Femur fractures are common. When subtrochanteric and supracondylar fractures are included, the femoral shaft represents about 1.6% of all bony injuries in children. Fractures are more common in boys (2.6:1), and occur in an interesting bimodal distribution with a peak during the toddler years (usually from simple falls) and then again in early adolescence (usually from higher-energy injury). A recent Swedish incidence study also showed a seasonal bimodal variation, with the peak in March and in August.

Although pediatric femoral shaft fractures create substantial short-term disability, with attention to detail and modern techniques, these major injuries can generally be treated successfully with few long-term sequelae. Over the past 20 years, there has been a dramatic and sustained trend toward the operative stabilization of femoral shaft fractures in school-aged children using flexible intramedullary nails, external fixation, locked intramedullary nails, and more recently, submuscular plate fixation. These advances have decreased the substantial early disability for the children as well as the family's burden of care during the recovery period.

**ANATOMY OF FEMORAL SHAFT FRACTURES**

Through remodeling during childhood, a child's bone changes from primarily weak woven bone to stronger lamellar bone. Strength also is increased by a change in geometry (Fig. 27-1). The increasing diameter and area of bone result in a markedly increased area moment of inertia, leading to an increase in strength. This progressive increase in bone strength helps explain the bimodal distribution of femoral fractures. In early childhood, the femur is relatively weak and breaks under load conditions reached in normal play. In adolescence,
by high-energy injuries; motor vehicle accidents account for over 90% of femur fractures in this age group.12,77,121 Pathologic femur fractures are relatively rare in children, but may occur because of generalized osteopenia in infants or young children with osteogenesis imperfecta. Osteogenesis imperfecta should be considered when a young child, with no history suggestive of abuse or significant trauma, presents with a femoral shaft fracture.131 Radiologic evaluation is often insufficient to diagnose osteogenesis imperfecta; skin biopsy, collagen analysis, and bone biopsy may be required to make a definitive diagnosis. Generalized osteopenia also may accompany neurologic diseases, such as cerebral palsy or myelomeningocele, leading to fracture with minor trauma in osteopenic bone.62,105,111 Pathologic fractures may occur in patients with neoplasms, most often benign lesions such as nonossifying fibroma, aneurysmal bone cyst, unicameral cyst, or eosinophilic granuloma. Although pathologic femur fractures are rare in children, it is essential that the orthopedist and radiologists study the initial injury films closely for the subtle signs of primary lesions predisposing to fracture, particularly in cases of low-energy injury from running or tripping. Radiographic signs of a pathologic fracture may include mixed lytic–blastic areas disrupting trabecular architecture, break in the cortex and periosteal reaction in malignant lesions such as osteosarcoma, or better-defined sclerotic borders with an intact cortex seen in benign lesions such as nonossifying fibroma (Fig. 27-2).

Stress fractures may occur in any location in the femoral shaft.28,101,137 In this era of high-intensity, year-round youth sports, orthopedists are more commonly encountering adolescents with femoral stress fractures from running, soccer, and basketball.23 Although uncommon (4% of all stress fractures in children), femoral shaft or femoral neck stress fractures should be considered in a child with thigh pain because an unrecognized stress fracture may progress to a displaced femoral fracture. A high index of suspicion is important, because even nontraditional sports can lead to stress fractures with extreme overuse; a recent report of bilateral femoral stress fractures were reported in a Rollerblade enthusiast.201

**DIAGNOSIS OF FEMORAL SHAFT FRACTURES**

The diagnosis of pediatric femoral shaft fractures is usually not subtle: There is a clear mechanism of injury, a deformity and swelling of the thigh, and obvious localized pain. The diagnosis is more difficult in patients with multiple trauma or head injury and in nonambulatory, severely disabled children. A physical examination usually is sufficient to document the presence of a femur fracture. In patients lacking sensation (myelomeningocele), the swelling and redness caused by a fracture may mimic infection.

In the setting of a femur fracture, a comprehensive physical examination should be performed looking for other sites of injury. Hypotension rarely results from an isolated femoral fracture. Waddell’s triad of femoral fracture, intra-abdominal or intrathoracic injury, and head injury are associated with high-velocity automobile injuries. Multiple trauma may necessitate rapid stabilization of femoral shaft fractures121,164 to facilitate overall care. This is particularly true with head injury and vascular disruption.
The hemodynamic significance of femoral fracture has been studied by two groups. Hematocrit levels below 30% rarely occur without multisystem injury. A declining hematocrit should not be attributed to closed femoral fracture until other sources of blood loss have been eliminated.

**X-Ray Findings of Femoral Shaft Fractures**

Radiographic evaluation should include the entire femur, including the hip and knee, because injury of the adjacent joints is common. An anteroposterior (AP) pelvis x-ray is a valuable supplement to standard femoral shaft views, because there may be associated intertrochanteric fractures of the hip, fractures of the femoral neck, or physeal injuries of the proximal femur. Distal femoral fractures may be associated with physeal injury about the knee, knee ligament injury, meniscal tears, and tibial fractures.

Plain x-rays generally are sufficient for making the diagnosis. In rare circumstances, bone scanning and magnetic resonance imaging (MRI) may be helpful in the diagnosis of small buckle fractures in limping children or stress fractures in athletes. The orthopedist should carefully evaluate radiographs for comminution or nondisplaced “butterfly” fragments, second fractures, joint dislocations, and pathologic, as these findings can substantially alter the treatment plan.

**Classification of Femoral Shaft Fractures**

Femoral fractures are classified as (a) transverse, spiral, or short oblique; (b) comminuted or noncomminuted; and (c) open or closed. Open fractures are classified according to Gustilo’s system. The presence or absence of vascular and neurologic injury is documented and is part of the description of the fracture. The most common femoral fracture in children (over 50%) is a simple transverse, closed, noncomminuted injury.

The level of the fracture (Fig. 27-3) leads to characteristic displacement of the fragments based on the attached muscles. With subtrochanteric fractures, the proximal fragment lies in abduction, flexion, and external rotation. The pull of the gastrocnemius on the distal fragment in a supracondylar fracture produces an extension deformity (posterior angulation of the femoral shaft), which may make the femur difficult to align.

**Treatment of Femoral Shaft Fractures**

Treatment of femoral shaft fractures in children depends on two primary considerations: Age (Table 27-1) and fracture pattern. Secondary considerations, especially in operative cases, include the child’s weight, associated injuries, and mechanism of injury. 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 factors. Kocher et al. summarized the current evidence for pediatric femur fracture treatment in a clinical practice guideline summary.

