

Role of Ilizarov External Fixator in the Management of Proximal/Distal Metadiaphyseal Pediatric Femur Fractures

Sanjeev Sabharwal, MD

Summary: Given the constraints of a short metaphyseal fragment and adjacent growth plates, there are limited options for operative fixation of metadiaphyseal fractures of the femur in children. This article outlines the surgical technique and reports early results of metadiaphyseal pediatric femur fractures treated with an Ilizarov external fixator by a single surgeon. Ten skeletally immature males with 5 proximal and 5 distal metadiaphyseal femur fractures underwent closed reduction and application of an Ilizarov external fixator. Time in the fixator averaged 138 (range, 104–180) days. At a mean follow-up of 26 months, there were no cases of loss of reduction, refracture, malalignment, leg length inequality, or loss of knee and hip mobility. Although superficial pin tract infections were common, no patient developed deep infection or required premature pin removal. One patient developed a transient foot drop after external fixation for a distal metadiaphyseal fracture, which recovered after revision of the pin construct. A low profile Ilizarov fixator can be effective in the management of certain metadiaphyseal pediatric femur fractures that may be difficult to manage by traditional methods.

Key Words: pediatric femur fracture, metadiaphysis, Ilizarov, external fixation

(*J Orthop Trauma* 2005;19:563–569)

Besides traction and spica casting, there are several different methods available for fixation of femoral shaft fractures in children. These include elastic intramedullary nailing, rigid intramedullary nailing, plate fixation, and use of unilateral external fixation.¹ However, given the concerns of avascular necrosis and injury to adjacent growth plates,^{2,3} these options are difficult to use in pediatric femur fractures at the proximal and distal metadiaphysis.

Although there are recent reports on the use of Ilizarov external fixator (Smith and Nephew Richards, Memphis, TN) in adults with supracondylar femur fractures,^{4–7} we cannot find a similar study in skeletally immature patients with proximal or distal metadiaphyseal femur fractures. This study was designed to report on the surgical technique and early results using a low profile Ilizarov external fixator in this subgroup of pediatric femur fractures that may not easily amenable to standard methods of fixation.

SURGICAL TECHNIQUE

The principles of femoral external fixation have been previously reported.^{8,9} Unlike the tibia, in which the anatomic and mechanical axes are the same, the femur has an average of $7 \pm 2^\circ$ difference, because the 2 axes converge at the distal end of the femur.¹⁰ The mechanical axis of the femur passes from the center of the femoral head to the center of the knee joint (Fig. 1A). The anatomic axis extends from the piriformis fossa, along the center of the femoral shaft, and exits just medial to the center of the knee, in line with the medial tibial spine (Fig. 1B). We use these axes and the population average alignment parameters of the femur to apply the Ilizarov external fixator.¹⁰ If the alignment of the opposite normal femur is available, those parameters can be used as well.

The patient is positioned supine on the radiolucent Jackson table with a rolled sheet under the ipsilateral lower torso. The entire leg, including the lower abdomen, is included in the sterile field. The concept of placing a proximal “reference” pin 90° to the proximal axis and the distal “reference” pin 90° to the distal axis is used. For fractures in the proximal metadiaphysis of the femur, typically the mechanical axis is easier to reference, because the normal mechanical lateral proximal femoral angle (LPFA-m)¹⁰ is 90° (Fig. 1A). It is measured on the AP radiograph as the angle between the line from the tip of the greater trochanter to the center of femoral head and a second line from the center of the femoral head to the midpoint of the femoral condyles. Although this angle need not be measured in an unreduced fracture, the concept is used for half-pin insertion. Thus, the proximal half-pin is placed parallel and distal to the line from the tip of greater trochanter to the center of the femoral head. To accurately place this pin, we sometimes place a temporary thin smooth wire going from the tip of the greater trochanter directed toward the center of the femoral head and place the reference half-pin essentially parallel and distal to it, at the level of the

Accepted for publication April 28, 2005.

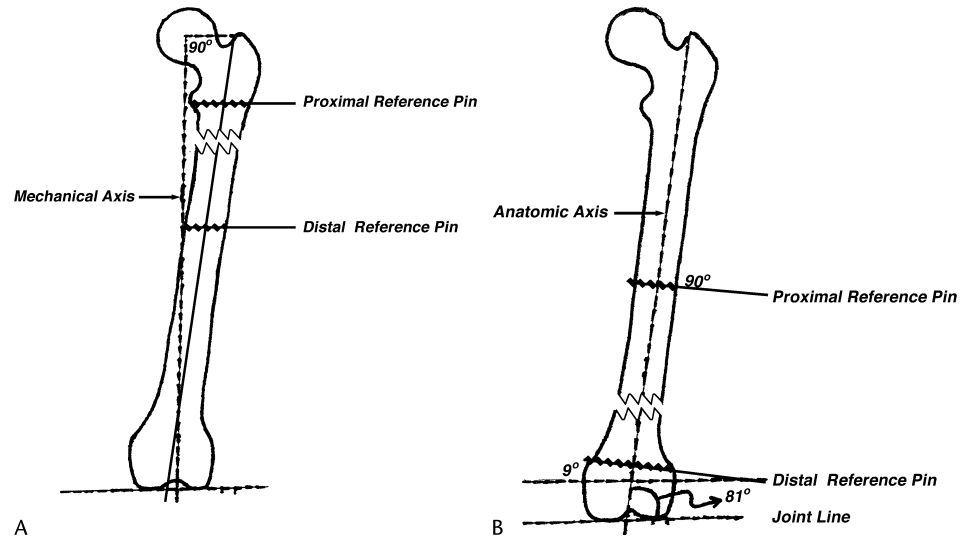
From The University Hospital, University of Medicine and Dentistry of New Jersey, Newark, NJ.

