wear an external fixator or adhere to the schedule of compression necessary for the Ilizarov method. In addition, plates and bone grafting can be used to treat patients who have segmental defects that are likely to produce clinically significant femoral shortening with compression. Other Ilizarov techniques, such as compression-distraction (bone transport), are required to treat patients with large segmental defects.[15,26]

Various modalities have also been applied to augment healing of nonunions, including bone morphogenetic proteins and low-intensity pulsed ultrasound. Use of bone morphogenetic proteins have been shown to stimulate healing of fracture nonunions in various bones, including the femur.[27–33] In most instances, the bone morphogenetic proteins are incorporated into some type of bone graft or composite bone allogenic material that is inserted at the nonunion site, thus requiring an open surgical procedure. By contrast, slow compression over a nail using external fixation is a minimally invasive technique that does not require exposure of the nonunion site. Treatment with bone graft and bone morphogenetic proteins would be more appropriate than slow compression over a nail using external fixation for treatment of femoral nonunions that have associated segmental defects that require bone grafting. Other Ilizarov techniques can also be used in such cases.[15,26]

Low-intensity pulsed ultrasound has been reported by many authors to augment bony healing for patients with nonunion.[34–36] Advantages of low-intensity pulsed ultrasound are that it is a noninvasive treatment and that it can be used either independently or in combination with definitive surgical stabilization. Some researchers have reported, however, that low-intensity pulsed ultrasound has not been shown to have a significant effect in the treatment of nonunions following reamed intramedullary nailing.[37,38]

Slow compression over a nail using external fixation provides excellent mechanical stability and establishes good bone-to-bone contact. The technique is performed with percutaneous application of the external fixator so that no further disruption of the bone or soft tissues occurs at the nonunion site. The presence of the intramedullary nail encourages pure compressive forces and discourages translational and shear moments. An intramedullary nail also protects the site of bony healing once the external fixator is removed. The compression at the nonunion site afforded by the external fixator provides mechanical stability and bone-to-bone contact, which promotes direct osteonal healing. No reaming of the medullary canal is performed and a smaller diameter nail is placed. Exchange nailing has been defined as the removal of an in situ intramedullary nail, reaming of the intramedullary canal, and insertion of a larger diameter intramedullary nail.[15] Therefore, slow compression over a nail using external fixation differs from exchange nailing, both from a biologic and a mechanical perspective.[15] The biologic effects of exchange nailing with reaming are local bone grafting and increased periosteal blood flow. The biologic effects of Ilizarov compression are direct bone-to-bone contact (similar to plate stabilization) while simultaneously allowing axial micromotion, which stimulates the local osseous biology. The mechanical effects of exchange nailing are a larger nail that is stiffer and stronger and a widening and lengthening of the isthmal portion of the medullary canal, which increases stability by increasing the endosteal cortical contact area of the nail. By contrast, the mechanical effects of placing the Ilizarov external fixator over a dynamically locked smaller diameter intramedullary nail are that shear and bending forces are minimized while allowing compression and axial micromotion at the nonunion site, which provides further biologic stimulation. The biologic effects of Ilizarov compression and the mechanical stability afforded by the Ilizarov construct and a smaller diameter intramedullary nail were sufficient to promote bony healing without reaming of the intramedullary canal in this small series of patients.

All patients in this series began weight bearing on their affected leg on the first postoperative day. The inherent stabil-

ity of the construct we used allows immediate weight bearing; most other treatment methods require an interval of nonweight bearing until the bone begins to heal. With our method, immediate weight bearing is not only possible due to the stability of construct, but is recommended; axial loading during ambulation is known to promote bony union using the Ilizarov method.[13] Weight bearing helps to prevent deconditioning and affords the patient greater function and mobility during recovery.

