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Complications of Pediatric Femoral Shaft and Distal Physeal Fractures

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Abstract

Fractures of the femoral shaft comprise about 1.6% of all bony injuries in children and are the most common pediatric orthopaedic injury that requires hospitalization. The treatment of femoral fractures in children is largely dependent on the child's age and size and takes into account multiple considerations: the child's weight, associated injuries, the fracture pattern, the mechanism of injury, institutional or surgeons' preferences, and economic and social concerns. In addition, during the past two decades, there has been a dramatic change favoring surgical fixation rather than casting because of the many advantages of fixation, including more rapid mobilization. The goal of treatment should be to ultimately obtain a healed fracture and avoid associated complications, such as nonunion or delayed union, angular or rotational deformity, unequal limb lengths, infection, neurovascular injury, disruption of the growth plate, muscle weakness, and/or compartment syndrome.

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Fractures of the femur are common injuries in pediatric patients. This chapter discusses fractures of the femoral shaft and distal femoral physis. At these locations, there is a substantial risk for complications. The goals of treatment for these fractures include a healed fracture and avoiding complications.

Femoral Shaft Fractures

Fractures of the femoral shaft comprise approximately 1.6% of all bony injuries in children and are the most common pediatric orthopaedic injury that requires hospitalization. Femoral shaft fractures in children are more common in boys and follow a bimodal age distribution, with the first peak occurring during the toddler years and a second peak in adolescence. Toddlers and young children are most commonly injured from simple falls, such as tripping while running or a fall from a low height. Older children and adolescents sustain fractures most commonly from higher-energy injuries, with nearly

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90% of the femoral fractures in older children resulting from motor vehicle crashes.[1,2]

Child abuse is another etiology of femoral fractures. Battered children often present first with a fracture, and it is estimated that orthopaedic surgeons see 30% to 50% of abused children. Consequently, orthopaedic surgeons are often responsible for distinguishing intentional from unintentional injuries in young children. Up to 60% of fractures seen in child abuse are isolated injuries, and the most common bone fractures are of the femur and the humerus. Long-bone diaphyseal fractures are the most common fracture patterns seen in intentional injuries.[1,2] These fractures are seen at least as often as the typical epiphyseal-metaphyseal fractures (corner or bucket-handle fractures) that are thought to be more pathognomonic of abuse.[1-4] Before walking age, up to 80% of femoral shaft fractures may be caused by abuse. In a study by Coffey et al[5] of more than 5,000 children at a trauma center, only 1% of the lower extremity fractures in children older than 18 months were caused by abuse, whereas child abuse was the direct cause in 67% of the fractures in children younger than 18 months. Other investigators have reported that 65% of the femoral fractures occurring in infants younger than 1 year were caused by abuse, with a much lower incidence of 35% in children aged 1 to 5 years.[3]

In younger children, it also is important to consider fractures that occur as a result of the failure of pathologic bone caused by minimal trauma. Although rare, this should be suspected in younger children with multiple fractures. Several common conditions can result in weakened bone and, therefore, lead to a predisposition to fracture, including osteogenesis imperfecta; disuse osteopenia in children with neuromuscular disease, such as cerebral palsy; myelomeningocele; and neoplasms.[1,2]

Treatment Options

The treatment of femoral fractures in children is largely dependent on a child's age and size. Any treatment decision, however, involves multiple considerations: the child's weight, associated injuries, the fracture pattern, the mechanism of injury, institutional or surgeons' preferences, and economic and social concerns.[4,6] Although femoral diaphyseal fractures can create substantial short-term disability, these injuries can be successfully treated with a variety of interventions. The scientific literature provides little evidence in terms of supporting one method of treatment over another because the outcomes in this population are believed to be good if an accepted method of treatment is executed effectively.[6] In the past, the standard of care for most pediatric diaphyseal femoral fractures was either casting or traction followed by casting. In the modern era, however, casting is used primarily for younger children who have a substantial capacity to undergo remodeling.[4]

The change in care plans for children and adolescents away from casting toward fixation has occurred during the past two decades. Pediatric orthopaedists have become familiar with pediatric intramedullary nail techniques and increasingly have recognized the advantages of fixation and rapid mobilization. Furthermore, early surgical treatment of a child with high-energy trauma, a head injury, or associated multiple trauma may reduce complications and decrease the overall hospital stay.[4] The American Academy of Orthopaedic Surgeons' guideline for the treatment of pediatric diaphyseal femoral fractures is, in the opinion of this chapter's authors, a good algorithm for treating most patients.[7]

Goals of Treatment

The goals of treatment should be to ultimately obtain a healed fracture and avoid associated complications, such as nonunion or delayed union, angular or rotational deformity, unequal leg lengths, infection, neurovascular injury, disruption of the growth plate, muscle weakness, and/or compartment syndrome.[1,2,4] Each primary treatment modality has associated complications that will be discussed in detail.