Ilizarov external fixator is a FDA-approved device manufactured by Smith & Nephew Richards (Memphis, TN).

Reprints: Sanjeev Sabharwal, MD, Department of Orthopedics Chief, Division of Pediatric Orthopedics UMDNJ—New Jersey Medical School, Doctors Office Center, 90 Bergen Street, Suite 7300, Newark, NJ (e-mail: sabharsa@umdnj.edu).

Copyright © 2005 by Lippincott Williams & Wilkins

FIGURE 1. A, Guide for pin insertion referenced off the mechanical axis of the femur, typically used for proximal metadiaphyseal femur fractures. Population average mechanical lateral proximal femoral angle (LPFA-m) of 90° is used.¹⁰ The proximal reference pin is inserted parallel and distal to the line between the tip of the greater trochanter and center of femoral head. Distal reference pin also is at right angles to the mechanical axis. Given the 7° difference between the anatomic and mechanical axis of the femur, this pin is angled slightly distal (approximately 7°) to the mid axis of the femoral shaft. **B,** Guide for pin insertion referenced off the anatomic axis of the femur, typically used for distal metadiaphyseal femur fractures. The proximal reference pin is inserted at right angles to the mid axis of the femoral diaphysis. The distal reference pin is directed cephalad about 9° in relation to the femoral condyles. This orients the distal ring at right angles to the anatomic axis, because the population average anatomic lateral distal femoral angle (LDFA-a) is 81°.¹⁰



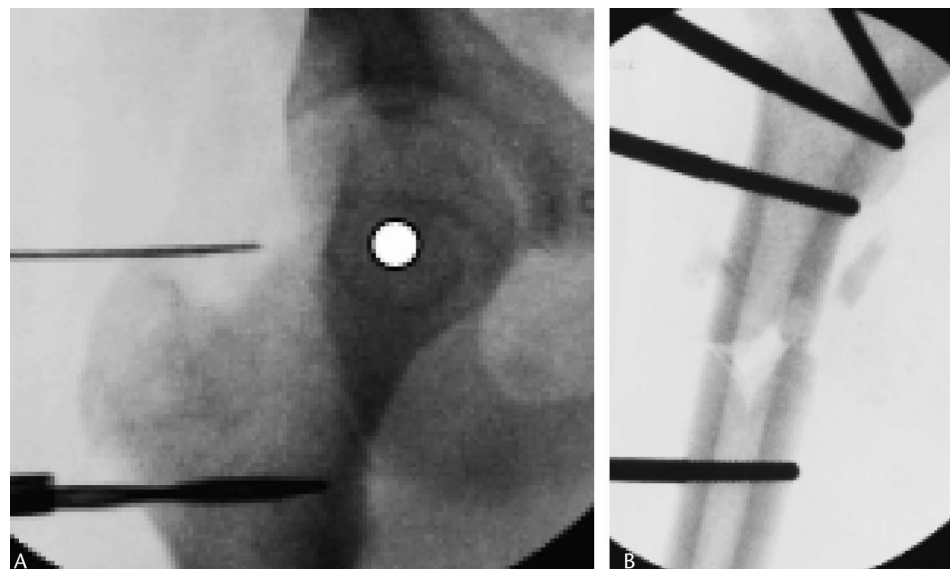
lesser trochanter (Fig. 2). In young children, with an unossified greater trochanteric apophysis, one needs to palpate the tip of the greater trochanter with a smooth wire to ensure proper pin placement. Given the average 7° difference between the anatomic and mechanical axes of the femur, the distal reference half-pin is directed slightly more distal, because it is inserted from the lateral to medial cortex of the femoral diaphysis (Fig. 1A).

For femoral fractures involving the distal metadiaphysis, the anatomic axis is more conveniently referenced. Proximally, fixation is inserted at right angles to the diaphysis (not metaphysis) of the femur. Distally, the reference wire or pin is placed in the supracondylar region, being 9° higher medially. This is so that the distal reference pin is at right angles to the

anatomic axis of the femur. The normal anatomic lateral distal femoral angle (LDFA-a)¹⁰ is 81° and is measured on the AP radiograph as the angle between the line along the center of the femoral shaft and a transverse line along the distal femoral condyles (Fig. 1B).

