Femoral-Shaft Fractures in Children and Adolescents

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Abstract

Femoral-shaft fractures are frequent in children and adolescents. Fortunately, most unite rapidly without significant complications or sequelae. Treatment options include spica casting, traction, external fixation, compression plating, and flexible or locked intramedullary nailing, each of which has advantages and disadvantages. Treatment is determined primarily on the basis of the age of the patient and the presence of associated injuries, but psychological, economic, and environmental factors also must be considered. The appropriate treatment can be determined only by careful consideration of all factors and close consultation with the family. Meticulous attention to technical details will help decrease the incidence of complications from both nonoperative and operative treatment.

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Femoral-shaft fractures are frequent in children and adolescents. Almost all unite relatively rapidly, regardless of the type or location of the fracture or the treatment method chosen. Complications do occur, however, including nonunion, delayed union, leg-length discrepancy, angular and torsional deformities, and vascular or nerve injuries. Careful evaluation of children with femoral-shaft fractures and use of appropriate age-based treatment methods can help avoid these pitfalls.

Femoral-shaft fractures in children often result from automobile-related accidents, falls from high places, and other high-energy trauma. The femoral fracture may be an isolated injury or may be one of several injuries, especially with high-energy trauma. Children with multiple trauma often also have fractures of the pelvis and tibia, as well as head, chest, and abdominal injuries. In very young children with femoral-shaft fractures, child abuse must be considered. Approximately 70% of femoral fractures in children younger than 3 years of age are the result of child abuse.[1] Other less common conditions that frequently are associated with pediatric femoral-shaft fractures include osteogenesis imperfecta, myelomeningocele, cerebral palsy, metabolic bone disorders, and benign skeletal lesions, such as metaphyseal cortical defects, nonossifying fibromas, fibrous dysplasia, eosinophilic granulomas, unicameral bone cysts, and aneurysmal bone cysts.

Decision-Making Considerations

Treatment guidelines for femoral-shaft fractures are based on the chronologic age, bone age, and size of the child, as well as the cause of the injury (Table 1). Initially, determining whether a traumatic fracture is an isolated injury or is part of polytrauma is critical in selecting the appropriate treatment. Economic concerns, the family's ability to care for a child in a spica cast or external fixator, and the advantages and disadvantages of any operative procedure also are important considerations. For example, the ability of the family to care for a child with an external fixator and to return for regular follow-up visits may determine its suitability. The reliability of the family in enforcing early non-weight-bearing may determine whether casting or cast bracing is appropriate.

In adolescents, psychological implications are especially important. Prolonged hospitalization alters the adolescent's self-image and interrupts social and educational development.[2,3] Clearly, fracture fixation with an external fixator, intramedullary nail, or compression plate and immediate mobilization are preferable to prolonged traction and hospitalization for most older adolescents, especially those approaching skeletal maturity. While these arguments seem to favor operative treatment of femoral-shaft fractures, the surgeon must also weigh

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Table 1
Treatment Options for Femoral-Shaft Fractures*

Age	Closed Head Injury and/or Multiple Trauma	Treatment Options: Closed Fracture	Treatment Options: Open Fracture†
0-2 years	No	Immediate spica cast *or* skin traction	External fixation *or* 90-90 femoral traction
	Yes	Immediate spica cast *or* skin traction	External fixation
3-5 years	No	Skin or skeletal traction *or* spica cast	External fixation *or* 90-90 femoral traction
	Yes	External fixation	External fixation
6-11 years	No	Traction-spica cast *or* external fixation *or* flexible IM nail	External fixation *or* flexible IM nail *or* compression plate
	Yes	External fixation *or* flexible IM nail *or* compression plate	External fixation *or* flexible IM nail *or* compression plate
12 years or older	No	Locked IM nail *or* external fixation *or* compression plate or femoral traction	Locked IM nail *or* external fixation
	Yes	Locked IM nail *or* external fixation *or* compression plate	Locked IM nail *or* external fixation

*IM = intramedullary.
†Open fractures also require debridement, appropriate intravenous antibiotic therapy, and tetanus vaccination.

the risks inherent in operative treatment, such as infection, refracture after removal of fixation, neurologic injury, limb shortening or overgrowth, and avascular necrosis of the femoral head.

The most difficult and controversial problem is the treatment of isolated femoral-shaft fractures in children 6 to 11 years of age. Good results can be obtained with spica casting, external fixation, flexible intramedullary nailing, and compression plating. No one method is the "right" way for every patient. The disadvantages of nonoperative treatment must be carefully weighed against the potential complications of a surgical procedure.