Spica Casting

The current standard of care for young children aged 6 months to 6 years with an isolated femoral diaphyseal fracture is the application of an immediate hip spica cast within 24 to 48 hours. Early spica casting is ideally indicated for femoral shaft fractures, with as much as 20 mm of initial shortening. The cast is generally worn for a period of 4 to 8 weeks. The advantages of an immediate spica cast include relatively low cost, low complication rates, and a very high rate of achieving union with proper alignment.[1,2,8,9]

However, the primary disadvantage of the immediate spica cast relates to the challenges of caring for the affected child. Families have reported substantial restrictions on mobility because most children are completely dependent, requiring the use of wagons or wheelchairs. This decrease in mobility further affects a child's presence in school and can cause a substantial loss of the parents' time from work to care for the child.[8,10] The social costs of this treatment method have been determined to be greatest when the child is of school age (older than 5 years) and both parents work.[1,2]

Technique

Two types of spica casting are commonly used. They differ based on the length of the cast placed on the unaffected limb, thereby allowing distinctive degrees of mobility while maintaining reduction (**Figure 1**). Excellent results have been reported using both the unilateral (single leg) hip spica cast and the one and one-half hip spica cast.[8] Currently, there is an increasing interest in using the more patient-friendly, unilateral hip spica cast. A study by Epps et al[8] documented the use of a single leg hip spica cast and found similar excellent results as seen with the one and one-half hip spica cast along with the possibility for increased mobility while undergoing treatment. Therefore, the recommendation for each type of spica cast is based on the ambulatory status of the child, with the unilateral hip spica cast used in ambulatory children and the one and one-half hip spica cast reserved for nonambulatory children.[8]

Tips for Spica Casting

In general, the positioning of the hip and the knees and the amount of recommended hip and knee flexion vary by physician training and preference and the position of the fracture. In most centers, casting is performed with sedation in an operating room. When the fracture occurs more proximally, it is necessary to increase the amount of hip flexion. Most physicians place children in the semisitting position, setting the hips and knees at approximately 45° of flexion. The legs are abducted approximately 30° on each side; this places the fracture into a valgus position to help counter the natural tendency of a more varus position that occurs during healing because of the unopposed thigh adductors.[8] This position also facilitates hip carrying of the child, eases toileting, and allows school-age children to attend class in a reclining wheelchair.[1,2] A single-leg spica cast is positioned with approximately 30° of hip and knee flexion, leaving the foot positioned such that the child may toe-touch on the fractured side to improve walking stability.[1,2,8] Obtaining excessive traction by grasping the calf or the foot of the fractured side or by pulling through a short leg cast is not recommended because of the risk of peroneal nerve stretching and excessive pressure on the calf musculature.

After the cast has hardened, AP and lateral radiographs are obtained. Acceptable reduction parameters include less than 15° of varus or valgus malalignment, less than 20° of AP malalignment, less than 30° of malrotation, and less than 2.5 cm of shortening. Children are then discharged after a 24-hour observation period, and radiographs are repeated in 7 to 10 days.[1,2,8] This is the ideal time for follow-up because the correction of small amounts of shortening and angulation may still be accomplished easily. If excessive angulation is discovered, there are two options for correction: (1) cast wedging for children who experience less than 15° of angulation and (2) a cast change. Children with excessive shortening may be treated by several different strategies, which are discussed in the next subsection.

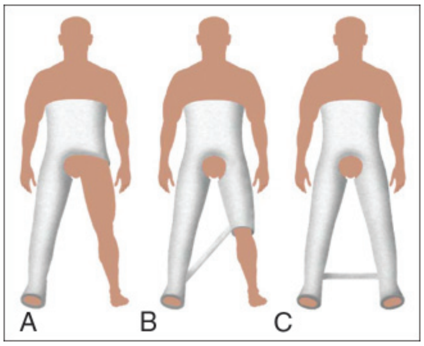

Figure 1 Spica casting options. **A,** Unilateral hip spica cast. **B,** One and one-half hip spica cast. **C,** Bilateral long leg hip spica cast. (Courtesy of Lucile Packard Children's Hospital, Palo Alto, CA.)

Complications of Spica Treatment

Shortening

Currently, the most commonly reported complication of spica cast treatment is excessive shortening of the fracture fragments, thereby resulting in a limb-length discrepancy.[9] Some shortening is acceptable but ideally should not exceed 2 cm. Because most children aged 2 to 10 years will predictably overgrow the shortened leg by 0.5 to 1 cm after the fracture heals, as much as 2.5 cm of shortening is acceptable in this age range. After immediate spica casting, the risk of losing initial reduction doubles with each centimeter of initial shortening identified preoperatively on radiographs (1 cm, 12%; 3 cm, 50%).[4]

By using the telescope test at the time of initial reduction and casting, the risk of shortening can be minimized. If more than 3 cm of shortening can be demonstrated under fluoroscopy in the operating room while applying gentle axial compression, traction or fixation rather than immediate spica casting is used.[1,2] In the study conducted by Thompson et al,[9] 25 mm was considered the upper limit of acceptable overlap of fracture fragments. This group reported

Figure 2 Clinical photograph of skin irritation caused by the difficulty of providing hygienic care in a child with a spica cast. (Courtesy of Shannon Safier, Philadelphia, PA.)

a sensitivity of 80% and a specificity of 85%; a positive telescope test puts a child at approximately 20 times the risk for unsatisfactory outcome.[4,9]

This chapter's authors prefer to use flexible intramedullary nailing to salvage shortening in acute fractures whenever possible. For fractures with excessive shortening or advanced healing, however, external fixation that permits lengthening through the callus is the preferred choice; alternatively, osteoclasis and static external fixation can be used. Traction is rarely used in the practices of this chapter's authors. For fractures that heal with excessive shortening, an appropriately timed epiphysiodesis of the opposite distal femur is the best method of treatment when the limb-length discrepancy is 5 cm or less. Gradual correction with a frame that permits angulation correction and lengthening is the treatment of choice for shortened fractures with excessive deformity.