Given the large soft-tissue envelope around the femur, the exact location of the underlying bone can be difficult to determine. To avoid eccentric pin placement and multiple misplaced skin incisions, one can “feel” the bone, by placing a thin smooth wire at the proposed site of half-pin insertion before making a skin incision. This is especially helpful in large patients in which manual palpation of the underlying bone is not possible. The diameter of half-pin used depends on the width of the underlying bone. The number and size of the

FIGURE 2. A, Intraoperative fluoroscopic view demonstrating the technique for placement of proximal half-pin, using a temporary thin wire as a guide from the tip of the greater trochanter pointing toward the center of femoral head. The half-pin is placed parallel and distal to this wire, at the level of the lesser trochanter. **B,** Final fluoroscopic view demonstrating reduction of a comminuted proximal femur shaft fracture in an obese adolescent.



half-pins is based on several factors, including underlying bone diameter, patient's size, bone quality, and comminution at the fracture site. Typically 2 or 3, 5-mm or 6-mm half-pins are placed in each fragment. For distal fractures, a 1.8-mm Ilizarov reference wire is placed as well. As a general guideline for size of the half-pin, one should not exceed one-third of the diameter of the underlying bone. Use of Hydroxyapatite coated half-pins is preferred.¹¹

For better control and reproducibility, we prefer hand insertion of predrilled half-pins as opposed to self-drilling half-pins inserted with a motorized power unit. Proper position and length of the half-pin can be checked by rotating the limb such that the half-pin is at right angles to the beam of the image intensifier. The optimal thread length of the half pin is when the pin tip protrudes just beyond the far cortex, with the thread-shank junction at the near cortex. Most currently available half-pins have a design flaw, in that as the shank length of the pin increases, so does the thread length. Given the relatively large soft-tissue envelope of the proximal femur compared with the bone diameter at that level, a pin with appropriate thread length may not have a long enough shank length to have adequate skin clearance for the external fixator. If an appropriate thread and shank length half-pin is not available, one can cut a portion of the threaded part of a longer shank half-pin to optimize the purchase of the half-pin to the bone and still allow adequate clearance of soft tissues.

The Ilizarov instrumentation set has various sizes of 90° and 120° arches, as well as half-rings that can be connected to make full rings. Two arches are used for proximal fractures, whereas a proximal arch and a distal complete ring are typically used for distal fractures (Fig. 3). Once the proximal and distal reference pins have been placed, the half-pin connection to the corresponding arch or ring is firmly secured. Care should be taken that the individual arches or rings are placed orthogonal to the corresponding fracture segments in all planes. For proximal fractures, the second half-pin can be placed obliquely from the base of the greater trochanter toward the lesser trochanter, and connected to the proximal arch via a post (Fig. 4). One also should consider seating and daily functional activities while assembling the fixator. Avoid placing components too far posterolaterally (problem with lying supine) or too anteriorly in the proximal thigh (problem with sitting up).

Once all the half-pins have been placed and secured to individual arches or rings, a closed reduction of the fracture is performed under fluoroscopic guidance. If the proximal and distal fixation constructs have been appropriately placed, normal bony alignment should be restored when the 2 arches or rings are brought parallel to each other. We aim for an anatomic reduction, as opposed to having the 2 bony fragments overlap in anticipation of significant future overgrowth, which is unlikely with external fixation.¹² Once an acceptable reduction is achieved, 3 evenly spaced threaded rods are inserted between the 2 arches or rings, which should be essentially parallel to each other. Conical washers and 2-hole plates (Figs. 4B, C) often are used to allow minor adjustments of translation and angulation in all planes. These can help overcome less than orthogonal alignment of the individual arches to the corresponding bony fragments.

To prevent significant loss of knee mobility related to tethering of the adjacent skin or underlying iliotibial band by the half-pins and wires, one should confirm near full flexion of the knee after final fracture reduction. If needed, limited skin and fascial release can be performed at the individual pin insertion sites.

Besides assessing fracture reduction with gross visualization of the limb and fluoroscopy, several additional techniques can be used to confirm acceptable alignment. Placing an electrocautery cord firmly stretched on the skin from the center of the femoral head to the center of the tibial plafond reproduces the mechanical axis of the entire limb. On average, the bovie cord should project 10 (range, 3–17) mm medial to the midpoint of the knee joint, in line with the medial tibial spine.¹⁰ An intraoperative portable radiograph of the entire femur can be performed to confirm acceptable alignment of the femur. The alignment parameters of the opposite normal limb can be used as a guide for gauging adequate reduction and alignment, as well.

Postoperative Management

Based on factors such as child's weight, ability to comply with weightbearing instructions, fracture comminution, and associated injuries, he/she is mobilized with physical therapy. Typically, for isolated fractures partial weightbearing is initiated, and gradually advanced to full weightbearing within 3 to 4 weeks. For pin site dressing, we use a 2-inch-gauze bandage (eg, Kling™) to wrap around the proximal and distal pin clusters (Fig. 4C). By limiting the motion between the skin and the pins, this type of bandage can decrease the incidence of infection and pin drainage in areas of a large soft-tissue sleeve, such as the proximal thigh.