**Treatment Variation with Age for Femoral Shaft Fractures**

**Infants**

Femoral shaft fractures in infants are usually stable because their periosteum is thick. In fractures occurring in infancy,
management should include evaluation for underlying metabolic bone abnormality or abuse. Once these have been ruled out, most infants with a proximal or midshaft femoral fracture are comfortably and successfully treated with simple splinting to provide some stability and comfort, with a Pavlik harness to improve the resting position of the fracture. For the rare unstable fracture, the Pavlik harness may not offer sufficient stabilization. Morris et al. reported a group of eight birth-related femur fractures. The typical fracture is a spiral fracture of the proximal femur with flexion of the proximal fragment. With thick periosteum, and remarkable remodeling potential, newborns rarely need a manipulative reduction of their fracture, nor rigid external immobilization. For femoral fractures with excessive shortening (>1 to 2 cm) or angulation (>30 degrees), spica casting may be used. Traction rarely is necessary in this age group.

**Preschool Children**

In children 6 months to 5 years of age, early spica casting (Fig. 27-4) is the treatment of choice for isolated femur fractures with less than 2 cm of initial shortening (Fig. 27-5). In low-energy fractures, the “walking spica” is ideal (Fig. 27-6). Femur fractures with more than 2 cm of initial shortening or marked instability and fractures that cannot be reduced with early spica casting require 3 to 10 days of skin or skeletal traction. Internal or external fixation is rarely needed in children less than 5 years of age. In rare circumstances, external fixation can be used for children with open fractures or multiple trauma. Intramedullary fixation is used in children with metabolic bone disease that predisposes to fracture or after multiple fractures, such as in osteogenesis imperfecta, or following multitrauma. Flexible nailing can be used in the normal-sized preschool child but is rarely necessary. Larger children (in whom reduction cannot be maintained with a spica cast) occasionally may benefit from flexible intramedullary nailing, traction, or in rare cases, submuscular plating.

**Children 5 to 11 Years of Age**

In children 5 to 11 years of age, many different methods can be used successfully, depending on the fracture type, patient characteristics, and surgeon skill and experience. For the rare, minimally displaced fracture, early spica casting usually produces satisfactory results, although cast wedging or a cast change may be necessary to avoid excessive shortening and angulation. In children with unstable, comminuted fractures, traction may be necessary prior to cast application. Although traction and casting is still a very acceptable and successful method of managing femur fractures in young school-age children, the cost and the social problems related to school-age children in casts have resulted in a strong trend toward fracture fixation. Spica cast management is generally not used for children with multiple trauma, head injury, vascular compromise, floating knee injuries, significant skin problems, or multiple fractures. Flexible

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**FIGURE 27-3** The relationship of fracture level and position of the proximal fragment. **A:** In the resting unfractured state, the position of the femur is relatively neutral because of balanced muscle pull. **B:** In proximal shaft fractures the proximal fragment assumes a position of flexion (iliopsoas), abduction (abductor muscle group), and lateral rotation (short external rotators). **C:** In midshaft fractures the effect is less extreme because there is compensation by the adductors and extensor attachments on the proximal fragment. **D:** Distal shaft fractures produce little alteration in the proximal fragment position because most muscles are attached to the same fragment, providing balance. **E:** Supracondylar fractures often assume a position of hyperextension of the distal fragment because of the pull of the gastrocnemius.

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**TABLE 27-1** Treatment Options for Isolated Femoral Shaft Fractures in Children and Adolescents

<table>
<thead>
<tr>
<th>Age</th>
<th>Treatments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Birth to 24 mos</td>
<td>Pavlik harness (newborn to 6 mos) Early spica cast Traction → spica cast (very rare)</td>
</tr>
<tr>
<td>24 mos–6 y</td>
<td>Early spica cast Traction → spica cast External fixation (rare) Flexible intramedullary nails (rare)</td>
</tr>
<tr>
<td>6–11 y</td>
<td>Flexible intramedullary nails Traction → spica cast Submuscular plate External fixation</td>
</tr>
<tr>
<td>12 y to maturity</td>
<td>Trochanteric entry intramedullary rod Flexible intramedullary nails Submuscular plate External fixation (rare)</td>
</tr>
</tbody>
</table>

Treatment choices are influenced by fracture pattern, the child’s weight, the presence of other injuries (head, chest, abdominal, etc.) and associated soft tissue trauma.
intramedullary nails are the predominant treatment for femur fractures in 5- to 11-year-olds, although submuscular plating and external fixation have their place, especially in length-unstable fractures, or in those difficult to manage fractures in the proximal and distal third of the femoral shaft.

**Age 11 to Skeletal Maturity**

Trochanteric entry, locked intramedullary nailing is now the primary mode of treatment for femur fractures in the preadolescent and adolescent age groups. Several studies designed to refine the indications for flexible intramedullary nailing have concluded that although most results are excellent or satisfactory in children older than 11, complications rise significantly when this popular technique is used for bigger and older children. In an international multicenter, retrospective study, Moroz et al.\textsuperscript{148} found a statistically significant relationship between age and outcome, with children older than 11 years or heavier than 49 kg faring worse. Sink et al.\textsuperscript{187} found a much higher rate of complications in length-unstable fractures. Fortunately, surgeons can now select from several
different trochanteric entry nails that allow a relatively safe, lateral entry point, with the stability of proximal and distal locking. With this new information and technology, locked intramedullary nailing is used commonly for obese children of ages 10 to 12, and most femoral shaft fractures in children of ages 13 to skeletal maturity.

**Treatment Variation with Fracture Pattern for Femoral Shaft Fractures**

In addition to age, the treating surgeon should consider fracture pattern, especially when choosing implant. Elastic nailing is ideal for the vast majority of length-stable midshaft femur fractures in children between the ages of 5 and 11 years old. For length-unstable fractures, the risk of shortening and malunion increases substantially when elastic nailing is used.186 Length-unstable fractures are best treated with locked trochanteric entry nailing in older children, external fixation in younger children, or submuscular plating in either of these age cohorts.

**Treatment Options for Femoral Shaft Fractures**

**Pavlik Harness for Femoral Shaft Fractures**

Stannard et al.194 popularized the use of the Pavlik harness for femur fractures in infants. This treatment is ideal for a proximal or midshaft femoral fracture that occurs as a birth-related injury. Reduction can be aided by a loosely wrapping cotton cast padding around the thigh if greater stability is needed. In a newborn infant in whom a femur fracture is noted in
the intensive care unit or nursery, the femur is immobilized with simple padding or a soft splint. For a stable fracture, this approach may be sufficient and will allow intravenous access to the feet if needed. The Pavlik harness can be applied with the hip in moderate flexion and abduction. This often helps align the distal fragment with the proximal fragment (Fig. 27-7). Evaluation of angulation in the coronal plane (varus–valgus) is difficult because of hyperflexion. Stannard et al.104 reported acceptable alignment in all patients with less than 1 cm of shortening. Morris et al.149 showed that all treatments, including traction, spica cast, and Pavlik harness, are effective and resulted in satisfactory outcome in all patients regardless of treatment.

Podeszwa et al.162 reported infants treated with a Pavlik had higher pain scores when compared to a immediate spica cast; however, none of the Pavlik patients had skin problems but one-third of the spica patients did.