The comparative economics of nonoperative and operative treatment of femoral-shaft fractures have been evaluated by several authors, but no clear consensus has been reached. Reeves et al[3] reported that the cost of nonoperative treatment was 46% higher than that of operative treatment, even considering the necessity for a second surgical procedure for implant removal. Newton and Mubarak[4] analyzed the financial aspects of femoral-shaft fracture treatment in 58 children and adolescents and determined that total charges were lowest for those treated with early spica casting ($5,494) and highest for those treated with skeletal traction ($21,093) or intramedullary nailing ($21,359). Certainly, cost is a major factor, but it should not be the overriding consideration in discussions of treatment options with the family.

Treatment Options

Neonatal Period to Age 2 Years

Because child abuse is relatively common in this age group, the orthopaedist must first carefully evaluate the child for this possibility. If child abuse is suspected, admission to the hospital after immediate spica casting is appropriate to allow further medical evaluation.[2]

Children with isolated traumatic femoral-shaft fractures and limb shortening of less than 1 to 2 cm (as visualized on the initial radiographs) may be treated with immediate (24 to 48 hours after injury) spica cast application (Fig. 1). In children with multiple injuries or initial limb shortening of more than 2 to 3 cm, skin traction may be used for 3 to 10 days before delayed spica casting is performed.

Age 3 to 5 Years

Immediate application of a double spica cast or 1½ spica cast is appropriate for isolated femoral-shaft fractures in children between the ages of 3 and 5 years with shortening of less than 1 to 2 cm on the initial radiographs. The child may be discharged from the hospital after application of the spica cast, but follow-up should be scheduled within a week of injury. If the radiographs reveal significant varus or anterior angulation, the cast should be wedged so that 5 to 10 degrees of anatomic alignment is obtained in all planes. Certainly,

Fig. 1 **A,** Radiograph obtained 3 weeks after immediate spica casting of an isolated stable femoral-shaft fracture in a 2-year-old child. **B,** Three months after injury, the fracture has healed in good position.

more angulation will remodel in the young child, but the upper limits of angulation should not exceed 20 degrees in the anteroposterior and lateral planes.

In children with isolated femoral fractures with more than 2 cm of shortening on the initial radiographs, 5 to 10 days of skeletal traction and delayed spica cast application are indicated. An early follow-up appointment should be scheduled, at which time the cast can be wedged if necessary.

In children with multiple trauma, treatment of more serious injuries takes precedence over treatment of femoral-shaft fractures. Although rarely necessary in this age group, a small-fragment external fixator allows treatment of ipsilateral limb injuries, such as a "floating-knee" injury, and can be beneficial in treating children who require early mobilization. External fixation may also be useful in rare cases when traction has not prevented significant shortening and angulation of the fracture, in children with head injuries, and in children with open fractures requiring soft-tissue reconstruction.

Age 6 to 11 Years

Although various treatment options are available for treatment of femoral-shaft fractures in children between the ages of 6 and 11 years, the treatment guidelines remain controversial. Each child should be carefully evaluated, and the family should be informed of all available options, as well as the risks and benefits of each.

The primary problems with early femoral casting are shortening and angulation of the fracture (Fig. 2), especially in fractures associated with polytrauma and those with disruption of the periosteal sleeve.[5-7] Pollak et al[7] reported the results of treatment of 47 closed femoral-shaft fractures in children younger than 10 years of age. They found that 50% of fractures caused by high-energy trauma (12 of 24) required repeat reduction or other treatment to correct excessive shortening or angulation that occurred after initial reduction. In contrast, only 8% of low-energy fractures (2 of 24) required repeat closed reduction. Immediate spica casting is preferred for low-energy fractures with less than 2 cm of shortening.

Skeletal traction with a femoral traction pin for 7 to 21 days is an appropriate treatment option when immediate spica casting is not feasible. This most commonly occurs in comminuted fractures and those

Fig. 2 **A,** Radiograph obtained 1 month after immediate spica casting of an isolated femoral-shaft fracture in a 6-year-old child shows varus alignment. **B,** Four months after injury, malunion with varus angulation of 25 degrees can be seen.

with significant shortening (more than 2 cm). Longitudinal skeletal or overhead 90-90 traction may be used for most diaphyseal fractures in this age group. The time in traction depends on the age and size of the child and the time required for the fracture to become "sticky." After traction, a spica cast, a 1½ spica cast, or a cast brace may be applied. For subtrochanteric femoral-shaft fractures, 90-90 femoral traction with the pin in the distal femur is indicated if initial radiographs show severe flexion, abduction, and external rotation of the proximal fragment.