Compartment Syndrome

Another important yet rare complication of spica casting is compartment syndrome in the affected lower leg. The classic signs of compartment syndrome are often unreliable in children. An increasing analgesic requirement may be the most sensitive marker because the thigh and the lower leg are not available for direct examination. Large and Frick[11] analyzed various factors associated with spica treatment that might contribute to the development of compartment syndrome and the subsequent possibility of permanent neural and muscular function loss. They hypothesized that the following factors may contribute to compartment syndrome: arterial spasm, increased tissue pressures from the injury, direct pressure, elevation of the leg, venous stasis, and traction application techniques during casting. Sitting position spica casts cause forced elevation of the leg when a patient is supine, thus leading to possible hypoperfusion, ischemia, and swelling; this cycle has been hypothesized to be causative for compartment syndrome in both well and affected legs.[11] Application of pressure on the calf during the casting procedure, either to maintain position or pull traction on the affected femur, has been reported as an additional factor.[4,11] Studies have shown that calf-supported positions, such as the 90/90 spica cast, lead to increased pressure in all four compartments of the leg compared with heel-supported positions, such as in a cast with the hip and the knee positioned at 45° or less of flexion.[11]

The current recommendations to lessen the risk of this complication include (1) applying a long leg cast first and then applying traction or (2) applying the upper part of the cast first while holding the foot of the fractured leg without applying traction. This avoids pressure in the calf region. Another option is to leave the foot out of the cast to allow increased ability to examine the patient for swelling and any signs of neurologic dysfunction. The parents also should be instructed to prop up the child in a semireclining position to lessen the degree of elevation associated with the seated position while in the spica cast. Educating parents about the warning signs of compartment syndrome—such as excessive pain, increased irritability, swelling, color changes, and/or problems with motor or sensory function—may improve the chances of early diagnosis should compartment syndrome occur.[11] Emergency fasciotomies of the lower leg to release all four compartments through medial and lateral skin incisions is the treatment of choice for patients with acute compartment syndromes after casting.

Skin Complications

Another important complication related to spica cast treatment is skin damage (**Figure 2**). The difficulties with hygiene, especially when a child wears a diaper, can result in the dreaded "poopy cast." Skin irritation akin to diaper rash, breakdown and maceration, urine burns, and even cellulitis may result from prolonged skin contact with liquid and solid waste trapped under the cast or in the padding. This chapter's authors recommend that parents change the child's diaper every 2 to 3 hours regardless of whether the diaper seems soiled and tuck a small diaper under the cast edges while covering the entire perineum with a second larger diaper. Increased wetness and/or foul odor require inspection and cast trimming or a complete change of cast. Although expensive, a waterproof, breathable liner may help to decrease skin problems.[1,2,4]

Flexible Intramedullary Nailing

Flexible intramedullary nailing—a technique first used in Nancy, France, in the early 1970s—has become an increasingly popular method of fixation for pediatric femoral fractures. Its ideal application is in skeletally immature children aged 5 to 11 years who have transverse fractures in the middle 60% of the femoral diaphysis.[1,2,4,6] Poor outcomes have been reported as five times more likely in patients who weigh more than 108.5 lb and four times more likely in patients older than 11 years.[1,2] This method of fixation functions as an internal splint that holds length and alignment but permits enough motion at the fracture site to generate sufficient callus.[4]

This technique offers relatively easy pin insertion and removal, satisfactory fixation, and earlier mobilization and return of function compared with nonsurgical techniques. There also are smaller scars compared with other surgical treatments, such as external fixation and plating.[1,2,6] Furthermore, this technique avoids the risks of femoral head osteonecrosis and premature greater trochanteric epiphysiodesis associated with rigid intramedullary devices and spares injury to the physes.[12]

Technique of Nail Insertion

The French pioneers in flexible intramedullary nailing stressed the critical importance of proper technique, including prebending the nails so that the apex of the bend is located at the fracture site to produce a spring effect.[1,2,13] By positioning the nails in this manner, the implants balance one another to prevent bending, control rotation, and add to the rigidity of fracture fixation. Nail insertion can take place in either an antegrade fashion for more distal fractures or a retrograde fashion for diaphyseal and more proximal fractures.[6] A disadvantage of proximal entry relates to the lack of safe medial and lateral starting points, which can result in unbalanced and asymmetric implants.[4]