**Spica Cast Treatment for Femoral Shaft Fractures**

Spica casting97,192 is usually the best treatment option for isolated femoral shaft fractures in children under 6 years of age, unless there is (a) shortening of more than 2 cm, (b) massive swelling of the thigh, or (c) an associated injury that precludes cast treatment. Several centers have adopted spica application in the emergency department as their standard treatment for infants and toddlers. Mansour et al.128 compared spica cast placement in the emergency department versus the operating room, and concluded that the outcome and complications were similar, but the children treated in the operating room had longer hospital stays and significantly higher hospital charges. Cassinelli et al.33 treated 145 femur fractures, all in children younger than age 7, with immediate spica cast application in the emergency department. All children younger than 2 years of age, and 86.5% of children of ages 2 to 5 years old, met acceptable alignment parameters on final radiographs. Rereduction in the operating room was needed in 11 patients. The investigators concluded that initial shortening was the only independent risk factor associated with lost reduction.

The advantages of a spica cast include low cost, excellent safety profile, and a very high rate of good results, with acceptable leg length equality, healing time, and motion.54,96

**FIGURE 27-7**  
A: A newborn baby presents with a classic proximal femoral birth fracture, in flexion and abduction. The baby was placed in the Pavlik harness. B: A follow-up check 2 weeks after injury shows excellent alignment and early callous. C: A follow-up at 4 weeks shows a healed fracture. The Pavlik harness was removed. D: Follow-up 7 weeks after injury shows the dramatic early remodeling that is typical of these fractures.
Hughes et al.\textsuperscript{90} evaluated 23 children ranging in age from 2 to 10 years who had femur fractures treated with early spica casting to determine the impact of treatment on the patients and their families. The greatest problems encountered by the family in caring for a child in a spica cast were transportation, cast intolerance by the child, and hygiene. In a similar study, Kocher\textsuperscript{109} used a validated questionnaire for assessing the impact of medical conditions on families demonstrated that for family, having a child in a spica cast is similar to having a child on renal dialysis. They found that the impact was greatest for children older than 5 years, and when both parents are working. Such data should inform the decisions of orthopedic surgeons and families who are trying to choose among the many options for young school-age children.

Illgen et al.\textsuperscript{95} in a series of 114 isolated femoral fractures in children under 6 years of age, found that 90-degree/90-degree spica casting was successful in 86\% without cast change or wedging, based on tolerance of shortening less than 1.5 cm and angulation less than 10 degrees. Similar excellent results have been reported by Czertak and Hennrikus\textsuperscript{41} using the 90/90 spica cast.

Thompson et al.\textsuperscript{197} described the telescope test in which patients were examined with fluoroscopy at the time of reduction and casting. If more than 3 cm of shortening could be demonstrated with gentle axial compression, traction was used rather than immediate spica casting. By using the telescope test, these researchers decreased unacceptable results (>2.5 cm of shortening) from 18\% to 5\%. Shortening is acceptable, but should not exceed 2 cm. This is best measured on a lateral x-ray taken through the cast. If follow-up x-rays reveal significant varus (>10 degrees) or anterior angulation (>30 degrees), the cast may be wedged. However, Weiss et al.\textsuperscript{211} noted that wedging of 90/90 spica casts can cause peroneal nerve palsy, especially during correction of valgus angulation (a problem that rarely occurs). For unacceptable position, the fracture can be manipulated and a new cast applied, or the cast can be removed and the patient placed in traction to regain or maintain length. Angular deformity of up to 15 degrees in the coronal plane and up to 30 degrees in the sagittal plane may be acceptable, depending on the patient’s age (Table 27-2). Finally, if shortening exceeds 2 cm, traction or an external fixator can be used (Fig. 27-8).

The position of the hips and knees in the spica cast is controversial. Some centers prefer a spica cast with the hip and knee flexed 90 degrees each. Studies have shown that the results from the sitting spica cast are good.\textsuperscript{133,143} The child is placed in a sitting position with the legs abducted about 30 degrees on either side. The synthetic material used for the cast gives it sufficient strength so that no bar is required between the legs. This not only allows the child to be carried on the parent’s hip but also aids in toiletry needs, making bedpans unnecessary. Also, a child who can sit upright during the day can attend school in a wheelchair. More recently, with reports about compartment syndrome of the leg after using the 90/90 spica cast, several centers have moved to a cast in which the hip and knee are more extended (about 45 degrees each) and the bottom of the foot cut out to prevent excessive shortening.\textsuperscript{134} Varying the amounts of hip and knee flexion in the spica cast based on the position of the fracture also has been recommended. The more proximal the fracture, the more the hip should be flexed.\textsuperscript{192}

<table>
<thead>
<tr>
<th>Age</th>
<th>Varus/Valgus (degrees)</th>
<th>Anterior/Posterior (degrees)</th>
<th>Shortening (mm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Birth to 2 y</td>
<td>30</td>
<td>30</td>
<td>15</td>
</tr>
<tr>
<td>2–5 y</td>
<td>15</td>
<td>20</td>
<td>20</td>
</tr>
<tr>
<td>6–10 y</td>
<td>10</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>11 y to maturity</td>
<td>5</td>
<td>10</td>
<td>10</td>
</tr>
</tbody>
</table>

![Figure 27-8](image-url) A proximal spiral femur fracture, which failed treatment with pins and plaster, and was salvaged with an external fixator.
Recently, there has been a resurgence of interest in the “walking spica cast” (Fig. 27-6). Epps et al. reported on immediate single leg spica cast for pediatric femoral diaphyseal fracture. In a series of 45 children, 90% of the children pulled to stand and 62% of the children walked independently by the end of treatment. Fifty percent of patients were able to return to school or day care while in the cast. Only two children had unacceptable shortening, and two required repeat reduction. Flynn et al. performed a prospective study of low-energy femoral shaft fractures in young children, comparing a walking spica cast to a traditional spica cast. Although the outcome with the two treatment methods was similar, the walking spica cast resulted in substantially lower burden of care for the family. Children with a walking spica are more likely to have their cast wedged in clinic to correct early loss of reduction. Practitioners of the single leg, or walking spica, have learned to use the technique only on toddlers with very stable, low-energy fractures. The cast must be extensively reinforced at the hip. With the hip and knee much more extended, the single leg spica not only improves function and ease of care, but also avoids a technique that has been associated with compartment syndrome in several children (see below). Increasingly, the walking spica is considered the best treatment for low-energy femur fractures in toddlers.

