Pediatric femoral shaft fractures: current and future treatment

Femoral shaft fractures are common in pediatric age groups. Children under the age of 2 years should be evaluated for evidence of non-accidental trauma (child abuse). Treatment of the fracture is dependent on the patient's age, weight, fracture configuration, soft-tissue injury, presence of other injuries and social situation. Pavlik harness treatment is preferred during the first 3 months of life and can be utilized up to 1 year of age. Immediate spica casting is most commonly used from 3 months to 5 years of age. Flexible intramedullary nailing has revolutionized the treatment of pediatric fractures and is most commonly used in the west for pediatric femur fractures in patients 5–12 years of age. Patients 12 years of age up to skeletal maturity present a dilemma and, most recently, lateral trochanteric nailing has been shown to be a safe option without the risks associated with nailing through the piriformis fossa in adolescents. Submuscular plate stabilization has been demonstrated by a number of authors to be a safe and effective method of stabilizing unstable fractures in all age groups from toddlers to skeletal maturity. External fixation, most often using monolateral external fixators, provides an effective method of treating polytraumatized patients and severe open fractures without internal fixation. The method is effective but has decreased in popularity in the west with reports of high rates of refracture.

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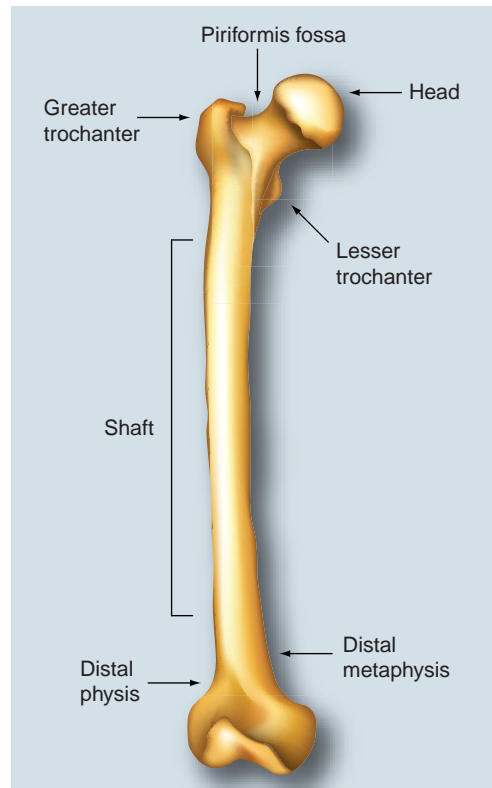St Louis Shriners Hospital,
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Femoral shaft fractures can occur in children of all ages. They account for 1.6% of all childhood fractures, and they lead to significant impact on the child and family [1]. The treatment of these fractures can vary greatly depending on the age of the patient and the fracture pattern. The incidence occurs in a bimodal distribution, with peaks in early childhood and mid-adolescence. In early childhood, the most common mechanism is a simple fall or twisting injury. In nonambulatory children, up to 80% of femoral shaft fractures are the sequelae of nonaccidental trauma (child abuse) [2]. In adolescents, the most common mechanism is a high-energy injury such as a motor vehicle collision. Traditionally, the treatment for closed femoral shaft fractures in children was a period of skeletal traction until signs of healing were seen on x-ray followed by spica casting for 3–12 weeks. This led to long hospitalizations and prolonged periods of bedrest. Over the past 20 years, treatment options have changed to allow early mobilization and much shorter hospitalizations.

The femoral shaft encompasses the area below the lesser trochanter of the femur and above the distal metaphysis. Figure 1 details the osseous anatomy of the femoral shaft. Fractures involving the proximal femur, in particular, involving the femoral neck, have substantially different consequences and treatment options. Likewise, distal femoral fractures, particularly those involving the distal femoral physis, present unique difficulties and consequences.

Pediatric femoral fractures are significantly different from those in adults in that children are capable of remodeling malaligned fractures through bone deposition in response to Wolff's law, depositing bone in areas of high stress as well as by reorienting the physes. In addition, the phenomenon of overgrowth occurs in children usually between the ages of 2–10 years, in which the affected limb grows faster than the unaffected limb over the 2 years following the fracture, usually a total of approximately 1.5 cm [3].