Most fractures can be treated with nails advanced in a retrograde fashion. To begin, medial and lateral starting drill holes are made 2.5 cm proximal to the distal femoral physis at approximately a 10° angle to the cortex. The first nail is advanced to the fracture site, the fracture is reduced, and the nail is then driven across it. The second nail is then advanced across the fracture site. Nail rotation and fracture manipulation make crossing the site easier. Both nails are then advanced proximally until they reach their final resting positions, with the nail that entered the lateral cortex resting just distal to the trochanteric apophysis and the medial nail pointing to the lesser trochanter. The nails are then cut distally. A small portion of the nail, less than 1 cm should be allowed to remain outside the cortex to facilitate removal and lessen irritation on the soft tissues.[10,13]

Complications of Flexible Nails

Soft-Tissue Irritation Around the Knee

Soft-tissue irritation at the insertion site is the most common complication of the procedure. This may be from nail contact with the quadriceps medially or, more commonly, the iliotibial band laterally. Patients with nail ends in excess of 10 mm or more report pain or irritation at the knee 4.5 times more often than those with shorter lengths of nail protrusion. For some patients, pain or irritation at the nail insertion sites may necessitate reoperation to advance, trim, or remove nails early.[6] To avoid this complication, the nail should be trimmed short enough to allow it to lie in apposition with the distal flare medially and just proximal to the physis laterally, deep to the iliotibial band. This chapter's authors prefer to trim the nail just before its final seating, with final positioning achieved by a hollow tamp. Alternatively, the nail may be pulled back from its final position, trimmed, and then advanced again. Although many patients will be symptomatic while the nails are in place, most will experience relief and regain full knee motion after hardware removal, which is typically done 9 to 12 months after the fracture occurred and when radiographs document complete healing.

Mismatched Nails and Loss of Reduction

Loss of reduction is typically caused by a combination of two important factors: improper implant usage and improper indications for flexible nails. The ideal titanium nail construct is two identical nails, each with a diameter that fills approximately 40% of the canal, contoured such that the maximal spread of the implants occurs at the fracture site. The largest possible nail size that permits two nails of similar size to fit into the medullary canal should be chosen. The correct nail size can be selected by preoperatively measuring the canal with radiography or intraoperatively placing the nail over the femoral canal using fluoroscopy. Using nails that are too small or mismatched increases the rate of complications.[1,2,6,13] The use of mismatched nails produces unequal force loads that can result in angulation, loss of reduction, or radiographic malunion. It has been reported that loss of reduction or radiographic malunion was 19 times more likely when mismatched nails were used.[6]

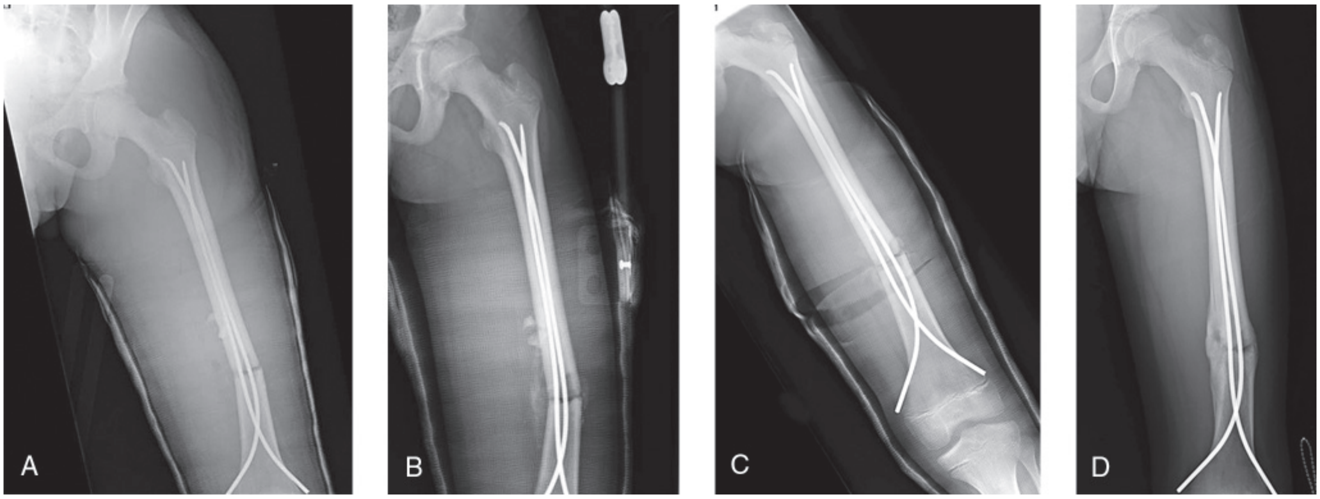

Figure 3 **A,** Immediate postoperative radiograph of a transverse femoral fracture in a 12-year-old girl treated with flexible nail fixation. **B,** Radiograph taken at the 1-week follow-up shows 15° of angulation in varus. **C,** Radiograph of the fracture after the cast was wedged in the clinic. **D,** Radiograph of the fracture at the 3-month follow-up.

Inadequate Nail Size and Loss of Reduction

The use of nails that are too small or too flexible can lead to loss of reduction because of the increased stress on the implants from an excessively large patient or an unstable fracture pattern. Nails that are 4.0 mm in diameter are best for children weighing less than approximately 110 lb and are not recommended for larger children. Flexible stainless steel nails are an alternative to titanium nails and have recently gained popularity because they are more rigid than equivalently sized titanium nails and may afford added stability for heavier patients. However, titanium nails allow more micromotion and therefore stimulate more rapid healing.