**Spica Cast Application: Technique**

The cast is applied in the operating room or, in some centers, the sedation unit or Emergency Department. For the sitting spica cast technique, a long leg cast is placed with the knee and ankle flexed at 90 degrees (Fig. 27-9B). Knee flexion greater than 60 degrees improved maintenance of length and reduction. However, if one applies excessive traction to maintain...
length (Fig. 27-10), the risk of compartment syndrome is unacceptably high. Less traction, less knee flexion, and accepting slightly more shortening is a reasonable compromise. Extra padding, or a felt pad, is placed in the area of the popliteal fossa. The knee should not be flexed after the padding is placed because the lump of material in the popliteal fossa may create vascular obstruction (Fig. 27-9A). Because most diaphyseal fractures lose reduction into varus angulation while in a spica cast, a valgus mold at the fracture site is recommended (Fig. 27-9C). The patient is then placed on a spica table, supporting the weight of the legs with manual traction, and the remainder of the cast is applied with the hips in 90 degrees of flexion and 30 degrees of abduction, holding the fracture out to length (Fig. 27-9D). It is mandatory to avoid excessive traction because compartment syndromes and skin sloughs have been reported. The leg should be placed in 15 degrees of external rotation to align the distal fragment with the external rotation of the proximal fragment. After the spica cast is in place, AP and lateral x-rays are obtained to ensure that length and angular and rotational alignment are maintained. We observe all patients for 24 hours after spica application to be sure that the child is not at risk for neurovascular compromise or compartment syndrome. Gore-Tex liners can be used to decrease the skin problems of diaper rash and superficial infection. Several centers have found that this has been beneficial, justifying the cost of a Gore-Tex liner.

For the single leg spica or “walking spica” technique, the long leg cast is applied with approximately 45 degrees of knee flexion, and when the remaining cast is placed, the hip is flexed 45 degrees and externally rotated 15 degrees. The hip should be reinforced anteriorly with multiple layers of extra fiberglass. The pelvic band should be fairly wide so that the hip is controlled as well as possible. A substantial valgus mold is important to prevent varus malangulation. We leave the foot out, stopping the distal end of the cast in the supramalleolar area, which is protected with plenty of extra padding. Seven to 10 days after injury, the child returns to clinic anticipating the need for cast wedging, if radiographs show the very common mild increase in shortening and varus angulation. Most toddlers pull to a stand and begin walking in their walking cast about 2 to 3 weeks after injury.

If excessive angulation occurs, the cast should be changed, with manipulation in the operating room. Casts can be wedged for less than 15 degrees of angulation. If shortening of more than 2 cm is documented, the child should be treated with cast change, traction, or conversion to external fixation, using lengthening techniques if the shortening is not detected until the fracture callus has developed. When conversion to external fixation is required, we recommend osteoclasts (either closed or open if needed) at the time of the application of the external fixator, with slow lengthening over a period of several weeks (1 mm per day) to reestablish acceptable length (Fig. 27-8).

Generally, the spica cast is worn for 4 to 8 weeks, depending on the age of the child and the severity of the soft tissue damage accompanying the fracture. Typically, an infant’s femoral shaft fracture will heal in 3 to 4 weeks; and a toddler’s fracture will heal in 6 weeks. After the cast is been removed, parents are encouraged to allow their children to stand and walk whenever the child is comfortable; most children will need to be carried or pushed in a stroller for a few days until hip and knee stiffness gradually results. Most joint stiffness resolves spontaneously in children after a few weeks. It is unusual to need formal physical therapy. In fact, aggressive joint range-of-motion exercises with the therapist immediately after cast removal make children anxious, and may prolong rather than hasten recovery. A few follow-up visits are recommended in the first year after femur fracture, analyzing gait, joint range of motion, and leg lengths.
**Traction and Casting**

Since as early as the 18th century, traction has been used for management of femur fractures. Vertical overhead traction with the hip flexed 90 degrees and the knee straight was introduced by Bryant in 1873, but this often resulted in vascular insufficiency, and it is now rarely used for treatment of femoral fractures. Modified Bryant traction, in which the knee is flexed 45 degrees, increases the safety of overhead skin traction.

Traction prior to spica casting is indicated when the fracture is length unstable and the family and surgeon agree that nonoperative measures are preferred. In general, skeletal traction then spica casting is not currently used for children who are older than 12 years of age, because of the significant risk of shortening and angular malunion; in children older than 12 years of age, internal fixation is recommended. Children who rapidly shortened in an early spica cast can be salvaged with cast removal and subsequent traction. The limit of skin traction is the interface between skin and tape or skin and foam traction boot. Skin complications, such as slough and blistering, usually occur when more than 5 lb of traction is applied. When more than 5 lb of traction is required, or simply for ease in patient management, skeletal traction can be used to maintain alignment.

The distal femur is the location of choice for a traction pin. Although proximal tibial traction pins have been recommended by some clinicians, growth arrest in the proximal tibial physis and subsequent recurvatum deformity have been associated with their use (Fig. 27-11). Also, knee ligament and meniscal injuries that sometimes accompany femoral fractures may be aggravated by the chronic pull of traction across the knee.

**Traction Pin Insertion: Technique**

After preparation of the thigh circumferentially from the knee to the midthigh, the limb is draped in a sterile manner. The knee is held in the position in which it will remain during traction; that is, if 90/90 traction is being used, the traction pin should be inserted with the knee bent 90 degrees. Because this technique is typically used in very young children, traction pin is placed in the operating room under general anesthesia. The technique is safest and most efficient if it is done with fluoroscopic x-ray control for optimal pin location. The location of pin insertion is 1 fingerbreadth above the patella with the knee extended or just above the flare of the distal femur. A small puncture wound is made over the medial side of the femur. A medial-to-lateral approach is used so that the traction pin does not migrate into the area of the femoral artery that runs through Hunter canal on the medial side of the femur. The best traction pin is the largest available threaded Steinmann pin. The pin is placed parallel to the joint surface to help maintain alignment while in traction. After the pin protrudes through the lateral cortex of the femur, a small incision is made over the tip of the pin. The pin is then driven far enough through the skin to allow fixation with a traction bow. If 90/90 traction is used, a short leg cast can be placed with a ring through its midportion to support the leg. Alternatively, a sling to support the calf may be used. If a sling is used, heel cord stretching should be performed while the patient is in traction.

After the skeletal traction pin has been placed in the distal femur, traction is applied in a 90/90 position (the hip and knee flexed 90 degrees) or in an oblique position (the hip flexed 20 to 60 degrees). If the oblique position is chosen, a Thomas splint or sling is necessary to support the leg. The fracture may be allowed to begin healing in traction, and x-rays should be obtained once or twice a week to monitor alignment and length. In preschool age children, traction will be necessary for 2 to 3 weeks; in school-age children, a full 3 weeks of traction is usually necessary before the fracture is stable enough to permit casting. In a child under 10 years of age, the ideal fracture position in traction should be less than 1 cm of shortening and slight valgus alignment to counteract the tendency to angulate into varus in the cast and the eventual overgrowth that
may occur (average 0.9 cm). If this method is used for adolescents (11 years or older), normal length should be maintained.