Initial care

When a child experiences a femoral shaft fracture, there will be immediate pain and inability to bear weight on the affected extremity. There will often be deformity and instability of the limb that will be obvious to caretakers. Delayed presentation to the emergency department is an indication of nonaccidental trauma. In the field, the limb should be stabilized in a splint, or in older children using a portable traction device, such as a Hare traction splint, to prevent

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Figure 1. Diagram of a femur.

movement of the bone fragments en route to the emergency department. This will decrease the child's pain as well as minimizing the injury to the surrounding soft tissues. Basic trauma protocol with attention to airway, breathing and circulation should be carefully observed, especially in the setting of high-energy trauma.

Emergency department care

Every child with a femoral shaft fracture should receive a careful, complete physical exam to avoid missing associated injuries. Associated soft-tissue injury, head trauma or additional fractures can occur in up to 40% of children who sustain a femoral shaft fracture due to high-energy trauma [4]. A careful neurovascular exam of the affected leg is also essential. Any splint or immobilization placed in the field should be removed. The overlying skin should be inspected, and even shallow abrasions or small lacerations should be recorded. Even a small 'poke hole' in the skin can represent an open fracture, with exposure of the fracture site to the outside environment. Patients will often require intravenous pain medications to achieve adequate pain control.

In the case of confirmed or suspected open fractures, intravenous antibiotics should be given as soon as possible. The time to the first dose

of antibiotics has been shown to be one of the most important predictors in the development of subsequent infection in open fractures [101]. Generally, a first generation cephalosporin, such as cefazolin, should be used in all open fractures. For fractures associated with a laceration longer than 2 cm, coverage for gram-negative organisms is commonly added. If the fracture site is contaminated by significant amounts of debris, particularly organic matter, anaerobic coverage should be added as well [5]. Fractures that are open due to gunshot wounds with low velocity weapons are not generally considered to have the same infection risk as other open fractures and a simple first generation cephalosporin is usually adequate.

Plain anteroposterior and lateral radiographs of the femur should be obtained after the patient's arrival in the emergency department. These radiographs in many cases can be adequately obtained and interpreted with the child still in the splint to avoid causing more pain. The radiographs should include both the hip and knee joints to rule out any associated fractures. Isolated views can be obtained as well if there is concern for additional fractures. Preferably, these x-rays should be taken without any overlying splint material if possible. Advanced imaging, such as CT scans or MRI, is not usually required for femoral shaft fractures.

Once a careful physical exam and x-rays have been performed, the limb should be immobilized as quickly as possible. This can be accomplished in a number of ways. If operative treatment is not delayed, positioning the limb using pillows can be effective. For more distal femoral shaft fractures, a well-padded long leg splint with posterior, medial and lateral plaster slabs can provide adequate immobilization while the patient is awaiting definitive treatment. Fractures of the proximal femoral shaft are not well controlled with long leg splints alone. These are better managed with the placement of skin traction. To apply skin traction, a large foam pad is attached with spray adhesive to the patient's lower leg. Then, 2–3 kg of weight is attached to the foam pad and allowed to hang over the foot of the bed. This applies a constant longitudinal traction across the fracture site, and keeps the bone fragments grossly aligned.

Skeletal traction is also an option for immobilization of femoral shaft fractures, particularly if there is a concern that definitive treatment may be delayed more than 24 h following the injury. To apply skeletal traction, under conscious sedation or after a local anesthetic, a

smooth or threaded Steinman pin is inserted through the skin on the medial side of the leg, driven across the distal metaphysis of the femur and through the lateral skin. Up to 10 kg of weight can be hung from the pin via a pulley traction system to provide more stability to the fracture site than skin traction can provide, especially in larger children. In our institution, we reserve skeletal traction for larger children with concomitant injuries that will delay their definitive treatment.

Definitive care can involve any of a number of treatment modalities depending on the age and size of the child.

Pavlik harness
◼ Indications
Children under the age of 3 months can be treated with a Pavlik harness. Some authors suggest that children can be treated by a Pavlik harness up to the age of 12 months [6–9]. Although these devices are most often associated with the treatment of hip dysplasia, they provide adequate immobilization to allow their use in infants with femur fractures. These very young children tolerate spica casting poorly with reported difficulties encountered with feeding and other care. Femur fractures in this age group are almost universally caused by low-energy injuries such as falls from diaper changing tables, or standing height, birth trauma and nonaccidental trauma and, thus, initial shortening at the fracture site is minimal. Because of the excellent remodeling capacity of these infants, poor alignment is often well tolerated and malaligned bones tend to straighten and normalize rapidly.