Unstable Fracture Patterns

In addition to patient size, unstable fracture patterns present another challenge because of the added stress placed on the implants. In a study using titanium elastic nails in pediatric femoral fractures, comminuted fractures stabilized with titanium elastic nails were more likely to experience complications, with these fractures being four times more likely to result in a loss of reduction than those without comminution.[6] It has been advised that fractures with greater than 25% cortical comminution be closely monitored to detect early loss of reduction and may even benefit from additional external immobilization or alternative methods of fixation.[14] In another study addressing unstable fracture patterns, the authors concluded that stainless steel nails might have an advantage over their titanium counterparts in maintaining reduction.[12]

Tips to Avoid Complications

To avoid loss of reduction, this chapter's authors always use two titanium nails of the same size that together fill 80% of the canal. Stainless steel nails are reserved for patients weighing more than 110 lb or a rigid locked lateral entry nail is used in place of flexible nails. If unstable fracture patterns are treated with flexible nails, this chapter's authors will often immobilize the limb in a unilateral spica cast for 3 to 4 weeks or use a knee-ankle-foot orthosis temporarily after surgery. However, if fracture stability is unclear, alternative methods of fixation that are better suited for unstable fracture patterns rather than flexible nails should be used, including submuscular plating and external fixation, both of which may be used to successfully treat unstable diaphyseal fracture patterns (**Figure 3**).

Distal Femoral Physeal Fractures

Distal femoral physeal fractures in children, most commonly Salter-Harris type II fractures, are relatively rare injuries and account for fewer than 2% of all physeal injuries.[1,2,15,16] The most common mechanism of injury is a varus or valgus stress positioned across the knee joint, such as from sports activities or motor vehicle crashes. In skeletally mature patients, this stress typically causes ligament disruption. However, in an immature knee, tensile forces are transmitted through the ligaments to the physis, which can lead to disruption of the periosteum, with a resulting fracture plane through the distal

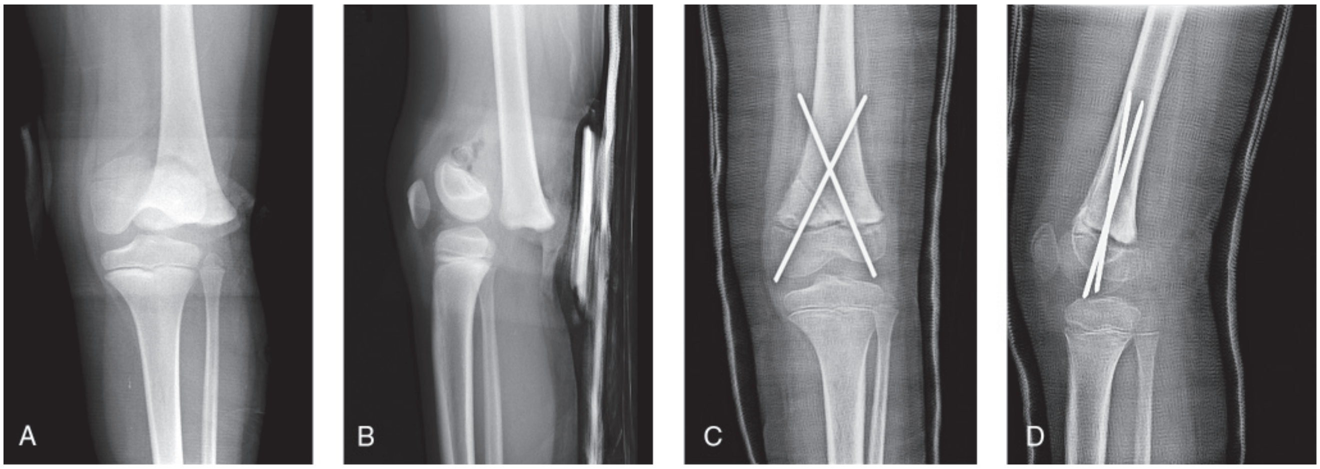

Figure 4 AP (**A**) and lateral (**B**) radiographs of a Salter-Harris type II fracture of the distal femoral physis in an 8-year-old girl. AP (**C**) and lateral (**D**) views of the fracture after closed reduction and percutaneous pinning in the operating room.

femoral physis.[1,2] Anterior displacement of Salter-Harris types I and II fractures may be associated with popliteal artery injuries, whereas severely displaced varus deformities may be associated with peroneal nerve palsies.

Treatment

Casting

Most nondisplaced fractures are treated with a long leg cast and no weight bearing on crutches for 4 weeks followed by progressive weight bearing in a cast or a hinged knee brace for an additional 4 weeks. All displaced fractures should be ideally treated with reduction, either closed or open, and fixation.