**Spica Casting, with Traction Pin Incorporated**

In rare circumstances, a child's femur fractures best treated by spica casting, incorporating a traction pin in the cast to maintain fracture length. This technique may be particularly useful in an environment where there are limited resources. In a study by Gross et al., 72 children with femoral fractures were treated with early cast brace/traction management. In this technique, a traction pin is placed in the distal femur and then incorporated in a cast brace. The traction pin is left long enough to be used for maintaining traction while the patient is in the cast brace or traction is applied directly to the cast. The patient is allowed to ambulate in the cast brace starting 3 days after application. Radiographs are taken of the fracture in the cast brace to document that excessive shortening is not occurring. The patient then is returned to traction in the cast brace until satisfactory callus is present to prevent shortening or angular deformity with weight bearing. The technique was not effective in older adolescents with midshaft fractures but achieved excellent results in children 5 to 12 years of age. The average hospital stay was 17 days.

**Complications of Spica Casting**

Comparative studies and retrospective reviews have demonstrated unsatisfactory results in a small, yet significant, percentage of patients treated with skeletal traction. Recently, increased attention has been focused on the risk of compartment syndrome in children treated in the 90/90 spica cast. Mubarak et al. presented a multicenter series of nine children with an average age of 3.5 years who developed compartment syndrome of the leg after treatment of a low-energy femur fracture in a 90/90 spica cast. These children had extensive muscle damage and the skin loss around the ankle (Fig. 27-13). The authors emphasize the risk in placing an initial below knee cast, then using that cast to apply traction while immobilizing the child in the 90/90 position. The authors recommend avoiding traction on a short leg cast, leaving the foot out, and using less hip and knee flexion (Fig. 27-14).

**Flexible Intramedullary Nail Fixation for Femoral Shaft Fractures**

In most centers, flexible intramedullary nailing is the standard treatment for midshaft femur fractures in children between the ages of 5 and 11 years old. The flexible intramedullary nailing technique can be performed with either stainless steel nails or titanium elastic nails. The popularity of flexible intramedullary nailing results from its safety, efficacy, and ease of implant removal. The flexible nailing technique offers satisfactory fixation, enough stress at the fracture site to allow abundant callous formation, and relatively easy insertion and removal. The implants are inexpensive and the technique has a short learning curve. The primary limitation of flexible nailing is the lack of rigid fixation. Length-unstable fractures can shorten and angulate, especially in older and heavier children. Compared to children with rigid fixation, children who have their femur fracture treated with flexible nailing clearly have more pain and muscle spasm in the early postoperative period. The surgeon should take this into consideration in planning the early rehabilitation.

As the flexible nailing technique has become more popular, there have been many studies to refine the technique and indications, and to elucidate the inherent limitations of fixation with flexible implants. Mechanical testing of femoral fracture fixation systems showed that the greatest rigidity is provided by an external fixation device and the least by flexible intramedullary rodding. Stainless steel rods are stiffer than titanium in bending tests. A study comparing steel to titanium flexible nails found a higher complication rate in the titanium group. They reported that a typical 3.5-mm stainless steel nail has the same
FIGURE 27-14 Authors recommended technique of spica cast application. A: The patient is placed on a child's fracture table. The leg is held in about 45-degree angle of flexion at the hip and knee with traction applied to the proximal calf. B: The 1½ spica is then applied down to the proximal calf. Molding of the thigh is accomplished during this phase. C: The x-rays of the femur are obtained and any wedging of the cast that is necessary can occur at this point in time. D: The leg portion of the cast and the cross bar are applied. The belly portion of the spica is trimmed to the umbilicus. (Reprinted from Mubarak SJ, Frick S, Sink E, et al. Volkmann contracture and compartment syndromes after femur fractures in children treated with 90/90 spica casts. J Pediatr Orthop. 2006;26(5):571.)
an angular malunion of more than 10 degrees. Narayanan et al.\textsuperscript{152} looked at one center’s learning curve with titanium elastic nails, studying the complications of 79 patients over a 5-year period. Nails that were bent excessively away from the bone led to irritation at the insertion site in 41. The center also had eight malunions and two refractures. They noted that complications could be diminished by using rods with similar diameter and contour, and by avoiding bending the distal end of the nail away from the bone and out into the soft tissues. Luhmann et al.\textsuperscript{123} reported 21 complications in 43 patients with titanium elastic nails. Most of the problems were minor, but a hypertrophic nonunion and a septic joint occurred in their cohort. They suggested that problems could be minimized by using the largest nail possible and leaving only 2.5 cm out of the femoral cortex.

Flexible nails are removed after fracture union at most centers. However, some surgeons choose to leave the implants permanently. There is a theoretical concern that if flexible nails are left in young children, they will come to lie in the distal diaphysis as the child grows older. This may create a stress riser in the distal diaphysis, leading to a theoretical risk of fracture (Fig. 27-15). Morshed et al.\textsuperscript{150} performed a retrospective analysis of 24 children treated with titanium elastic nails and followed for an average of 3.6 years. The original plan with these children was to retain their implants. However, about 25% of the children had their nails removed for persistent discomfort.

**Fixation with Flexible Intramedullary Nails: Technique**

Preoperative Planning. The ideal patient for flexible intramedullary nailing is the child between the ages of 5 and 11 years old with a length-stable femur fracture, in the mid-80% of the diaphysis (Fig. 27-16), who has a body weight less than 50 kg.\textsuperscript{148} Unstable fracture patterns can also be treated with
flexible nailing, but the risk of shortening and angular malunion is greater, and supplemental immobilization during early healing phase may be valuable.

Initial radiographs should be studied carefully for fracture lines that propagate proximally and distally, and might be otherwise unnoticed (Fig. 27-17). Although it is technically difficult to obtain satisfactory fixation with a retrograde technique when the fracture is near the distal metaphysis, a recent biomechanical study demonstrated that retrograde insertion provides better stability than antegrade insertion for distal femoral shaft fractures. Nail size is determined by measuring the minimum diameter of the diaphysis, then multiplying by 0.4 to get nail diameter. For instance, if the minimum diameter of the diaphyseal canal is 1 cm, the 4-mm nails are used. Always choose the largest possible nail size that permits two nails to fit medullary canal.

Flexible nailing is most effectively performed on a fracture table, with a fracture reduced to near-anatomic position before incisions are made. Alternatively, a fluoroscopic table can be used, but the surgeon should assure that a reduction can be obtained prior to the start of the procedure, and extra assistance may be necessary.

The procedure described is with titanium elastic rods, but other devices are available and can be used with slight variations in procedure.

Rod Bending. The distance from the top of the inserted rod to the level of the fracture site is measured, and a gentle 30-degree bend is placed in the nail. The technique of elastic fixation of femoral fractures as described by Ligier et al. requires that a bend be placed in the midportion of the rod at the level of the fracture site. This produces a spring effect (Fig. 27-18) that adds to the rigidity of the fracture fixation. The spread of the rods in opposite directions provides a “prestressed” fixation, which increases resistance to bending. The opposite bends of the two rods at the level of the fracture significantly increase resistance to varus and valgus stress, as well as torsion. A second bend is sometimes helpful near the entering tip of the nail to facilitate clearance of the opposite cortex during initial insertion. Based on the report by Sagan et al., sagittal plane configuration should be considered as well. An apex-posterior bend in one of the nails, with the nail shoe pointing anteriorly in the proximal femur, resists apex-anterior malunion.