◼ Technical notes
The proximal part of the femur in femoral shaft fractures tends to assume a characteristic position due to the unopposed forces of the muscles attached to this portion of the bone. The proximal femur flexes due to the iliopsoas muscle, abducts due to the gluteus medius and minimus muscles, and externally rotates due to the short external rotators. The Pavlik harness places the distal portion of the femur in a very similar position, leading to very good alignment. Care should be taken to avoid positions of extreme hip flexion as this has been associated with patients with hip dysplasia and could theoretically occur during fracture treatment, with the development of a usually reversible femoral nerve neurapraxia and resulting transient paralysis of the quadriceps muscle.

◼ Outcomes
Owing to the excellent remodeling capacity of infants, results of this treatment are excellent, providing good pain relief and a high rate of rapid union, usually in 3 weeks or less.

◼ Complications
Few complications are associated with this method of treatment. There is a risk of malunion and persistent malalignment when applied in children older than 3 months. Large children, over the age of 6 months, have been noted to have transient femoral nerve palsies associated with excessive flexion in children with hip dysplasia.

Early spica casting
◼ Indications
Currently, the most common nonoperative management of femoral shaft fractures in children 5 years and younger involves placing the patient in a spica cast within 24–48 h of injury. These casts extend from the foot of the involved extremity to the hip, wrap around the pelvis and abdomen up to the lower edge of the ribs or nipple line, and extend down to the contralateral knee (**F**igure 2). The lower extremities are placed in a semi-sitting position so that the patient can sit upright in a chair. Placing the hips in 90° of flexion, with 45° of abduction and the knee in 90° of flexion nearly universally results in adequate alignment. Although spica casts can be successfully used in older children, up to 10–12 years of age, the larger the child, the more difficult it is to hold the fracture stable without a period of preliminary traction. More recently, a number of centers have reported results with a single leg

Figure 2. A 4-year-old male in a spica cast.

'walking spica' allowing children up to 8 years of age to be ambulatory after early application of a spica cast (FIGURE 3).

■ Technical notes

In order to obtain a well-molded cast and an adequate reduction of the fracture site, spica casts are placed with the patient under conscious sedation or general anesthesia. The patient is placed onto the 'spica table' with support for the upper torso and a small perineal post. With an assistant holding the legs with 90° of flexion at the hip and the knee, stockinette is placed, then cotton padding,

Figure 3. A 7-year-old male displaying a walking spica cast.

followed by plaster or fiberglass. Care is taken to avoid making the cast too tight, especially around the torso, and to leave adequate exposure of the groin and buttocks for perineal care (FIGURE 4). The fracture is reduced with the use of fluoroscopic x-rays and held in place while the cast dries. Smooth tape is placed around the edges of the cast to smooth any potentially irritating edges.

In our institution, young children with femoral shaft fractures amenable to spica casting are admitted to the orthopedics service and the spica cast is placed under general anesthesia in the operating room. The patients are generally discharged the day of the procedure or the next morning, after the family receives training on spica cast care from the nursing staff. Some institutions choose to place spica casts under conscious sedation in the emergency department and discharge the patient directly home after the procedure [10].

■ Outcomes

When the patients are selected appropriately, early spica casting has very good overall results with high rates of healing. Spica casting also has an excellent safety profile, with low rates of infection or major complications. Between 86 and 96% of patients never require a cast change or any further interventions. When patients do require a cast change secondary to loss of reduction, the vast majority can be treated successfully in their second cast and never require any operative intervention [11–13]. See FIGURE 5A for an x-ray of a femoral shaft fracture in a 3-year-old boy being treated successfully in a spica cast. FIGURE 5B shows his x-ray 3 months later, with a well-healed fracture.

■ Complications

Although spica casting is a nonoperative form of treatment, it is not without potential complications. The risks of general anesthesia or conscious sedation are not avoided. Skin maceration is the most common early complication, especially in the perineal area, occasionally necessitating a cast change under repeat general anesthesia (FIGURE 6). Loss of reduction is more common in spica casts than in operative treatment. These patients should be followed up with repeat radiographs in 2–3 weeks to detect any early loss of reduction or shortening [14,15]. In young children with significant growth remaining, angulation up to 20° can be tolerated since the bone will remodel significantly over time [16]. In older children, a more anatomic reduction is required. Although rare, there have been reports of compartment syndrome in children after application of spica casts in which the long leg portion is applied first.

Excessive traction can then be applied easily, leading to pressure on the posterior leg and resulting compartment syndrome and necrosis, which can lead to lifelong disability [17]. Caring for children in a spica cast can also place a significant burden on the family with time out of work and school.