The patient is typically allowed to take shower 1 week after fixator application. No specific pin care regimen besides daily cleaning with a spray bottle filled with warm water or half strength hydrogen peroxide and drying the skin-pin interface is used. The patient rewraps the pin sites daily. An outpatient prescription for a 10-day course of oral antibiotics (usually a first generation cephalosporin) with 3 refills is given at the first postoperative visit, which is usually 1 week after surgery. The patient's caretaker is instructed to start the antibiotics at the initial sign of pin site inflammation. If significant swelling or erythema persists despite a 10-day course of oral antibiotics other options can be considered individually or in combination. These include prescribing a different orally administered antibiotic, using intravenous antibiotics, limited skin release at the pin site, curettage of the pin tract under local anesthesia, or pin removal with insertion of another pin at a different location under general anesthesia.

When clinical and radiographic evidence of early healing is noted, the frame is dynamized by selective removal of 1 or 2 half-pins or wires. This can be combined with loosening the nuts attached to the threaded rods or performing 1-mm to 2-mm of acute compression between the rings to increase axial loading at the fracture site. A clinical indicator supporting readiness for fixator removal is when the patient is able to walk painlessly on a fully dynamized fixator without any walking aids. Another strategy to test the appropriate timing of frame removal can be based on radiographic assessment, such that at

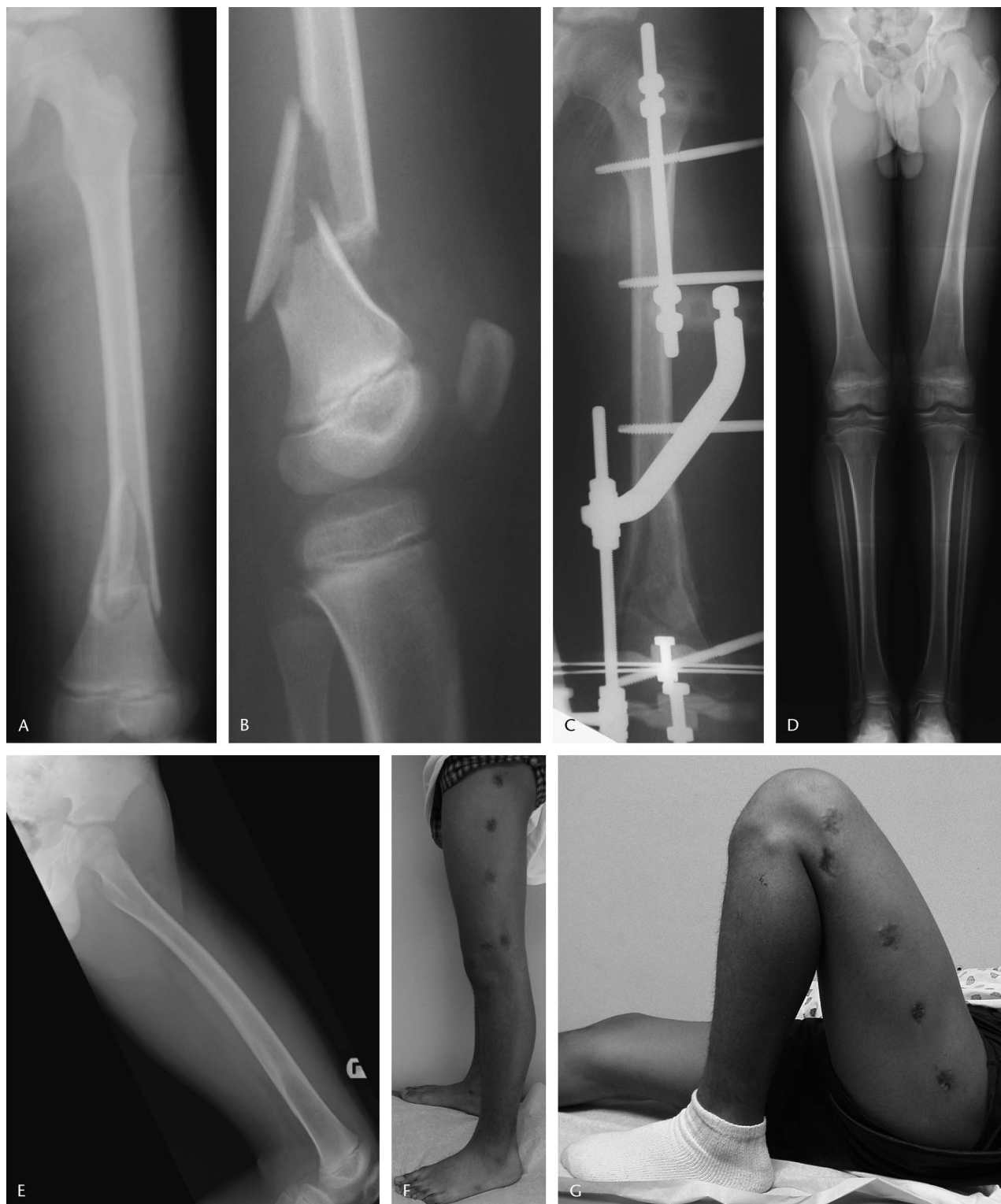


FIGURE 3. Anteroposterior (A) and lateral (B) radiographs of a 9-year-old male who sustained a comminuted distal metadiaphyseal left femur fracture. Early postoperative (C) and final radiographs (D, E) 1 year after closed reduction and external fixation demonstrating satisfactory healing and alignment. Clinical follow-up 3 months after fixator removal with return of full knee mobility (F, G). Note the visible scars at the half-pin insertion sites.