Most pediatric femur fractures are fixed with 4-mm diameter nails; in smaller children, 3.5-mm nails may be necessary. Two nails of similar size should be used, and they should be as large as possible. Using nails that are too small, or mismatched in size, increases the rate of complications. It is very unusual to use nails smaller than 3.5 mm, except in the very youngest, smallest children.

Retrograde Insertion. After the child is placed on the fracture table and the fracture reduced as much as possible, the leg is prepared and draped with the thigh (hip to knee) exposed. The image intensifier is used to localize the placement of skin incisions by viewing the distal femur in the AP and lateral planes.
Incisions are made on the medial and lateral side distal to the insertion site in the bone. The proximal end of the 2- to 3-cm incision should be at or just distal to the level of the insertion site, which is about 2.5 to 3 cm proximal to the distal femoral physis (Fig. 27-19). A 4.5-mm drill bit or awl is used to make a hole in the cortex of the bone. The distal femoral metaphysis is opened 2.5 cm proximal to the distal femoral physis using a drill or awl. The drill is then steeply angled in the frontal plane to facilitate passage of the nail through the dense pediatric metaphyseal bone.

Upon insertion the rod glances off the cortex as it advances toward the fracture site. Both medial and lateral rods are...
inserted to the level of the fracture. At this point, the fracture reduction is optimized if necessary with a radiolucent fracture reduction tool which holds the unstable femoral fracture in the appropriate position to allow fixation. The surgeon judge which nail will be most difficult to get across the fracture site, and pass it first. If the easier nail is passed first, it may stabilize the two fragments such that the second, more difficult nail, cannot be passed easily. The two nails then are driven into the proximal end of the femur, with one driven toward the femoral neck and the other toward the greater trochanter. On the lateral, one nail should have its tip pointing anteriorly. When passing the second nail across the fracture site and rotating it, care must be taken not to wind one rod around the other. After the nails are driven across the fracture and before they are seated, fluoroscopy is used to confirm satisfactory reduction of the fracture and to ensure that the nails did not comminute the fracture as they were driven into the proximal fragment.

The nails are pulled back approximately 2 cm, the end of each nail is cut, then driven back securely into the femur. The end of the nail should lie adjacent to the bone of the distal femoral metaphysis, exposed just enough to allow easy removal once the fracture is healed. Do not bend the exposed to distal tip of the nail away from femoral metaphysis as this will irritate surrounding tissues.

A proximal insertion site can also be used. An insertion site through the lateral border of the trochanter avoids creating the stress riser that results from subtrochanteric entry.

Technique Tip. Mazda et al.\textsuperscript{132} emphasized that for insertion of titanium elastic nails, the nails have to be bent into an even curve over the entire length, and the summit of the curve must be at the level of the fracture or very close to it in comminuted fractures. The depth of curvature should be about three times the diameter of the femoral canal. Flynn et al.\textsuperscript{48} also stressed the importance of contouring both nails with similar gentle curvatures, choosing nails that are 40% of the narrowest diaphyseal diameter and using medial and lateral starting points that are at the same level in the metaphysis.

In length-unstable fractures, an endcap has been shown to confer increased stability that might lessen the risk of shortening\textsuperscript{106} and nail backout.

Postoperative Management. A knee immobilizer is beneficial in the early postoperative course to decrease knee pain and quadriceps spasm. When the flexible nailing technique is used for length-unstable fracture, walking (or one leg) spica is recommended, generally for about 4 to 6 weeks until callus is visible on radiographs. For length-stable fractures, touch-down weight bearing could begin as soon as the patient is comfortable. Gentle knee exercises and quadriceps strengthening can be begun, but there should be no aggressive passive motion of the knee, which increases the motion at the fracture site and increases quadriceps spasm. Postoperative knee motion does return to normal over time. Full weight bearing generally is tolerated by 6 weeks. Ozdemir et al.\textsuperscript{160} recommended the use of postoperative functional bracing, demonstrating effectiveness in a group of patients treated with elastic rodding. Such postoperative support may occasionally be required, but in most cases it appears not to be needed.

The nails can be removed 6 to 12 months after injury when the fracture is fully healed, usually as an outpatient procedure.

**Complications of Flexible Intramedullary Nailing**

Complications are relatively infrequent after flexible intramedullary nailing. In 351 fractures reported in seven studies,\textsuperscript{10,31,53,60,120,123,132} one nonunion, one infection, and no occurrence of osteonecrosis were reported. Approximately 12% of patients had malunions, most often mild varus deformities, and approximately 3% had clinically significant leg length discrepancies from either overgrowth or shortening. A recent study noted overgrowth of more than 1 cm in 8.2% of preschool children treated with titanium elastic nailing.\textsuperscript{149} This is a much higher rate of overgrowth than seen in older children, suggesting the technique should be used infrequently in preschool children. Mazda et al.\textsuperscript{132} pointed out a technique-related complication that occurred in 10 of their 34 patients: Rods were left too long and caused painful bursae and limited knee flexion. All 10 patients had the nails removed 2 to 5 months after surgery. Flexible nails inserted in a retrograde fashion may also penetrate into the knee joint, causing an acute synovitis.\textsuperscript{174}

In a multicenter study\textsuperscript{58} that included 58 femoral fractures stabilized with titanium elastic nails, irritation of the soft tissue near the knee by the nail tip occurred in four patients (7%), leading to a deeper infection in two patients. This study also reported one refracture after premature nail removal, leading to a recommendation that nail removal be delayed until callus is solid around all cortices and the fracture line is no longer visible. Ozdemir et al.\textsuperscript{160} measured overgrowth with a scanogram and found that the average increase in length was 1.8 mm, suggesting that significant femoral overgrowth is not seen with this method of treatment.

Flynn et al.\textsuperscript{96} compared traction and spica cast with titanium elastic nails for treatment of femoral fractures in 83 consecutive school-aged children. The three unsatisfactory results were treated with traction followed by casting. The overall complication rate was 34% in the traction group and 21% in the elastic nail group.

An international multicenter study focused on factors that predict a higher rate of complications after flexible nailing of pediatric femoral shaft fractures.\textsuperscript{50} Analyzing 234 fractures in 229 patients from six different Level 1 trauma centers, the authors found significantly more problems in older, heavier children. A poor outcome was five times more likely in patients who weigh more than 108.5 lb. A poor outcome was also almost four times more likely in patients older than 11 years old. The authors concluded that results were generally excellent for titanium elastic nailing, but poor results were more likely in children older than 11 years and heavier than 50 kg. Ho et al.\textsuperscript{87} reported a 34% complication rate in patients 10 years and older, but only a 9% complication rate in patients younger than 10 years, emphasizing the concept that complications of flexible nailing are higher in older, heavier children.