Surgical Treatment

Salter-Harris Type I and II Fractures

Displaced Salter-Harris type I fractures require reduction under anesthesia. After manual reduction has been achieved, the fracture is secured with crossed, percutaneously placed, smooth Kirschner wires.[17] For Salter-Harris type II fractures (**Figure 4**) with a small Thurston-Holland fragment, treatment is done similarly as for Salter-Harris type I fractures. This chapter's authors bury the Kirschner wires beneath the skin and then return to the operating room in 4 to 6 weeks to remove them. Alternatively, the wires may be cut outside the skin and removed in the clinic at 3 to 4 weeks. If the metaphyseal fragment is large, one or two 4.5- to 7.3-mm cannulated screws with washers are placed transversely through the metaphyseal fragment into the bone of the femoral shaft while holding the reduction. Ideally, the threads of the screws completely cross the fracture site and achieve compression. After the procedure has been completed, a long leg cast is then applied for a period of 4 to 6 weeks to aid in stabilization.

Salter-Harris Types III and IV Fractures

Nearly all Salter-Harris types III and IV fractures, regardless of whether they are displaced, are best treated with fixation because of their unstable nature and the tendency to displace in a cast alone during the first several weeks after injury if fixation is not used.[17] In addition, these fractures are intra-articular as well as physeal, and, hence, anatomic alignment with stable fixation improves the chances of a good outcome. For minimally displaced fractures, percutaneous placement of smooth wires or cannulated screws is one option and is preferred by this chapter's authors when possible. Open reduction is necessary for fractures not amenable to closed reduction. Medial condylar types III and IV fractures are more common than lateral condylar types III and IV fractures. An anteromedial or an anterolateral approach to the knee is used to perform open reduction, based on the location of the fracture[1,2] (**Figure 5**).

Screw placement can, at times, be challenging. One study highly recommended obtaining a CT scan preoperatively to help plan the placement of percutaneous cannulated screws.[17] One or two cannulated screws placed through the epiphysis and parallel to the physis, avoiding the notch, is sufficient fixation for most fractures. Screw sizes vary from 4.5 mm to 7.3 mm, depending on the size of the patient. To ensure proper placement of the implant, it is important to rotate the leg under fluoroscopy to visualize the screw at its

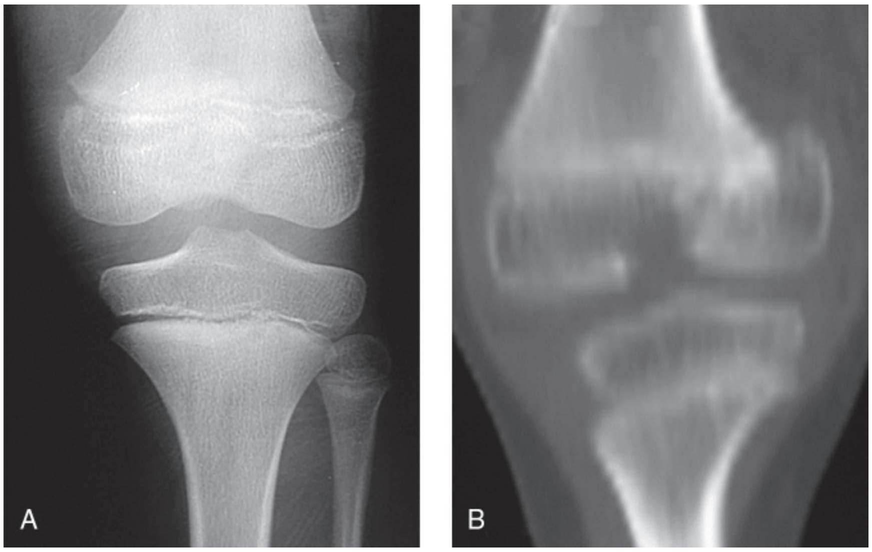

Figure 5 **A,** AP radiograph of a Salter-Harris type III fracture of the distal femur in an 11-year-old boy. **B,** CT scan of the fracture.

longest length. By doing so, the surgeon can verify that the screw is not sitting outside the bone or potentially in soft tissue. After fixation, a long leg cast is applied. Most fractures heal within 6 to 8 weeks of injury. Knee stiffness after fracture healing can be reduced by encouraging knee motion as soon as fracture healing is evident clinically and radiographically. Return to activities can be expected 3 to 4 months after the fracture. All skeletally immature patients who sustain these fractures should be followed radiographically at 4- to 6-month intervals until skeletal maturity to facilitate early diagnosis of growth arrest.

Complications

Growth Arrest

The most common and serious complication of fractures of the distal femoral physis is growth disturbance leading to angular deformity and/or shortening.[1,2] These fractures have a reported incidence of 30% to 70% of growth arrest.[15,17] In one meta-analysis of the published literature from 1950 to 2007 that included 564 fractures, 52% of the fractures resulted in growth disturbance.[18] Overall, high risks for growth arrest include displaced fractures, nonanatomic reduction, and open fractures.