For children with multiple injuries, with or without head injury, four options are available: external fixation, flexible intramedullary nailing, compression plate fixation, and locked intramedullary nailing. Early spica casting generally is contraindicated for children older than 8 to 10 years of age, children with excessively large thighs, and children with severely comminuted fractures and significant shortening (Fig. 3).[8,9] The use of a locked, reamed, intramedullary nail generally is contraindicated in children of this age because the femoral canal is smaller than the nail and the risk of injury to the blood supply of the femoral head is increased.

A B

Fig. 3 **A,** Initial radiograph obtained after immediate spica casting of an isolated femoral-shaft fracture in an 8-year-old child shows 3 cm of shortening. **B,** Lateral radiograph obtained 4 months after injury shows only 1 cm of shortening after traction and delayed spica casting.

Aronson and Tursky[10] reported treatment of 44 femoral fractures with primary external fixation and early weight-bearing. Most patients returned to school by 4 weeks, and all had full knee motion 6 weeks after fixator removal. Of 16 patients with a follow-up of at least 18 months, 6 (38%) had minimal overgrowth of 2 mm or more (average, 5.8 mm). Complications included pin-tract infections in 8.5% of patients, varus deformity in 2 patients who were in a cast brace for 6 weeks after fixator removal, and valgus deformity of one fracture under compression with a Wagner fixator. Evanoff et al[11] reported 100% union without loss of joint motion after external fixation of 25 femoral fractures in children with head or multiple injuries (average age, 8 years 5 months).

Ward et al[12] reported the use of AO compression plates for the treatment of femoral-shaft fractures in 25 children aged 6 to 16 years, 22 of whom had associated fractures or multisystem injuries. Follow-up data were available for 24 patients, 23 (96%) of whom had healed fractures an average of 11 weeks after injury. According to these authors, plate fixation offers the advantages of anatomic reduction, ease of insertion, simplified nursing care, rapid mobilization without casting, and applicability to any size of femoral shaft. Disadvantages of plate fixation include the long incision that is necessary and the risks of plate breakage and stress fracture after plate removal. They recommend plate fixation only for children younger than 11 years of age with closed head injuries or multiple trauma.

Heinrich et al[13] recommend the use of flexible intramedullary nails for fixation of diaphyseal femoral fractures in children with multiple-system injury, head injury, spasticity, multiple long-bone fractures, a floating-knee injury, preexisting pulmonary dysfunction, more than 10 degrees of varus / valgus angulation, more than 15 degrees of anterior / posterior angulation, or more than 2 cm of shortening. Flexible intramedullary nailing may be appropriate for selected fractures in children older than 10 years of age and for pathologic fractures at significant risk for refracture. The authors reported on flexible intramedullary nailing of 89 diaphyseal femoral fractures in 87 children. One refracture occurred 1 week after nail removal, 1 patient had excessive valgus angulation of a distal-third femoral fracture stabilized with two medial nails, and in 1 patient with myelomeningocele the nail "backed out," with collapse at the fracture site. All fractures eventually united, and all children regained preoperative ranges of hip and knee motion. Excessive overgrowth did not occur.

Age 12 Years to Skeletal Maturity

The most conservative nonoperative treatment regimen for isolated femoral-shaft fractures in this age group is skeletal traction, followed by application of a spica cast or a cast brace. However, problems associated with traction and casting in adolescents, such as malunion, shortening, and loss of knee motion, make it least favored. In a comparison of internal fixation with traction and casting of femoral-shaft fractures in adolescents, Reeves et al[3] found that patients treated with traction and casting had a mean hospital stay of 26 days, compared with a mean of 9 days for those treated with internal fixation. Four (9%) delayed unions and five (11%) malunions occurred in the 44 fractures treated nonoperatively; no delayed unions, nonunions, or malunions occurred in the 52 fractures treated operatively.

Operative options for children with multiple trauma or isolated femoral fractures, with or without head injury, include external fixation, intramedullary nailing, and compression plating. Compression plating and external fixation are especially indicated in children in this age group who are hemodynamically unstable on admission to the hospital or trauma unit, with or without pelvic trauma or abdominal injury.

At my institution, we used interlocking intramedullary nails for the treatment of 31 femoral-shaft fractures in 30 patients between the ages of 10 and 15 years.[14] All fractures united, and the average leg-length discrepancy was 0.51 cm. Two patients had overgrowth of more than 2.5 cm. No angular or rotational malunions occurred. All nails were removed an average of 14 months after injury; no refracture or femoral-neck fracture occurred after nail removal. Growth of the greater trochanter and femoral neck did not appear to be significantly affected by crossing the trochanteric apophysis with the proximal interlocking screw or by inserting the nail into the piriformis fossa. Thinning of the femoral neck was not seen, probably because the patients were older and because the design changes in the femoral nail allowed a decrease in the cross-sectional diameter of the proximal portion to 12 mm. One patient exhibited mild overgrowth of the femoral neck. More recently, we have used pediatric "intermediate" interlocking nails for femoral canals with diameters as small as 8 mm.