Salem and Keppler\textsuperscript{179} noted a 47% incidence of torsional malunion 213 degrees in the patients they treated at one center in Germany. These authors could not determine if the torsional malunion was due to instability after fixation, or faulty surgical
technique. In either case, the findings call attention to the need for rotational assessment after fixation.

**External Fixation for Femoral Shaft Fractures**

External fixation of femoral shaft fractures offers an efficient, convenient method to align and stabilize the fractured pediatric femur. It is the method of choice when severe soft tissue injury precludes nailing or submuscular plating, when a fracture shortens excessively in a spica cast, or as part of a "damage-control" strategy. In head-injured or multiply injured patients and those with open fractures, external fixation offers an excellent method of rapid fracture stabilization. It is also valuable for very proximal or distal fractures, where options for flexible nailing, plating, or casting are limited. External fixation is particularly valuable for the benign pathologic fracture (e.g., through a nonossifying fibroma) at the distal metaphyseal-diaphyseal junction (Fig. 27-20), where the fracture will heal rapidly, but angular malunion must be avoided.

Aronson and Tursky reported their early experience with 44 femoral fractures treated with primary external fixation and early weight bearing. Most patients returned to school by 4 weeks after fracture and had full knee motion by 6 weeks after the fixator was removed. In this early study, end-on alignment was the goal and overgrowth was minimal. Recently, Matzkin et al. reported on a series of 40 pediatric femur fractures treated with external fixation. Seventy-two percent of their series were dynamized prior to external fixator removal, and their refracture rate was only 2.5%. They had no overgrowth, but one patient ended up 5 cm short.

Following early enthusiasm for the use of external devices, the last decade saw waning interest in their use because of complications with pin track infections, pin site scarring, delayed union, and refracture. These complications, coupled with the very low complication rate from flexible nailing, led to a decline of external fixation for pediatric femoral shaft fractures. Data from comparison studies also contributed to the change. Bar-On et al. compared external fixation with flexible intramedullary rodding in a prospective randomized study. They found that the early postoperative course was similar but that the time to return to school and to resume full activity was less with intramedullary fixation. Muscle strength was better in the flexible intramedullary fixation group at 14 months after fracture. Parental satisfaction was also significantly better in the flexible intramedullary rodding group. Bar-On et al. recommended that external fixation be reserved for open or severely comminuted fractures.

**Frame Application: Technique**

During preoperative planning, the fracture should be studied carefully for comminution, or fracture lines that propagate proximally or distally. The surgeon should assure that the fixator devices available are long enough to span the distance between the optimal proximal and distal pin insertion sites.

![AP (A) and lateral (B) radiographs a low-energy short oblique fracture through a fibrous cortical defect in the distal femur; this type of fracture is not unusual. The surgeon judged that there was enough distance between the fracture site and the growth plate to allow external fixation.](image)
As in the elastic nailing technique, either the fracture table or radiolucent table can be used, although the fracture table is much more efficient, as an anatomic reduction can be obtained before prepping and draping. First we try to reduce the fracture both in length and alignment. If the fracture is open, it should be irrigated and debrided before application of the external fixation device. With the fracture optimally aligned, fixation is begun. The minimal and maximal length constraints characteristic of all external fixation systems must be kept in mind, and the angular adjustment intrinsic to the fixation device should be determined. Rotation is constrained with all external fixation systems once the first pins are placed. That is, if parallel pins are placed with the fracture in 40 degrees of malrotation, a 40-degree malalignment will exist. Rotational correction must be obtained before placing the pins in the proximal and distal shafts of the femur (Fig. 27-21).

Application of the fixator is similar no matter what device is chosen. One pin is placed proximally in the shaft, and another pin is placed distally perpendicular to the long axis of the shaft. Alignment is based on the long axis of the shaft, rather than to the joint surface. Rotation should be checked before the second pin is placed because it constrains rotation but not angulation or length. After pins are correctly placed, all fixation nuts are secured and sterile dressings are applied to pins.

Technique Tips. Pin sizes vary with manufacturers, as do drill sizes. In general the pins are placed through predrilled holes to avoid thermal necrosis of bone. Sharp drills should be used. The manufacturer’s recommendation for drill and screw sizes should be checked before starting the procedure. Some
self-drilling and self-tapping pins are available. At least two pins should be placed proximally and two distally. An intermediate or auxiliary pin may be beneficial.

Postoperative Care. The key to preventing pin site irritation is avoiding tension at the skin–pin interface. We recommend that our patients clean their pin sites daily with soap and water, perhaps as part of regular bath or shower. Showering is allowed once the wound is stable and there is no communication between the pin and the fracture hematoma. Antibiotics are commonly used at some point while the fixator is in place, because pin site infections are common and easily resolved with antibiotic treatment, usually cephalosporin.

There are two general strategies regarding fixator removal. The external fixation device can be used as “portable traction.” With this strategy, the fixator is left in place until early callus stabilizes the fracture. At this point, usually 6 to 8 weeks after injury, the fixator device is removed and a walking spica cast is placed. This minimizes stress shielding from the fixator, and allows time for the pin holes to fill in while the cast is on. The alternative, classic strategy, involves using the fixator until the fracture is completely healed. Fixator dynamization, which is difficult in small, young children, is essential for this classic strategy. The surgeon should not remove the device until three or four cortices show bridging bone continuous on AP and lateral x-rays, typically 3 to 4 months after injury.

Complications of External Fixation

The most common complication of external fixation is pin track irritation/infection, which has been reported to occur in up to 72% of patients.143 This problem generally is easily treated with oral antibiotics and local pin site care. Sola et al.191 reported a decreased number of pin track infections after changing their pin care protocol from cleansing with peroxide to simply having the patient shower daily. Superficial infections should be treated with external fixation, it is relatively uncommon in children with femoral fractures unless major soft tissue injury is present.52

Rigid Intramedullary Rod Fixation for Femoral Shaft Fractures

With reports by Beaty et al.12 and others in the early 1990s alerting surgeons that antegrade intramedullary nailing can be complicated by osteonecrosis of the proximal femur, flexible nailing (either antegrade or retrograde) quickly became more popular than standard locked, antegrade rigid intramedullary nailing. Recently, however, locked antegrade femoral nailing for pediatric femur fractures has enjoyed a resurgence of interest with the introduction of newer generation implants that allow a very lateral trochanteric entry point. These newer implant systems avoid a piniformis entry site, reducing (but perhaps not completely eliminating) the risk of osteonecrosis.88,107 Antegrade-locked intramedullary fixation is particularly valuable for adolescent femur fractures. Comparative studies by Reeves et al.169 and Kirby et al.,108 as well as retrospective reviews of traction and casting, suggest that femoral fractures in adolescents are better treated with intramedullary fixation than with traditional traction and casting (Table 27-3). Keeler et al.107 reported on 80 femur fractures in patients 8 to 18 years old treated with a lateral trochanteric entry starting point. There was no osteonecrosis, no malunion, and a 2.5% infection rate.