Leg-length discrepancies can occur after non-operative or operative treatment of femoral shaft fractures. The injured leg can be shorter due to shortening at the fracture site or longer due to overgrowth of the injured femur during the healing process. Average overgrowth is between 6 and 10 mm when patients are followed over approximately 4 years, most of which occurs within the first 2 years after injury, and may be higher in patients between the ages of 4 and 7 years old [18]. Patients should have yearly standing x-rays of both legs to evaluate for any developing leg-length discrepancy for at least 2 years postinjury.

Flexible intramedullary nailing
■ Indications
The availability of flexible nails in North America transformed the treatment of pediatric femoral shaft fractures in the early 2000s [19,20]. Flexible nailing of femoral shaft fractures allows for early mobilization of the patient and even early weight bearing in certain circumstances. This option is ideal for children younger than 12 years old when a spica cast is not desirable secondary to the patient's size, fracture pattern, overlying soft-tissue damage or family situation. Children less than 50 kg with transverse fractures in the central third of the shaft


Figure 4. Operative room positioning on a spica table for cast application.

can generally start weight bearing immediately postoperatively. Flexible intramedullary nails can be best used when the fracture pattern is transverse or oblique with minimal comminution. Long spiral fractures in older children and comminuted fractures can shorten, and other treatment options should be considered [21]. Children aged 6 years and above are good candidates for flexible intramedullary nailing but, recently, social considerations and the difficulty associated with caring for children in spica casts have led some to consider nailing for younger children as well.

■ Technical notes
Two flexible nails, made of titanium or stainless steel, are inserted in a retrograde fashion through small incisions over the distal metaphysis, 2 cm above the physis. The size of the nails is selected based on the diameter of the patient's
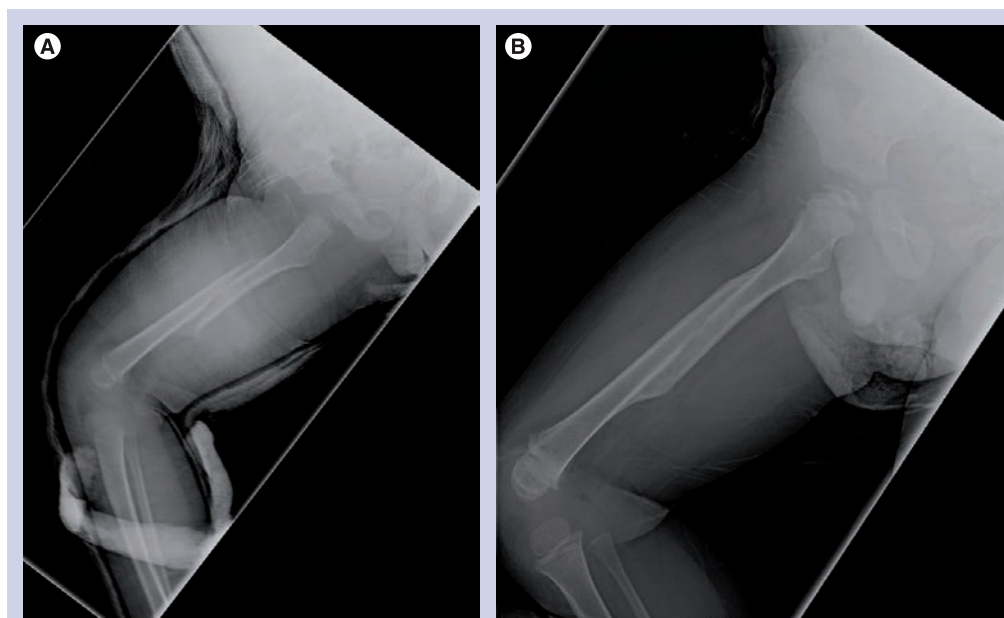
Figure 5. (A) A radiograph of a 3-year-old male being treated in a spica cast and (B) a radiograph 3 months after successful treatment in a spica cast.

Figure 6. Example of skin problems related to spica cast care.

intramedullary canal on preoperative radiographs. A hole is made in the bony cortex with a drill. The nails are then prebent, inserted and are advanced under fluoroscopic guidance until they reach the level of the fracture. The fracture is then reduced and held in place by an assistant while the rods are advanced across the fracture site (FIGURE 7). Some authors recommend advancing both nails to the fracture site prior to reduction while others suggest inserting and passing one nail at a time. In cases where the fracture cannot be reduced well enough to allow passage of the nails, an open reduction can be performed with a small incision directly over the fracture site. After the nails are inserted to within 1–2 cm of their final position, the nails are cut and then impacted to their final position, approximately 1 cm from the surface of the distal femur, and the wounds are closed. There is often no postoperative immobilization required. At our institution, the nails are removed if symptomatic after complete fracture healing has been achieved in 6–12 months.