Although the results were good in most patients, two important complications did occur. Two patients had more than 2.5 cm of overgrowth, which necessitated epiphysiodesis because of leg-length discrepancy. Segmental avascular necrosis of the femoral head developed in another patient; this was not seen on radiographs until 8 months after injury (Fig. 4). To our knowledge, this was the first report of this complication in the English-language literature.

Technique

Spica Casting

The spica cast may be applied immediately or within 24 to 48 hours if other extremity injuries require evaluation. The patient should be under intravenous sedation or general anesthesia. The hips and knee should be flexed 90 degrees. This position allows a young child (less

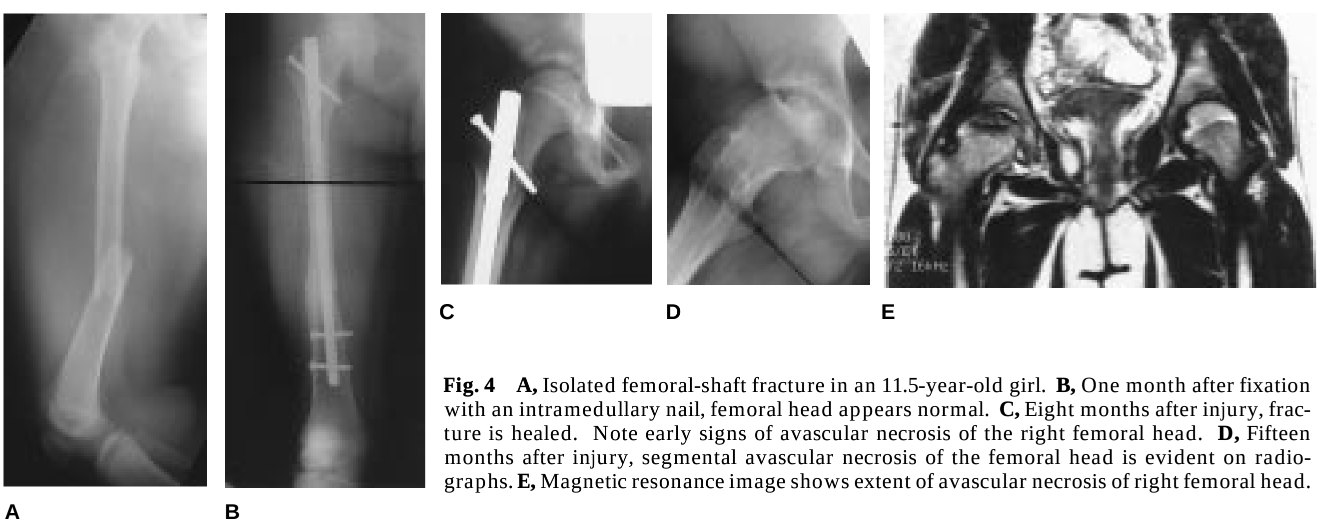


Fig. 4 **A,** Isolated femoral-shaft fracture in an 11.5-year-old girl. **B,** One month after fixation with an intramedullary nail, femoral head appears normal. **C,** Eight months after injury, fracture is healed. Note early signs of avascular necrosis of the right femoral head. **D,** Fifteen months after injury, segmental avascular necrosis of the femoral head is evident on radiographs. **E,** Magnetic resonance image shows extent of avascular necrosis of right femoral head.

than 8 years of age) to be carried on the parent's hip. Close observation is required to detect signs of neurovascular compromise during the early postinjury period.

McCarthy[9] described a technique in which the cast is applied in stages. He believes that decreasing the variables during cast application and fracture reduction produces better results and decreases the risk of malalignment and shortening. McCarthy's technique of early spica-cast application is as follows:

The child is anesthetized in the hospital bed and then transferred to the spica table. Stockinettes are placed over the torso, the affected leg, and the unaffected leg to the knee. Appropriate felt pads are placed over the bony prominences and around the edges of the cast after two or three layers of cast padding have been applied. A short-leg cast made of a quick-drying fiberglass-resin material is applied to the affected leg, with felt pads beneath the posterior upper calf. The foot may be included in younger children, but the cast usually ends 1 to 2 inches proximal to the malleoli in children older than 5 years of age. While this portion of the cast is hardening, the remainder of the cast is applied to the torso and the unaffected leg with the hip in 90 degrees of flexion and 30 degrees of abduction. This position allows the patient to sit in the cast. The hip on the affected side remains free at this stage.