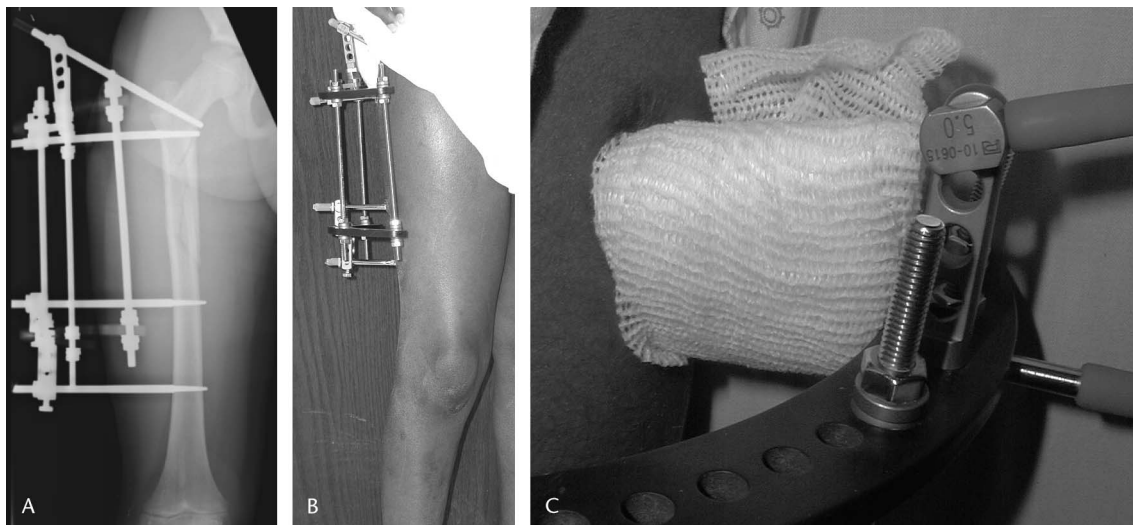


FIGURE 4. A, Early postoperative radiograph of the right femur in a 10-year-old male who sustained a displaced, spiral subtrochanteric fracture with significant shortening treated with closed reduction and Ilizarov external fixation. B, Clinical photograph of the same patient demonstrating the low profile Ilizarov external fixator with the two femoral arches connected with 3 threaded rods and sets of conical washers. The conical washers can aid in fracture reduction by allowing minor changes in angulation and translation between the femoral arches. C, Clinical picture demonstrating pin site dressing using a 2-inch Kling™. (Figures 4A and B reprinted with permission.⁹)

least 3 of 4 cortices have reconstituted at the original fracture site on 2 orthogonal radiographs. To assess healing and ability of the limb to handle physiologic loads, one can also remove the threaded rods connecting the femoral arches and have the patient walk in the office with half-pins still in.

We prefer removing the external fixator under general anesthesia. This enhances the ability to assess healing with fluoroscopy, clean and undermine puckered pin tracts, and apply appropriate immobilization devices, all of which we believe outweighs the potential risks and costs of administering general anesthesia. In our experience, this approach decreases the risk of refractures and offsets the inconvenience of a short trip to the operating room for both the patient and surgeon. The patient is placed in a prefabricated HKAFO (for proximal fractures) or a long leg cast (for distal fractures) for 1 to 2 weeks. The patient is typically sent home the same day soon after he/she is fully awake and comfortable and allowed weightbearing as tolerated.

METHODS AND RESULTS

After institutional review board approval, children, who sustained a metadiaphyseal femoral fracture during a 4-year period (from July 1999 to June 2003) who were treated with an Ilizarov external fixator at an urban level 1 trauma center by a single pediatric orthopedic surgeon, were retrospectively reviewed. Fractures involving the proximal or distal physis, remaining femoral diaphysis, as well as metadiaphyseal fractures treated with other means and femoral fractures in adults were excluded. A total of 133 children younger than aged 18 years with the diagnosis of femoral fracture who were treated by the author during the study period were identified. A variety of methods, such as immediate cast application, skeletal traction followed by spica casting, elastic intramedullary nailing,

open reduction with internal fixation, and the use of monolateral external fixation, as well as Ilizarov external fixation were used. Ten children met the inclusion criteria. They were all males with an average age at injury of $12 + 7$ years with a range from $7 + 5$ to $15 + 10$ years. The mechanism of injury was a fall in 4, motor vehicle accident in 5, and a pathologic fracture related to a benign cyst in 1 patient. Nine fractures were acute and presented to the emergency room. The remaining patient was an 11-year-old obese male who presented 17 days after immediate spica casting. Radiographs in the cast revealed 3 cm of shortening and 25° of varus angulation of a comminuted proximal metadiaphyseal fracture.