Figure 7. Flexible nail insertion.

■ Outcomes

Flexible nailing is a safe and reliable method of fixation for pediatric femoral shaft fractures. They do not provide rigid fixation, but allow enough stability to permit for early mobilization and fracture healing. In one series reported in 2001, shortly after these implants became available in North America, 57 out of 58 patients had an excellent or satisfactory result, but four patients had a malunion with an angulation of over 10°. The one patient with a poor result had a malunion with 20° of angulation and 15 mm of shortening [22]. FIGURE 8A–C shows x-rays of a femoral shaft fracture in a 10-year-old male preoperatively, immediately postoperatively, and at the time of final follow-up after treatment with flexible nails. Moroz et al. reported poorer outcomes in patients over 49 kg and in patients aged 11 years and over [21].

■ Complications

Although complications are rare for flexible nailing, infection, nonunion and malunion are all potential complications, with 10% of patients reported by Flynn et al. developing shortening or unacceptable angulation [22]. Deep infection happens rarely, but is a serious complication requiring repeat operations (often more than one) and a prolonged course of intravenous antibiotics. The most common complication of flexible nailing is knee pain related to prominent nails at the distal femur. This knee pain can be cured with nail removal, but removing nails sooner than 6–12 months after injury leads to an increased chance of refracture. As discussed in the section on early spica casting, leg-length discrepancy either from malunion with fracture shortening or femoral overgrowth is a possible complication. Complications rates after flexible nailing of femoral shaft fractures are approximately four-times higher for children older than 11 years or heavier than 50 kg [22]. Although flexible nails can be used in some subtrochanteric or supracondylar fractures, use in these areas becomes more problematic and technically difficult.

Submuscular plating
■ Indications

Open reduction internal fixation with submuscular plating of femoral shaft fractures is a technique with limited incisions and indirect reduction techniques that has been developed to be less invasive than traditional plating techniques, but is still more invasive than either flexible nailing or rigid intramedullary nailing. Therefore, it is reserved for cases in which intramedullary
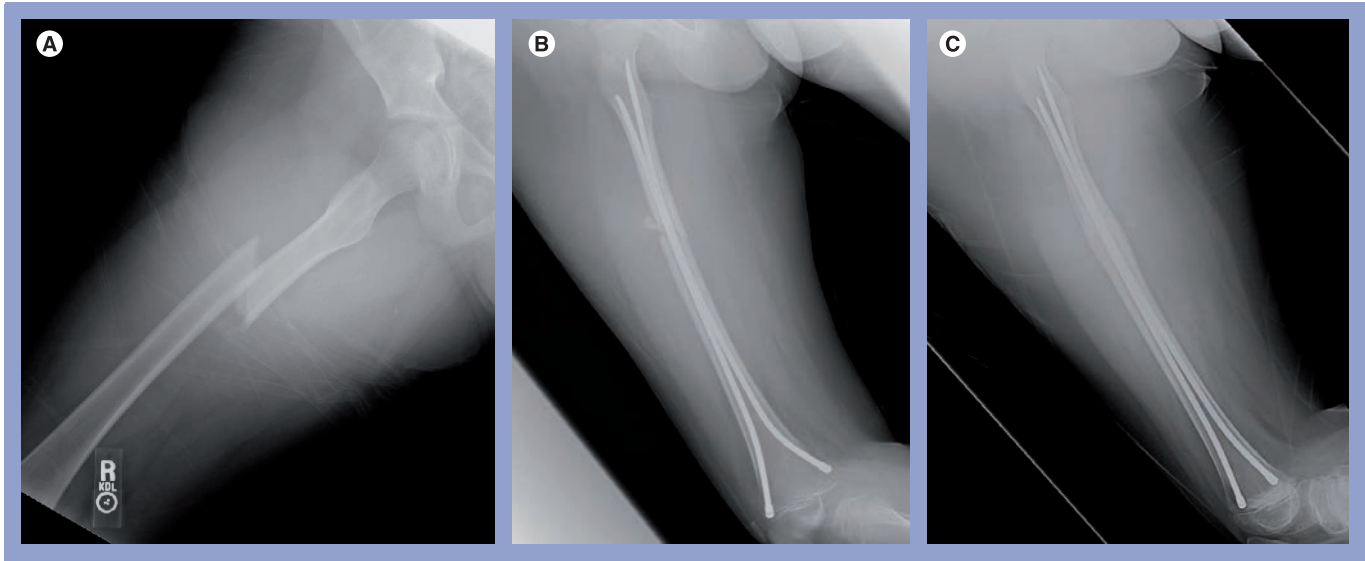
Figure 8. (A) Preoperative radiograph of a 10-year-old male before flexible nail insertion, (B) immediate postoperative radiograph after flexible nail insertion and (C) final follow-up radiograph.