There was no clinically significant increase in leg length discrepancy following treatment with slow compression over a nail using external fixation. These five patients were selected for treatment with this technique in part because their nonunion patterns were such that clinically significant shortening was not likely to result from the compression phase of treatment. In particular, none of the patients had a segmental defect at presentation. Two of the patients had preoperative leg length discrepancies of 25 mm or greater. Each of these patients experienced a 5 mm increase in leg length discrepancy following treatment with slow compression over a nail using external fixation. None of the patients who had a preoperative leg length discrepancy has opted to have lengthening since concluding treatment with slow compression over a nail using external fixation.

The duration of external fixation in this series does not necessarily reflect the time to bony union. The duration of external fixation instead reflects an attempt to obtain definitive bony union for these patients who had failed multiple surgical interventions. Retaining the external fixator for a month or two longer than may be necessary is preferred to removing the external fixator one day too soon. For the patients in this series, external fixation was removed and the intramedullary nails were statically locked when CT of the nonunion site revealed bony bridging of at least 25% of the cross-sectional area.[15]

The use of external fixation over an intramedullary nail has been previously described in successful treatment of nonunions.[11,39] Patel et al used compression with external fixation over an intramedullary nail to successfully treat ten patients with nonunions of the humerus that had failed intramedullary nailing.[39] Four of these cases had also failed one or more exchange nailings. All 10 patients in that series reported decreased pain and increased function at an average follow up of 31 months. No deep infections occurred during or after treatment with external fixation.[39]

Menon et al used compression with external fixation over an intramedullary nail to successfully treat two patients with nonunions of the femur, three patients with nonunions of the tibia, and four patients with nonunions of the humerus.[11] Three of the nonunions (one femur, one tibia, one humerus) had failed exchange nailing before undergoing the external fixation technique. All patients reported decreased pain and improved function at an average follow up of 19 months. A deep, residual infection occurred in one patient with nonunion of the tibia and required debridement and soft tissue reconstruction. This patient had a history of infection before undergoing the compression over a nail using external fixation technique.[11]

None of the patients in our series had a history of deep infection, nor did any patient acquire an infection during or following treatment. It is well known that placement of an intramedullary nail after removal of an external fixator increases the likelihood of infection.[14,40] This situation should not be considered the same as that of slow compression over a nail using external fixation, wherein the intramedullary nail and external fixator procedures are performed simultaneously, and the majority of the implants traversing the medullary canal are thin tensioned wires.

Nonunion of the femoral diaphysis or diaphyseal-metaphyseal junction following exchange nailing is uncommon. Treatment with exchange nailing for nonunion of the femur is successful for most of patients.[4,6,20] Only 5 patients with femoral nonunion following treatment with one or more exchange nails presented to our clinic in a 7-year period. The small sample size is a weakness of this report. Randomization of patients to other types of treatment was impractical given the small sample size and no similar cohort was available for comparison. The true success rate of slow compression over a nail using external fixation relative to other treatment options is difficult to define without a larger sample or a multicenter study.

The results of this report, however, do show that slow compression over a nail using external fixation can be successful in appropriately selected patients. The union rate for treatment with slow compression over a nail using external fixation in this small series was 100%. Others have shown similar techniques to be successful for treatment of nonunions in several long bones.[11,39] In addition, the slow compression over a nail using external fixation technique has several advantages relative to other treatment options, including plating, nail dynamization, bone grafting, and use of various modalities to promote bone healing.

To the best of our knowledge, this is the first series describing the use of slow compression over a nail using external fixation to treat aseptic nonunions of the femoral diaphysis or diaphyseal-metaphyseal junction that have failed one or more previous exchange nailings. All of the nonunions healed without the need for additional surgeries. No infections developed during or after treatment. All of the patients improved their ambulatory status and weight bearing ability and reported a significant decrease in pain. Exchange nailing remains the treatment of choice when a femoral nonunion occurs after fracture treatment with an intramedullary nail. Slow compression over a nail using external fixation promotes the healing of aseptic nonunions of the femoral diaphysis or diaphyseal-metaphyseal junction that have failed one or more prior exchange nailings.

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