All 10 patients had closed metadiaphyseal femur fractures: 5 proximal and 5 distal in location. Both the proximal and distal femoral growth plates were radiographically visible at the time of injury in all cases. The fracture pattern was comminuted in 9 and spiral in 1. Based on the OTA classification, there were 2 32-B1.1, 3 32-B2.1, 3 32-B2.3, and 2 32-B3.3.

All patients were treated by closed manipulation of the fracture under general anesthesia with application of an Ilizarov external fixator. None required an open reduction or needed any blood transfusion in the perioperative period. The hospital stay averaged 5 (range, 3–7) days. At an average follow-up of 26 (range, 6–51) months, all fractures had united. The time in the external fixator averaged 138 (range, 104–180) days. There were no cases of loss of reduction, refracture, vascular injury, need for knee manipulation, or pin site infections requiring pin removal or exchange. All patients regained full hip and knee mobility within 3 months of fixator removal (Figs. 3F, G).

Long leg standing radiographs and scanograms of both lower extremities were reviewed at follow-up (Fig. 3D). No patient had any mechanical axis deviation compared with the

normal values outlined in the literature (3–17 mm medial to the midpoint of the knee joint). The lateral distal femoral angle (mechanical) averaged 87°, with a range from 84° to 90°. These values were within normal population values.¹⁰ No patient had more than 5° of angulation on the lateral view radiographs. There were no cases of leg length discrepancy >1 cm nor any rotational deformities noted on clinical examination. At the time of latest follow-up, 5 patients were skeletally mature.

There was 1 case of transient foot drop after external fixation for a distal femur metaphyseal fracture. This was a 14-year-old obese male, who was initially treated for adolescent Blount's disease with a left-sided proximal tibial osteotomy and gradual correction of angulation with lateral translation of the distal fragment using a Taylor Spatial Frame (Smith and Nephew Richards). After satisfactory healing and realignment, the external fixator was removed, and he was gradually mobilized, weightbearing as tolerated. Two months after removal of the tibial frame, he slipped on ice and sustained a comminuted distal femoral metadiaphyseal fracture on the same side as the healed tibial osteotomy. Secondary to the large size of the patient, location of the fracture, and open distal femoral physis, Ilizarov external fixation was chosen for definitive fracture management. Because of associated osteopenia, distal femoral fixation, which consisted of 2 1.8-mm wires and a half-pin, was supplemented with 2 proximal tibial half-pins, inserted anteromedial and anterolaterally. This was the only patient in the series who had fixation extended beyond the femur. Postoperatively, he was noted to have a foot drop with isolated loss of motor function of the toe and ankle dorsiflexors. Interestingly, he had normal strength of ankle evertors and invertors and no sensory loss in the entire lower extremity, including the first web space. He was taken back to surgery after a 48-hour observation period with no change in his neurologic function. One of the distal femoral wires was reinserted in a slightly different plane and the anterolateral proximal tibial half-pin was exchanged for a more anteriorly located half-pin. His neurologic function significantly improved during the next 48 hours and fully recovered after several weeks. Given the significant early recovery of neurologic function after pin exchange, peroneal nerve exploration was not performed. The femoral fracture healed uneventfully

DISCUSSION

There are several reports on the use of unilateral external fixators for pediatric femoral shaft fractures with mixed results.^{13–23} Typical problems with the use of unilateral fixators include malreduction,^{13–15,18} loss of reduction, delayed healing,^{21,23} pin tract infections,^{12,13,16,21,24} cosmetic concerns with pin scarring,²⁵ need to place intra-articular half-pins in the distal femoral epiphyses,³ and refracture after fixator removal.^{16,19,21} Most of these complications seem technical in nature. These problems may be avoided by using proper technique of insertion of appropriately sized half-pins,⁹ use of a more modular multiplanar external fixator along with gradual dynamization, and appropriate timing of fixator removal as well as post removal protection of the fractured limb.^{9,16} By

using hydroxyapatite coated half-pins,¹¹ avoiding thermal necrosis by using sharp drill bits,⁹ early use of oral antibiotics for pin site drainage, and performing appropriate pin site releases and care, pin-related complaints hopefully can be minimized. Although puckering of the skin edges at the pin sites is avoided by appropriate undermining of the adjacent skin,^{9,26} the scars can be visible (Fig. 3G). This may be a cosmetic concern,²⁵ especially in girls, and the family should be counseled regarding this issue preoperatively.

There are no reports in the English literature on the use of an Ilizarov fixator for pediatric femur fractures. However, there are a few case series on the use of unilateral,⁷ circular,^{5,6} and hybrid⁴ external fixators for supracondylar femoral fractures in adults. Unlike our patients, a significant number of patients in these reports^{4–7} had associated soft-tissue injury, many with segmental bone loss and intra-articular extension. The outcome was compromised with complications, such as loss of knee mobility, angular malalignment, delayed healing, deep infections, and unplanned subsequent surgeries.