fixation is not advisable due to bone loss or comminution of the fracture site. This technique can be used in children of any age and size. No postoperative immobilization is required, but children cannot bear weight on the affected extremity until the fracture has healed. Figure 9 shows a femoral shaft fracture in a 4-year-old female treated with submuscular plating. She was struck by a car and sustained multiple lower extremity and abdominal injuries. As evident from the x-ray, her femoral shaft has disrupted bone for a long segment, and would be prone to collapse with intramedullary fixation alone.

■ Technical notes
The goal of submuscular plating is to insert a long plate along the lateral cortex while disrupting as little periosteum and soft tissue as possible. This is done by making an incision distally and sliding the plate proximally beneath the muscular layer along the bone. The proximal screws can be placed under x-ray guidance using several small incisions.

■ Outcomes
Patients treated with submuscular plating typically do very well, with the vast majority going on to uneventful healing [23]. It is difficult to compare outcomes of submuscular plating to other techniques. Since plating is typically used for more complicated fractures, the rates of nonunion, malunion and leg-length discrepancy are expected to be higher regardless of technique. The technique allows early mobilization and motion with minimal soft-tissue disruption.

■ Complications
Early weight bearing can lead to plate breakage and nonunion, and most authors limit initial weight bearing. Overgrowth of the femur during healing leading to a leg-length discrepancy is more common if excessive periosteal stripping occurs. Most authors recommend that the plates are routinely removed. Delayed removal can potentially lead to the plate becoming buried, leading to difficulty in later removal. If the plates are not removed, the patient will always have a small risk of fracturing at either end of the plate or through a screw hole, since the plate acts as a stress riser on the bone.

Rigid intramedullary nailing
■ Indications
For children aged 8 years and older, rigid intramedullary nailing provides more rigid fixation of the fracture than flexible nailing. This allows for rapid mobilization in this age group and often even allows for early weight bearing. Rigid nails also allow for rotational control of the fracture fragments with interlock screws placed across the bone fragments and through the screw both proximally and distally. This provides increased stability for fracture patterns that tend to be rotationally unstable, such as spiral fractures. Rigid intramedullary nailing is the most common treatment of femoral shaft fractures in the adult population.

■ Technical notes
In contrast to flexible nails, rigid intramedullary nails are inserted in an antegrade fashion,
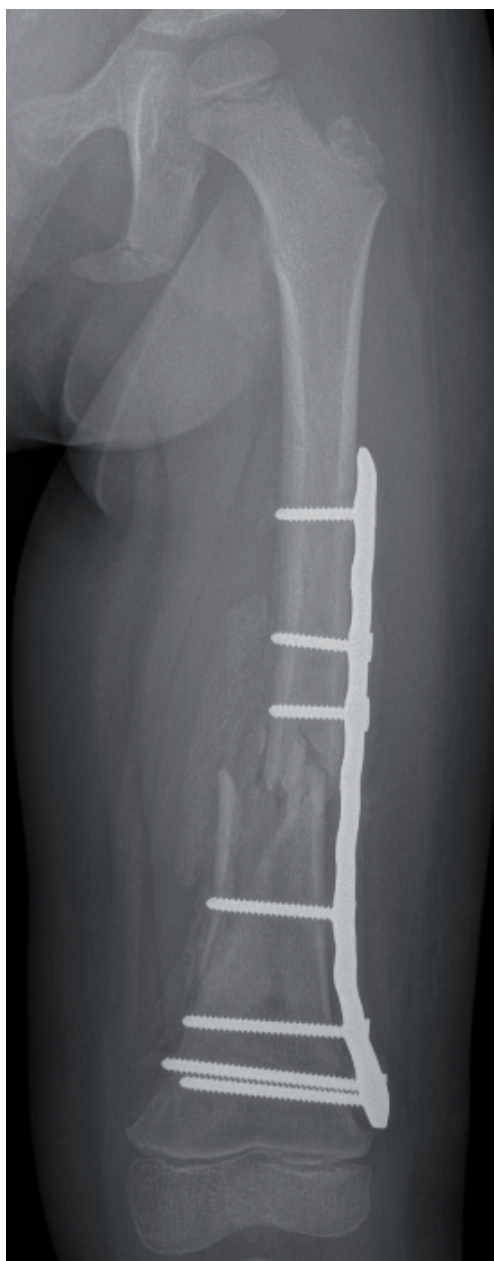
Figure 9. A 4-year-old female treated with submuscular plating.