Consequences of Growth Arrest

The consequences of growth arrest are most severe in children younger than 10 to 12 years because of their rapid growth and advancing skeletal maturation. The distal femoral physis grows about 9 mm per year in a healthy child and accounts for nearly 40% of the overall growth of the lower extremity. Because of this, complete growth arrest of the distal femur can produce a substantial difference in limb length, and an incomplete arrest can produce significant angular deformity of the knee.[17]

Diagnosis

Growth arrest is typically the result of bony bridge formation resulting from either direct physeal trauma to the resting chondrocytes or a nonanatomic reduction. Screw fixation that crosses the physis is another etiology. Radiographs can be examined for the appearance of a Park-Harris line, which is a fine, sclerotic line within the metaphysis that develops parallel to and proximal to the physis. If normal growth has resumed after the fracture, this line grows away from the physis in a symmetric and parallel fashion. However, if an oblique line appears, this indicates asymmetric growth and warrants further follow-up.[1,2] MRI also is useful for the early detection of bone bridge formation; MRI can detect growth disturbance as early as 2 months after the initial injury.[1,2,15]

Prevention

Growth arrest may be seen after any fracture type regardless of displacement but is most common after displaced fractures. The risk can be diminished in patients with displaced fractures by achieving anatomic reduction with as little surgery as possible and maintaining the reduction with stable fixation that does not harm the physis. In a rabbit model, transphyseal smooth wires that disrupt less than 7% of the cross-sectional area of the distal femoral physis do not cause growth disturbance.[16] In contrast, transphyseal screws or plates that cross the physis should be avoided because these implants will inhibit physeal growth.

Surgical Options

If growth arrest is identified early in a child with at least 2 years of growth remaining and MRI mapping of the physeal bar shows that less than 50% of the growth plate is bridged, physeal bar resection and interposition with fat is an option. Completion of the partial arrest and epiphysiodesis of the contralateral distal femur also may be done when the physeal bar has been identified soon after fracture healing and no significant limb-length discrepancy or angulation has occurred. Appropriately timed epiphysiodeses, osteotomies, and limb-lengthening procedures done separately or combined are other options used to treat growth arrest depending on the age of the child, the expected limb-length discrepancy, and the degree of angulation (**Figure 6**).

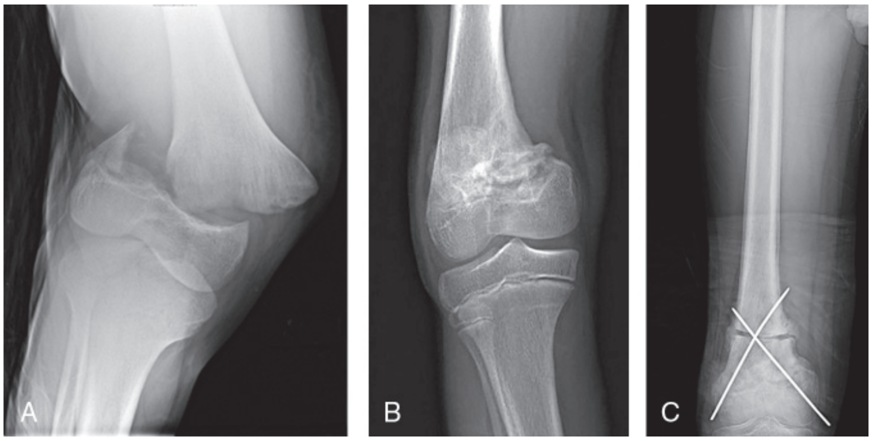

Figure 6 **A,** AP radiograph taken in the emergency department of a Salter-Harris type II fracture of the distal femur in a 13-year-old boy. **B,** AP radiograph taken 6 months after treatment shows formation of a physeal bar and angular deformity. **C,** AP view of the fracture after a corrective osteotomy was performed.

Vascular Injury

Vascular injury can occur in association with distal femoral fractures, especially if the epiphysis is displaced anteriorly with severe apex posterior angulation because the popliteal artery may be stretched or lacerated by the distal end of the femoral metaphysis. In the emergency department, it is critical that (1) pulses are palpated and (2) capillary refill is assessed to determine if an associated vascular injury has occurred. If the diagnosis of arterial injury is not clear, measuring the ankle-brachial index has been shown to be reliable for detecting a possible arterial injury compared with assessing pulses by either palpation or Doppler signal assessment.[17] If a patient has poor distal limb perfusion or none at all, the best option is to proceed to the operating room emergently for reduction and fracture fixation. If perfusion to the limb is not restored, open exploration in the popliteal space is indicated. A lower leg fasciotomy is performed before leaving the operating room if the limb ischemia time is longer than 4 to 6 hours.

Compartment Syndrome

Compartment syndrome of the lower leg has been reported to occur in 1.3% of Salter-Harris fractures, and peroneal nerve palsy has been observed in 7.3%.[17] Improper casting of a swollen extremity in greater than 90° of flexion after fracture reduction or immobilization of a nondisplaced fracture in this position can compromise the popliteal vessel and interfere with distal circulation, potentially leading to compartment syndrome. Other etiologies of compartment syndrome include associated lower leg trauma, such as a crush injury or a tibia fracture (floating knee variant), and prolonged limb ischemia from an arterial injury. If severe swelling is noted after fracture fixation, the limb should be splinted in 20° to 30° of flexion and casted when the swelling has subsided. To reduce the risk of compartment syndrome after a floating knee injury, stable fixation of both fractures and postoperative splinting is best. Compartment syndrome of the lower leg is treated with four-compartment fasciotomies.