Once the cast over the torso and leg has hardened, a C-arm image intensifier or radiographic unit is brought into position to monitor reduction of the fracture as it is affected by distraction and rotation. A lead-gloved fist is used to determine the optimal location of cast molds to hold the reduction. End-to-end reduction of transverse fractures usually is possible, but severe soft-tissue disruption may make maintenance of the reduction difficult. A distal femoral traction pin may be incorporated into the cast, but this is rarely necessary.

Distraction is applied through the leg with the knee in 90 degrees of flexion, avoiding any manual pressure in the popliteal space, which should be padded with felt. The force is applied through the hardened calf section of the cast. The image intensifier is moved aside, and cast material and splints are molded around the thigh. The unconnected sections of the cast are joined with firm molds in the locations selected; these may be checked radiographically during application if necessary. Permanent radiographs are obtained. The stockinette is brought over the edge of the cast and is held in place with a roll of fiberglass to eliminate rough edges. If fracture reduction is not acceptable, opening wedges can be made in the thigh section, or the section from the hip to the knee can be removed and the reduction maneuver repeated. The parents are carefully instructed in management of the child in the cast, and the patient is discharged, usually 1 or 2 days after surgery. At 1 week, the reduction is checked radiographically. If any reduction has been lost, cast wedging can be used for correction.

Traction

If traction is necessary in a child younger than 2 years of age, longitudinal skin traction or skin traction at a 45-degree angle with 4 to 5 lb of weight is recommended. Direct overhead skin traction increases the risk of neurovascular compromise and should not be used for femoral-shaft fractures in children of this age. Careful reevaluation of the skin and neurovascular status is necessary while the child is in traction.

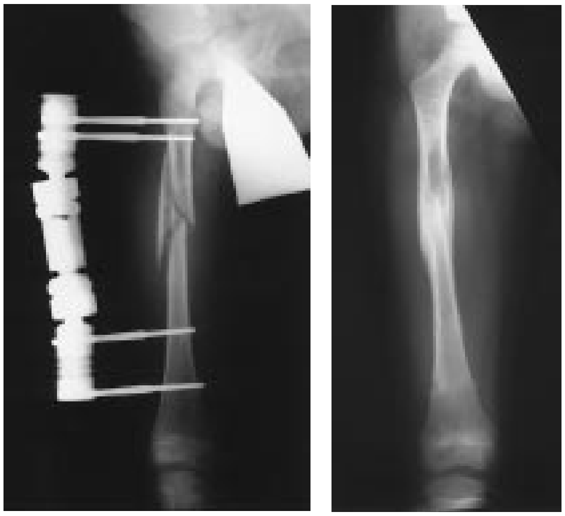
In children between the ages of 2 and 5 years, a 5/64-inch Steinmann pin inserted in the distal femur is preferable when skin traction is inadequate. If a proximal tibial pin is required, it should be placed distal to the tibial tubercle and the anterior aspect of the proximal tibial physis to minimize the risk of growth arrest and subsequent genu recurvatum deformity. A tibial traction pin is indicated if a distal supracondylar fracture makes femoral pin placement difficult or if skin problems make pin placement in the distal femur risky. Skeletal traction for 5 to 14 days usually is necessary before application of a delayed spica cast.

Aronson et al[15] found that oblique placement of femoral traction pins was associated with an increased incidence of varus or valgus angulation. Pins for skeletal traction should be placed parallel to the axis of the knee joint. In children older than 11 years of age, the fracture should be reduced out to length without excessive shortening.

External Fixation

For external fixation of femoral-shaft fractures, Aronson and Tursky[10] recommend the use of four half-pins, which are predrilled and hand-screwed laterally into the bone. The most proximal pin is placed laterally from the base of the greater trochanter across to the lesser trochanter, perpendicular to the shaft. The proximal fragment is held in a neutral position (as based on the position of the trochanters and the distal fragment in a true anteroposterior projection), and the second (most distal) pin is placed at least 5 cm proximal to the distal femoral physis, perpendicular to the shaft and parallel to the first pin. Length and varus-valgus alignment are corrected by attaching these first two pins to the side bar. The inner pins are placed after adjustment of the sagittal-plane alignment by flexion or extension of the fracture site (Fig. 5).

Aronson and Tursky recommend early progressive weight-bearing



A B

Fig. 5 **A,** Radiographs obtained 2 weeks after external fixation of a comminuted femoral-shaft fracture in an 8-year-old child. **B,** Four months after the fracture, immediately after removal of the external fixator, fracture is seen to be healed in good position.

and dynamization of the fixator, if necessary, to promote bone healing. At 10 to 12 weeks, the knee is manipulated and the fixator and pins are removed with the use of general anesthesia on an outpatient basis.