In the current series of patients, we did have one major complication: a postoperative foot drop, leading to an unplanned surgical intervention after external fixation of a distal metadiaphyseal femur fracture, as discussed previously. Several possible ways of avoiding such a complication can be considered in patients who may have had previous surgery or trauma that could have altered the normal relationship of the peroneal nerve around the proximal tibia. These include an open technique for placement of the anterolateral metaphyseal half-pin, placing the half-pin more anteriorly, and flexing the knee to allow the nerve to displace posteriorly. Although we were unable to find a similar report of selective injury to a motor branch of the peroneal nerve with previous high tibial osteotomy, displacement of the common peroneal nerve associated with proximal tibia fracture has been reported.²⁷

Although there are a few reports on the use of traction for subtrochanteric pediatric femur fractures,^{28,29} there are no series in the literature dealing exclusively with proximal metadiaphyseal femur fractures in children or adults who were treated with an external fixator. Sabharwal et al³⁰ recently described the technique of performing a percutaneous subtrochanteric femoral osteotomy for treatment of developmental coxa vara in children using a low-profile Ilizarov fixator.

The Ilizarov device is not necessary for the acute management of the more common diaphyseal location of femur fractures in children. Standard treatment methods should be used based on patient's age, fracture pattern, psychosocial factors, and surgeon's preference.¹ However, for the metadiaphyseal fractures in skeletally immature individuals, given the constraints of a short metaphyseal fragment and adjacent growth plates, fixation options are more limited. Although a monolateral fixator can be used for certain metadiaphyseal fractures, the Ilizarov device appears more modular, allows for multiplanar pin fixation, and avoids intraepiphyseal placement of half-pins, which may be required in fractures with relatively short metaphyseal fragments treated with monolateral external fixators. Recently, traction^{28,29} and submuscular plating^{31,32} has been reported for managing complex proximal and distal pediatric femur fractures with satisfactory outcome in majority of patients.

Compared with internal fixation, there are several potential benefits associated with application of the Ilizarov fixator. These include avoidance of a large open surgical exposure, decreased potential for significant blood loss, no need for supplemental cast immobilization, ability to achieve bony stability without violating adjacent growth plate and epiphyses, and capability to perform residual correction at the fracture site after fixation. Certain other complications typically seen with internal fixation devices, such as plates and nails, also can be minimized. These include prominent hardware after fracture healing,²⁸ implant failure,^{32,33} incisional pain and scarring,^{28,33} leg length discrepancy,³²⁻³⁴ avascular necrosis of the femoral head,² need for a second major surgical procedure for removing an internal implant,^{3,31-34} and potential for deep infection.³⁴

In children who present several days after a femur fracture with unacceptable shortening and/or angulation (as seen in 1 of our patients), the Ilizarov device can be used to perform gradual correction while allowing the patient to mobilize out of bed. By avoiding the need for skeletal traction followed by spica casting, significantly earlier mobilization with normalization of the gait pattern has been reported with the use of external fixation for femoral fractures.^{22,27,28}

There are drawbacks associated with the use of an Ilizarov external fixator. These include a need to be familiar with the use of the device; however, other external fixator systems can be used if the principles outlined above are followed. The bulkiness of the fixator, soft-tissue binding by the bony anchors hindering joint motion along with the possibility of pin site drainage, and prominent scars^{25,26} are other disadvantages. Finally, our patients spent an average of 138 (range, 104–180) days in the fixator; a time period that some patients might not be willing to undergo.

Based on our experience using the operative technique described in this report, an Ilizarov external fixator can be added to the list of options available for management of pediatric femoral fractures involving the metadiaphysis.

ACKNOWLEDGMENTS

The author thanks Drs. Rahul Mittal and Caixia Zhao for their assistance.