starting from the proximal femur, through a 2 cm incision. Traditionally the starting point for the nail was in the piriformis fossa. This starting point has been associated in adolescents with reports of avascular necrosis of the femoral head [24,25]. Recently, however, newer nails have been developed that allow for a starting point on the lateral aspect of the greater trochanter. A guidewire is inserted into the proximal fragment and the fracture is reduced by an assistant to allow passage of the guidewire into the intramedullary canal of the distal fragment. In a similar technique to the reduction maneuver performed while placing

flexible nails, a closed reduction is done if possible, using fluoroscopic x-ray guidance, but some of these fractures require open reduction with a 4–5 cm incision over the fracture site. Once the guidewire is in place with the fracture reduced, the nail is advanced over the guidewire and the guidewire is withdrawn. The interlocking screws are placed proximally and distally through 1 cm incisions to hold the nail in place.

■ **Outcomes**
In adolescents, rigid intramedullary nailing has lower rates of malunion, nonunion and leg-length discrepancy than nonoperative treatment with spica casting [26]. The number of femoral shaft fractures that go on to complete healing after treatment with rigid intramedullary nailing has been reported to be close to 100% [27]. These nails can be removed if they cause irritation to the overlying soft tissues once the fracture has healed. FIGURE 10 shows a femoral shaft fracture in a 17-year-old male treated successfully with a rigid intramedullary nail.

■ **Complications**
Avascular necrosis of the femoral head is a potentially devastating complication from rigid intramedullary nailing. Avascular necrosis can lead to pain, femoral head collapse and destruction of the hip joint, requiring total hip arthroplasty at a very young age. The femoral head's vascular supply is primarily from the lateral circumflex femoral artery, which can be subject to disruption during nail insertion through the piriformis fossa. There is one report of avascular necrosis after nailing through the tip of the greater trochanter. There have been no reports of avascular necrosis following lateral trochanteric entry nailing [28]. Disruption of the proximal physis with femoral neck valgus and narrowing [29,30] has also been reported, but the incidence of this complication has also decreased with the change to a lateral trochanteric starting point. With this entry point, specialized nail systems are required to maximize the ease of entry and decrease problems with insertion. As with any invasive procedure, there is a risk of infection with rigid intramedullary nailing, which has been reported to be 2–3%. Overall, rigid intramedullary nailing with a greater trochanter starting point is a safe, effective treatment for femoral shaft fractures in adolescents, with extremely high rates of successful fracture healing [31].

External fixation

■ Indications

External fixation was used for pediatric femoral shaft fractures more frequently prior to the availability of flexible intramedullary nails. Currently, external fixation is reserved for open fractures with extensive softtissue damage or gross contamination and unstable fractures. In cases of extensive soft-tissue damage, external fixation is preferred because it provides rigid fixation to protect the soft tissues and is non-invasive at the level of the fracture. External fixation is also preferred in some open fractures with gross contamination of the wound, when placing a foreign body such as a flexible nail through the fracture site would increase the already high risk of infection. External fixation is the quickest way to stabilize a femoral shaft fracture and can be used when rapid fixation is necessary, as in the case of a patient with multiple other life-threatening injuries. External fixation allows lengthening through a fracture, which makes it useful in fractures with unacceptable shortening.

■ Technical notes

When placing an external fixator, percutaneous pins are placed into the femur using fluoroscopic guidance to insure correct placement. Two pins, approximately 2 cm apart, are placed into the proximal shaft, and two pins are placed into the distal shaft. All pins enter from the lateral side. The fracture is then reduced, and the pins are connected to a rigid bar that runs parallel to the long axis of the femur.