Although rarely indicated, use of a smaller external fixator, with two 4-mm pins placed proximally and two placed distally in the femur, is an effective treatment method in children less than 5 years of age with multiple trauma, open fracture, or severe head trauma.

Intramedullary Nailing

For flexible intramedullary nailing (Enders Nail, Smith & Nephew Richards, Memphis), Heinrich et al[13] recommend 3.5-mm nails in children between the ages of 6 and 11 years and 4.0-mm nails in children older than 11 years of age. Technical considerations include the use of a fracture table, fluoroscopy, and a sterile tourniquet.

The fracture is reduced with longitudinal traction before the incision is made for nail insertion. For the medial approach, a 5-cm skin incision is made 1.5 cm distal to the physis, extending proximally. For the lateral approach, a 6-cm incision is made laterally, beginning 1.5 cm distal to the physis. A longitudinally oriented oblong entry hole is made in the cortex proximal to the physis.

The nail should be long enough to extend from the level of the distal femoral physis to approximately 2 cm distal to the greater trochanteric physis. The tip of the nail is bent approximately 1.5 cm from the blunt end to an angle of 25 degrees, to allow the rod to bounce off the cortical bone inside the medullary canal. The nail is rotated back and forth through an arc of approximately 30 degrees while the tip is in contact with the opposite cortex to prevent it from becoming embedded. After the nail has bounced off the opposite cortex, it is driven to the fracture under fluoroscopy. The thigh is manipulated, and the nail is passed across the fracture.

If a second nail is being inserted from the opposite side of the distal femur, it is introduced into the medullary canal at this time and is driven across the fracture before the first nail is driven into its final position (Fig. 6). The eyelet of the nail should rest several millimeters proximal to the distal femoral physis. The eyelet is bent away from the bone 10 to 15 degrees to make nail removal easier. The second nail is then driven into its final position. If the second nail is inserted from the same side as the first, a second entry portal is placed anterior or posterior to the first (Fig. 7).

The orientation of the second nail must be kept in mind to prevent the nail from becoming twisted around the first as it is rotated to bounce off the cortex and when it is passed across the fracture. The second nail is always rotated to turn its tip away from the first nail. Care must be taken to prevent distraction while the nails are driven into place. Longitudinal traction is released after the nails have crossed the fracture. If necessary, the fracture is manually compressed to prevent distraction. The position and alignment of the fracture are checked with fluoroscopy as the nails are advanced and after tourniquet release.

Although retrograde rod insertion is suitable in most cases, antegrade insertion may be required for fractures with distal supracondylar malalignment. A longitudinal skin incision approximately 5 cm long at the metaphyseal-diaphyseal junction just below the greater trochanter is used for insertion of an S-configuration rod (bent by the surgeon at a point approximately 5 cm distal to the eyelet) across the fracture, followed by a C-configuration rod or two divergent C-configuration rods.

For rigid intramedullary nailing in adolescents aged 12 years and older, dissection should be limited to the base of the femoral neck and the piriformis fossa–greater trochanter junction and should not extend into the posterior capsule of the midportion of the femoral neck. This is to protect the blood supply to the femoral head. Dissection can be further decreased by removing the

Fig. 6 **Above,** Subtrochanteric femoral fracture in an 8-year-old child with multiple trauma. **Right,** Radiograph obtained 10 weeks after fixation with medial and lateral flexible nails.

posterior third of the tip of the greater trochanter and inserting the nail in the junction of the piriformis fossa with the base of the greater trochanter. This will prevent dissection near the origin of the lateral ascending cervical artery, which is close to the piriformis fossa. Great care should be taken to prevent the slipping of awl-type devices anterior and posterior to the neck. The proximal end of the nail should be left long (up to 1 cm) if later removal is anticipated (Fig. 8). Nails may be removed 9 to 18 months after radiographic evidence of union.

Special Fractures

Open Femoral Fractures

External fixation of open femoral-shaft fractures simplifies wound care and allows early mobilization.[16] The configuration of the external fixator is determined on the basis of the child's size and the fracture pattern. Generally, monolateral half-pin frames are satisfactory; thin-wire circular frames have a limited role in the management of acute fractures. External fixation provides good fracture control, but, as always, family cooperation is required to manage pin and fixator care.