REFERENCES

- Sanders JO, Browne RH, Mooney JF, et al. Treatment of femoral fractures in children by pediatric orthopedists: results of a 1998 survey. *J Pediatr Orthop*. 2001;21:436–441.
- Beatty JH, Austin SM, Warner WC, et al. Interlocking intramedullary nailing of femoral shaft fractures in adolescents: preliminary results and complications. *J Pediatr Orthop*. 1994;14:178–183.
- Smith NC, Parker D, McNicol D. Supracondylar fractures of the femur in Children. *J Pediatr Orthop*. 2001;21:600–603.
- Ali F, Saleh M. Treatment of isolated complex distal femoral fractures by external fixation. *Injury*. 2000;31:139–146.
- Arazi M, Memik R, Ogun T, et al. Ilizarov external fixation for severely comminuted supracondylar and intercondylar fractures of the distal femur. *J Bone Joint Surg Br*. 2001;83:663–667.
- Hutson JJ Jr, Zych GA. Treatment of comminuted intraarticular distal femur fractures with limited internal and external tensioned wire fixation. *J Orthop Trauma*. 2000;14:405–413.
- Marsh JL, Jansen H, Yoong HK, et al. Supracondylar fractures of the femur treated by external fixation. *J Orthop Trauma*. 1997;11:405–410.
- Kishan S, Sabharwal S, Behrens F, et al. External fixation of the femur: basic concepts. *Tech Orthop*. 2002;17:239–244.
- Sabharwal S, Kishan S, Behrens F. Principles of external fixation of the femur. *Am J Orthop*. 2005;34:218–223.
- Paley D, Herzenberg JE, Tetsworth K, et al. Deformity planning for frontal and sagittal plane corrective osteotomies. *Orthop Clin North Am*. 1994;25:425–465.
- Moroni A, Vannini F, Mosca M, et al. State of the art review: techniques to avoid pin loosening and infection in external fixation. *J Orthop Trauma*. 2002;16:189–195.
- Hedin H, Hjørth K, Larsson S, et al. Radiological outcome after external fixation of 97 femoral shaft fractures in children. *Injury*. 2003;34:287–292.
- Blasier RD, Aronson J, Tursky EA. External fixation of pediatric femur fractures. *J Pediatr Orthop*. 1997;17:342–346.
- De Sanctis N, Gambardella A, Pempinello C, et al. The use of external fixators in femur fractures in children. *J Pediatr Orthop*. 1996;16:613–620.
- Domb BG, Sponseller PD, Ain M, et al. Comparison of dynamic versus static external fixation for pediatric femur fractures. *J Pediatr Orthop*. 2002;22:428–430.
- Gregory P, Pevny T, Teague D. Early complications with external fixation of pediatric femoral shaft fractures. *J Orthop Trauma*. 1996;10:191–198.
- Hayden JD, Wynn-Jones H, Oxborrow NJ, et al. Early pin failure following external femoral fracture fixation in a head-injured child. *J Orthop Trauma*. 2001;15:572–574.
- Kapukaya A, Subasi M, Necmioglu S, et al. Treatment of closed femoral diaphyseal fractures with external fixators in children. *Arch Orthop Trauma Surg*. 1998;117:387–389.
- Skaggs DL, Leet AI, Money MD, et al. Secondary fractures associated with external fixation in pediatric femur fractures. *J Pediatr Orthop*. 1999;19:582–586.
- Hedin H, Borgquist L, Larsson S. Cost analysis of three methods of treating femoral shaft fractures in children: a comparison of traction in hospital, traction in hospital/home and external fixation. *Acta Orthop Scand*. 2004;75:241–248.
- Miner T, Carroll KL. Outcomes of external fixation of pediatric femoral shaft fractures. *J Pediatr Orthop*. 2000;20:405–410.
- Wong J, Boyd R, Keenan NW, et al. Gait patterns after fracture of the femoral shaft in children, managed by external fixation or early hip spica cast. *J Pediatr Orthop*. 2004;24:463–471.
- Kesemenli CC, Subasi M, Arslan H, et al. Is external fixation in pediatric femoral fractures a risk factor for refracture? *J Pediatr Orthop*. 2004;24:17–20.
- Mishra V, Perkins RD. Recalcitrant soft tissue pin-tract infection: a delayed complication of pediatric femoral shaft fracture treated with external fixator. *J Trauma*. 2004;57:895–897.
- Karlen LK, Yinusa W, Yan LS, et al. Analysis of scar formation after lower limb lengthening: influence on cosmesis and patient satisfaction. *J Pediatr Orthop*. 2004;24:706–710.
- Öznu A, Kaykocoglu A. A simple technique for improving the appearance of pin-site scars. *Plast Reconstr Surg*. 2002;110:710–711.
- El-Shazly M, Saleh M. Displacement of the common peroneal nerve associated with upper tibial fracture: Implications of fine wire fixation. *J Orthop Trauma*. 2002;16:204–207.
- Jeng C, Sponseller PD, Yates A, Paletta G. Subtrochanteric femoral fractures in children: alignment after 90°–90° traction and cast application. *Clin Orthop Relat Res*. 1997;1:170–174.
- Theologis TN, Cole WG. Management of subtrochanteric fractures of the femur in children. *J Pediatr Orthop*. 1998;18:22–25.
- Sabharwal S, Mittal R, Cox G. Percutaneous triplanar femoral osteotomy correction for Developmental Coxa Vara. *J Pediatr Orthop*. 2005;25:28–33.
- Agus H, Kalenderer O, Eryanilmaz G, et al. Biological internal fixation of comminuted femur shaft fractures by bridge plating in children. *J Pediatr Orthop*. 2003;23:184–189.
- Kanlic EM, Anglen JO, Smith DG, et al. Advantages of submuscular bridge plating for complex pediatric femur fractures. *Clin Orthop*. 2004;426:244–251.
- Caird MS, Mueller KA, Puryear A, et al. Compression plating of pediatric femur shaft fractures. *J Pediatr Orthop*. 2003;23:448–452.
- Eren OT, Kucukkaya M, Kockesen C, et al. Open reduction and plate fixation of femoral shaft fractures in children aged 4 to 10. *J Pediatr Orthop*. 2003;23:190–193.