■ Outcomes

While external fixation is a good option for some pediatric femur fractures, and can lead to good outcomes, the early recovery is generally not as good as the early recovery for flexible intramedullary nails [32]. Patients with external fixation take longer to return to school, more muscle weakness and lower parental satisfaction scores.

■ Complications

Minor complications, especially superficial pin-site infections, occur in up to 72% of patients over the course of treatment with an external fixator [33]. Pin-site infections can be managed with pin-site hygiene and oral antibiotics. Refracture through a pin site or at the original fracture site has been reported to be as high as 12% in some series [34]. Permanent knee stiffness, while reported in adults, is very uncommon in children. Pin-site scars are often cosmetically unappealing and patients may request secondary scar revision.

Conclusion

Treatment for pediatric femoral shaft fractures has changed dramatically over the past several decades. The shift from nonoperative treatment with prolonged traction followed by spica casting to immediate spica casting or operative fixation has decreased lengths of hospitalization and the time to return to normal activities. Multiple treatment techniques are used, depending on the age and size of the patient, as well as on the type of fracture, and the surgeon should be prepared to select the optimal method for each given clinical situation. Nonoperative treatment with immediate

Figure 10. Rigid intramedullary nailing of a femur fracture in a 17-year-old male.

spica casting is used for young children with mild or moderately displaced fractures. Flexible intramedullary nailing is used in children less than 12 years old. Rigid intramedullary nailing with a lateral greater trochanter starting point is used in adolescents. Submuscular plating is used in patients with significant bone loss or comminution that would make intramedullary fixation less favorable. External fixation is used in patients with severe surrounding soft-tissue injury or with associated injuries necessitating rapid fixation.

Future perspective

As pediatric femur fracture management has changed, multiple methods have been developed to treat the radically different clinical situations encountered in treating children of differing maturity, bony stability and weight. Because of these differing clinical presentations, multiple methods of treatment will become the norm. Intramedullary stabilization has continued to gain in popularity because of the simplicity of application, low complication rate and effectiveness in providing alignment, and will be extended into lower age groups as low as age 12–18 months. As intramedullary stabilization has become the accepted norm in adults, with the advent of lateral trochanteric nailing systems, rigid, locked intramedullary nailing will become increasingly accepted as the standard to which other methods will be compared in adolescent patients above 10 years of age and above 50 kg. Submuscular plating will continue to be an important treatment modality and will be increasingly utilized for comminuted, unstable fractures of all ages. Surgical stabilization with early mobilization and motion will become the standard for pediatric femur fractures as it is with adults.

Acknowledgements

Executive summary
Initial care
▪ Careful physical examination.
▪ Splinting or traction are used to minimize pain.
▪ Plain radiographs are usually adequate to evaluate fracture.
Pavlik harness
▪ Preferred age under 3 months.
▪ Can be used up to 1 year of age.
▪ Advantages: simple, allows rapid healing and allows care of infant with minimal disruption.
▪ Disadvantages: alignment often inexact, requiring remodeling and discomfort early in healing process.
Early spica casting
▪ Current preferred treatment age is 3 months to 5 years.
▪ Advantages: simple, nonoperative and effective for most fractures.
▪ Disadvantages: allows shortening in unstable fractures and difficulty caring for child in spica.
Flexible intramedullary nailing
▪ Revolutionized pediatric fracture care.
▪ Current preferred treatment for children aged 6–11 years.
▪ Advantages: familiar technique, allows early mobilization, minimally invasive, effective for most stable fractures and minimal immobilization usually needed.
▪ Disadvantages: can allow shortening in unstable fracture patterns, increased risk of malunion and delayed union in children over 11 years old or over 50 kg.
Submuscular plating
▪ Applicable to all ages with unstable fracture patterns.
▪ Advantages: stable fixation in unstable fracture patterns, no age limitations and early motion allowed.
▪ Disadvantages: larger and more incisions than in flexible intramedullary nailing and initially limited weight bearing.
Lateral trochanteric nailing
▪ Effective in children over 10 years of age.
▪ Advantages: low risk of avascular necrosis compared with piriformis entry nailing, stable fixation for unstable fracture patterns, minimal soft-tissue dissection, and allows early mobility and weight bearing.
▪ Disadvantages: not applicable to younger patients and specialized intramedullary nails required.
External fixation
▪ Particularly useful for polytraumatized patients and open fractures.
▪ Advantages: minimally invasive and fast to apply, stable fixation and applicable to all ages.
▪ Disadvantages: multiple pin scars may require revision for cosmetic reasons and refracture after fixator removal has been reported in up to 20% of cases.

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