Plate fixation allows early mobilization, as well as anatomic reduction of the femoral fracture. Wound care and treatment of other injuries are also easier in children with multiple trauma. However, this is a more invasive technique with the potential for infection and additional injury to the already traumatized soft tissues in the area of the fracture. In emergency situations, plate fixation can be used for Gustilo-Anderson type I and type II fractures; however, external fixation or intramedullary nailing is better suited for type III fractures in older adolescents. Plate breakage can occur if bone grafting is not used for severe medial cortex comminution.[12]

In adolescents aged 12 years and older, intramedullary nailing is especially useful. Closed nailing after irrigation and debridement of the fracture allows early mobilization and easy wound care, especially in patients with Gustilo-Anderson type I, II, IIIA, and IIIB injuries.

Femoral Fractures in Patients With Metabolic or Neuromuscular Disorders

A special group of femoral-shaft fractures includes those that occur in patients with metabolic or neuromuscular disorders, such as osteogenesis imperfecta, myelomeningocele, and cerebral palsy. For patients with osteogenesis imperfecta who have the potential for ambulation, surgical treatment with Rush or Bailey-

A B

Fig. 7 **A,** Distal femoral-shaft fracture in a 9-year-old child with multiple trauma. **B,** Radiograph obtained 5 months after fixation with two lateral flexible nails.

Fig. 8 Radiograph obtained 3 months after fixation of a femoral-shaft fracture in a 12-year-old child with multiple trauma, including a closed head injury. A 9-mm pediatric locked intramedullary nail was used.

Dubow rods is recommended for repeated fractures or angular deformity. Cast immobilization usually is avoided in patients with myelomeningocele or cerebral palsy because of the frequency of osteoporosis and refracture in these patients. If possible, existing leg braces are modified for treatment of the femoral fracture. In nonambulatory patients, a simple pillow splint may be used.

Floating-Knee Injuries

These rare injuries occur when ipsilateral fractures of the femoral and tibial shafts or the surrounding physes leave the knee joint "floating" without distal or proximal bone attachments.[17] Ipsilateral fractures occur most frequently when a pedestrian or cyclist is struck by an automobile. Major soft-tissue injuries, open fractures, and head injuries are common. In general, at least one of the leg fractures, usually that of the tibia, should be fixed. The femoral fracture can then be treated by the most appropriate option. If both fractures are open, external fixation of both may be appropriate. If immediate mobilization is necessary, fixation of both fractures with external fixation, intramedullary nails, compression plates, or any combination of these may be indicated.

Complications

Delayed Union and Nonunion

Delayed union and nonunion of femoral-shaft fractures in children are rare and usually occur after fractures with segmental bone loss, open fractures, subtrochanteric fractures that have been poorly aligned in traction, and fractures in which soft tissue is interposed between the fracture fragments.[18] Bone grafting and internal fixation are the usual treatment. Delayed union of a femoral fracture treated with casting in a child aged 1 to 5 years probably is best treated by continuing cast immobilization until bridging callus forms. For the rare femoral-shaft nonunion in a child aged 6 to 11 years, bone grafting and plate-and-screw fixation remain the traditional treatment methods. Recently, insertion of an interlocking intramedullary nail and bone grafting have been considered and are preferred by some, particularly for the rare nonunion in patients aged 12 years and older.

Leg-Length Discrepancy

The most common sequela after femoral-shaft fractures in children is leg-length discrepancy.[18] The fractured femur may be initially short as a result of overriding of the fragments at union. Growth acceleration then occurs to make up the difference, but often this acceleration continues and overgrowth occurs.

The potential for growth stimulation from femoral fractures has long been recognized, but the exact cause of this phenomenon is still unknown. Growth acceleration has been attributed to age, sex, fracture type, fracture level, handedness, and the amount of overriding of the fracture fragments. Age seems to be the most constant factor, but fractures in the proximal third of the femur and oblique comminuted fractures also have been associated with relatively greater growth acceleration. According to Staheli,[19] shortening is more likely in patients older than 10 years of age; in those between 2 and 10 years of age, overgrowth is more likely, especially if traction has been used.

Because the average overgrowth after femoral fracture is approximately 1.5 cm, shortening of 2 to 3 cm in the cast is the maximum acceptable discrepancy. The maximum acceptable shortening depends on the age of the child. For example, in a 6-year-old child, 2.5 cm may be acceptable, whereas only 1 to 2 cm should be accepted in a 14-year-old approaching skeletal maturity. In patients 2 to 10 years of age with more than 3 cm of shortening after immediate spica casting, the cast is removed, traction is reapplied until acceptable length is obtained, and then a new cast is applied. For early shortening of more than 3 cm in a patient aged 11 or older, reinstitution of traction and reapplication of the cast also may be appropriate. If however, the shortening is unacceptable at 6 weeks after fracture, one must decide whether osteoclasis and distraction with external fixation is preferable to a later limb-length equalization procedure. Currently, the trend is to correct the shortening immediately with external fixation if possible.