Knee Stiffness

Long-term loss of knee range of motion has been reported in as many as 25% of patients with Salter-Harris type II fractures of the distal femur.[17] Limitation of knee motion may be caused by intra-articular adhesions, capsular contracture, or muscular contracture. This should be treated with an aggressive physical therapy program that includes both active and active assisted range-of-motion exercises. For patients with persistent knee stiffness in whom conservative treatment has failed, MRI is indicated to rule out intra-articular processes, such as meniscal tears or chondral lesions that may be contributing to the difficulty with rehabilitation. Arthroscopic-assisted manipulation under anesthesia and surgical release of contractures are rarely necessary but are options for patients with persistent loss of knee motion.[1,2]

Summary

Femoral shaft fractures and distal femoral physeal fractures are common injuries in pediatric patients and frequently require stabilization and/or fixation. Complications are common in both of these types of injuries but can be minimized by understanding the treatment options and adhering to proper techniques.

References

1. Kasser JB, Beaty JH: Femoral shaft fractures, in Beaty JH, Kasser JR, eds: *Rockwood and Wilkins' Fractures in Children,* ed 6. Philadelphia, PA, Lippincott Williams & Wilkins, 2006, pp 893-936.
2. Skaggs DL: Extra-articular injuries of the knee, in Beaty JH, Kasser JR, eds: *Rockwood and Wilkins' Fractures in Children,* ed 6. Philadelphia, PA, Lippincott Williams & Wilkins, 2006, pp 937-984.
3. Blakemore LC, Loder RT, Hensinger RN: Role of intentional abuse in children 1 to 5 years old with isolated femoral shaft fractures. *J Pediatr Orthop* 1996;16(5):585-588.
4. Flynn JM, Schwend RM: Management of pediatric femoral shaft fractures. *J Am Acad Orthop Surg* 2004;12(5):347-359.
5. Coffey C, Haley K, Hayes J, Groner JI: The risk of child abuse in infants and toddlers with lower extremity injuries. *J Pediatr Surg* 2005;40(1):120-123.
6. Narayanan UG, Hyman JE, Wainwright AM, Rang M, Alman BA: Complications of elastic stable intramedullary nail fixation of pediatric femoral fractures, and how to avoid them. *J Pediatr Orthop* 2004;24(4):363-369.
7. American Academy of Orthopaedic Surgeons: *Clinical Practice Guideline on Treatment of Pediatric Diaphyseal Femur Fractures*. Rosemont, IL, American Academy of Orthopaedic Surgeons, June 2009. http://www.aaos.org/research/guidelines/PDFFguideline.pdf.
8. Epps HR, Molenaar E, O'Connor DP: Immediate single-leg spica cast for pediatric femoral diaphysis fractures. *J Pediatr Orthop* 2006;26(4):491-496.
9. Thompson JD, Buehler KC, Sponseller PD, et al: Shortening in femoral shaft fractures in children treated with spica cast. *Clin Orthop Relat Res* 1997;338:74-78.
10. Flynn JM, Hresko T, Reynolds RA, Blasier RD, Davidson R, Kasser J: Titanium elastic nails for pediatric femur fractures: A multicenter study of early results with analysis of complications. *J Pediatr Orthop* 2001;21(1):4-8.
11. Large TM, Frick SL: Compartment syndrome of the leg after treatment of a femoral fracture with an early sitting spica cast: A report of two cases. *J Bone Joint Surg Am* 2003;85(11):2207-2210.
12. Rathjen KE, Riccio AI, De La Garza D: Stainless steel flexible intramedullary fixation of unstable femoral shaft fractures in children. *J Pediatr Orthop* 2007;27(4):432-441.
13. Lascombes P: *Flexible Intramedullary Nailing in Children: The Nancy University Manual*. Berlin, Germany, Springer, 2010.
14. Sink EL, Gralla J, Repine M: Complications of pediatric femur fractures treated with titanium elastic nails: A comparison of fracture types. *J Pediatr Orthop* 2005;25(5):577-580.
15. Arkader A, Warner WC Jr, Horn BD, Shaw RN, Wells L: Predicting the outcome of physeal fractures of the distal femur. *J Pediatr Orthop* 2007;27(6):703-708.
16. Butcher CC, Hoffman EB: Supracondylar fractures of the femur in children: Closed reduction and percutaneous pinning of displaced fractures. *J Pediatr Orthop* 2005;25(2):145-148.
17. Wall EJ, May MM: Growth plate fractures of the distal femur. *J Pediatr Orthop* 2012;32(suppl 1):S40-S46.
18. Basener CJ, Mehlman CT, DiPasquale TG: Growth disturbance after distal femoral growth plate fractures in children: A meta-analysis. *J Orthop Trauma* 2009;23(9):663-667.

Video Reference

Parikh S: *Elastic Stable Intramedullary Nailing (ESIN) for Femoral Shaft Fractures: Surgical Technique* [video]. Cininnati, OH, Cincinnati Children's Hospital, 2012. http://orthoportal.aaos.org/emedia/singleVideoPlayer.aspx?resource=EMEDIA_OSVL_12_20. Accessed October 20, 2014.