Angular Deformity

Some degree of angular deformity is frequent after femoral-shaft fractures in children, but this usually remodels with growth. The maximal acceptable amount of deformity remains controversial, however. Factors that may be important to the outcome include the age of the child, the direction of the angular deformity, and its location in the femoral shaft. Recommendations in the literature have ranged from allowing no angulation, to allowing some angulation in certain directions, to allowing limited angulation in any direction. As a general guideline, angulation deformity of more than 15 degrees in the coronal plane and 20 degrees in the sagittal plane is unacceptable, but this varies somewhat according to the age of the patient. For example, in a newborn or young child, as much as 45 degrees of angulation in the sagittal plane may be acceptable, especially in the proximal femur, whereas only 5 degrees of angulation in the distal femur may be acceptable in a 13-year-old.

Late development of genu recurvatum deformity of the proximal tibia after femoral-shaft fracture has been the most commonly reported complication of placement of a traction pin or wire through or near the anterior aspect of the proximal tibial physis, excessive traction, pin-tract infection, or prolonged cast immobilization. Femoral pins are preferred for traction, but if tibial pins are required, the proximal anterior tibial physis must be avoided. Femoral traction pins should be placed one or two finger breadths proximal to the superior pole of the patella to avoid the distal femoral physis.

If significant angular deformity is present after fracture union, corrective osteotomy should be delayed for at least a year unless the deformity is severe enough to impair function. This will allow determination of remodeling potential before deciding that surgical correction is necessary. The ideal osteotomy corrects the deformity at the site of fracture. In juvenile patients, however, metaphyseal osteotomy of the proximal or distal femur may be necessary. In adolescents with midshaft deformities, diaphyseal osteotomy and fixation with an interlocking intramedullary nail are preferable.

Torsional Deformities

According to Verbeek et al,[20] rotational deformities of 10 to more than 30 degrees occur in one third of children after conservative treatment of femoral-shaft fractures. Malkawi et al[21] found rotational deformities of less than 10 degrees in two thirds of 31 patients, but all were asymptomatic. Torsional deformity usually is expressed as increased femoral anteversion on the fractured side, compared with the opposite side, as demonstrated by anteversion radiographic views; a difference of more than 10 degrees has been the criterion of significant deformity. However, Brouwer et al[22] challenged this criterion, citing differences of 0 to 15 degrees in a control group of 100 normal volunteers. The accuracy of measurements from plain radiographs also has been disputed, and Norbeck et al[23] suggest the use of computed tomography for greater accuracy.

The permanence of rotational deformities also has been controversial. Although several authors have reported that no spontaneous correction occurs, this has been challenged by others, including Brouwer et al[22] and Verbeek et al.[20]

Despite conflicting reports and opinions, I believe that torsional deformities usually are asymptomatic and rarely require treatment. Norbeck et al[23] reported the case of one patient with a 30-degree internal rotation deformity that required corrective osteotomy.

Other Complications

Vascular injury may occur at the time of femoral fracture, and secondary limb ischemia has been reported after the use of both skin and skeletal traction. Vascular injury occurs most frequently with displaced Salter-Harris physeal fractures of the distal femur or distal metaphyseal fractures. If the arteriographic or clinical findings indicate that vascular repair is necessary after femoral-shaft fracture, either open reduction and internal fixation or external fixation of the fracture is recommended.

Weiss et al[24] reported peroneal nerve palsy in 4 of 110 patients treated with 90-90 traction and casting. I have seen 2 children younger than 2 years of age with peroneal nerve palsy after skin traction and immediate spica casting. In my experience, the natural history of peroneal nerve injury with femoral-shaft fractures in children seems to be spontaneous recovery. In infants, however, the development of an early contracture of the tendo Achilles is likely. Because of the rapid growth in younger children, this contracture can develop quickly; if peroneal nerve injury is suspected, the extremity may be braced until the peroneal nerve recovers.

Pin-tract infections occasionally occur with the use of skeletal traction, but most are minor infections that resolve with local wound care and antibiotic therapy. Occasionally, however, the infections may lead to osteomyelitis of the femoral metaphysis or a ring sequestrum that requires surgical debridement.

Summary

Regardless of the treatment method chosen, almost all femoral-shaft fractures in children and adolescents unite without serious complications. While some general guidelines are helpful, the treatment choice must be individualized for each patient depending on age, fracture type, and environmental factors, such as the family's social and psychological circumstances. All the risks and benefits of each treatment option should be thoroughly discussed with the family to help them and the physician make the best treatment decision for each patient.

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