Length-unstable adolescent femur fractures benefit from interlocking proximally and distally to maintain length and rotational alignment.13,24,73 Beaty et al.12 reported the use of interlocking intramedullary nails for the treatment of 31 femoral shaft fractures in 30 patients 10 to 15 years of age. All fractures united, and the average leg length discrepancy was 0.51 cm. No angular or rotational malunions occurred. All nails were removed at an average of 14 months after injury; no refracture or femoral neck fracture occurred after nail removal. One case of osteonecrosis of the femoral head occurred, which was thought to be secondary to injury to the ascending cervical artery during nail insertion.

Reamed antegrade nailing in children with an open proximal femoral physis must absolutely avoid the piriformis fossa, because of the risk of proximal femoral growth abnormalities,167 the risk of osteonecrosis of the femoral head,12,141,169,106 the size of the proximal femur, and the relative success of other treatment methods. However, Maruenda-Paulino et al.129 reported good results using 9-mm Kuntscher rods in children 7 to 12 years of age, and Beaty et al.12 reported the use of pediatric “intermediate” interlocking nails for femoral canals with diameters as small as 8 mm. Townsend and Hoffinger202 and Mombemer et al.146 published reviews of trochanteric nailing in adolescents with very good results. The combined series includes 92 patients of age 10 to 17+ 6 years with no reported cases of osteonecrosis and no significant alteration in proximal femoral anatomy.
TABLE 27.3 Results of Treatment of Femoral Shaft Fractures in Adolescents

<table>
<thead>
<tr>
<th>Series</th>
<th>No. of Patients</th>
<th>Average Age (Range in Years)</th>
<th>Treatment</th>
<th>Results and Complications (n)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Kirby et al.(^{108})</td>
<td>13</td>
<td>12 + 7 (10 + 11−15 + 6)</td>
<td>Traction + cast</td>
<td>Short &gt;2.5 cm (2)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Significant residual angulation (4)</td>
</tr>
<tr>
<td></td>
<td>12</td>
<td>12 + 0 (10 + 10−15 + 7)</td>
<td>Intramedullary nailing</td>
<td>No overgrowth</td>
</tr>
<tr>
<td>Ziv et al.(^{213})</td>
<td>17</td>
<td>8 + 3 (6−12)</td>
<td>Intramedullary nailing (9 Rush pins, 9 Kuntscher nails)</td>
<td>No leg length discrepancy &gt;1 cm</td>
</tr>
<tr>
<td>Reeves et al.(^{163})</td>
<td>41</td>
<td>12 + 4 (9 + 9−16 + 4)</td>
<td>Traction + cast</td>
<td>Change in AID 0.5−1 cm = 3 with Kuntscher nails</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>14 + 11 (11−16 + 10)</td>
<td>Intramedullary nailing</td>
<td>No infection, nonunion, or malunion</td>
</tr>
<tr>
<td>Beaty et al.(^{12})</td>
<td>30</td>
<td>12 + 3 (10−15)</td>
<td>Intramedullary nailing</td>
<td>Overgrowth &gt;2.5 cm (2)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>AVN femoral head (1)</td>
</tr>
<tr>
<td>Aronson et al.(^{6})</td>
<td>42</td>
<td>9 + 7 (2 + 5−17 + 8)</td>
<td>External fixation</td>
<td>8.5% pin infection</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>10% cast or reapplication</td>
</tr>
<tr>
<td>Ligier et al.(^{120})</td>
<td>123</td>
<td>10 (5−16)</td>
<td>Flexible IM rods</td>
<td>1 infection</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>13 wound ulcerations</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>2 LLD &gt;2 cm</td>
</tr>
<tr>
<td>Mazda et al.(^{132})</td>
<td>34</td>
<td>9.5 (6−17)</td>
<td>Flexible IM rods</td>
<td>1–1.5 cm overgrowth (3)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1–15-degree malalignment (2)</td>
</tr>
</tbody>
</table>

LLD, leg length discrepancy.

Open fractures in older adolescents can be effectively treated with intramedullary rodding, either as delayed or primary treatment, including those caused by gunshot wounds and high-velocity injuries.\(^{16,200}\) Antegrade intramedullary rod insertion maintains length, prevents angular malunion and nonunion, and allows the patient to be rapidly mobilized and discharged from the hospital. However, other techniques with fewer potential risks should be considered.

Retrograde rodding of the femur has become an accepted procedure in adults.\(^{159,171}\) In a large patient approaching skeletal maturity (bone age >16 years) but with an open proximal femoral physis and an unstable fracture pattern, one might consider this treatment as a way to avoid the risk of osteonecrosis yet stabilize the fracture. If growth from the distal femur is predicted to be less than 1 cm, leg length inequality should not be a problem. Ricci et al.\(^{171}\) have shown that the complication rate with this technique compares favorably to that of antegrade nailing, with a higher rate of knee pain but a lower rate of hip pain. The malunion rate was slightly lower with retrograde rodding than with antegrade rodding of the femur.

Antegrade Transtrochanteric Intramedullary Nailing: Technique

The patient is placed either supine or in the lateral decubitus position on a fracture table. The upper end of the femur is approached through a 3-cm longitudinal incision proximal that allows access to the lateral trochanteric entry point. The skin incision can be precisely placed after localization on both the AP and lateral views. Dissection should be limited to the lateral aspect of the greater trochanter, avoiding the piriformis fossa. This prevents dissection near the origin of the lateral ascending cervical artery medial to the piriformis fossa. The rod should be inserted through the lateral aspect of the greater trochanter. In children and adolescents, it’s preferable to choose the smallest implant, with the smallest diameter reaming, to avoid damage to the proximal femoral insertion area.

The technique for reaming and nail insertion varies according to the specifics of the implant chosen. In general, the smallest rod that maintains contact with the femoral cortices is used (generally 9 mm or less) and is locked proximally and distally (Fig. 27-22). Only one distal locking screw is necessary, but two can be used.\(^{106}\) Rods that have an expanded proximal cross section should be avoided, as they require excessive removal of bone from the child’s proximal femur. The proximal end of the nail should be left slightly long (up to 1 cm) to make later removal easier. The rod chosen should be angled proximally and specifically designed for transtrochanteric insertion (Fig. 27-23).

Technique Tips. Dissection should be limited to the lateral aspect of the greater trochanter (Fig. 27-24), without extending to the capsule or midportion of the femoral neck. Some systems provide a small diameter, semiflexible tube that can be inserted up to the fracture site after initial entry-site reaming. This tube is extremely valuable in manipulating the flexed, abducted proximal fragment in proximal-third femur fractures.

Postoperative Management. Nails can be removed 9 to 18 months after radiographic union to prevent bony overgrowth.
over the proximal tip of the nail. We do not routinely remove locked antegrade nails from our teenage patients unless they are symptomatic or request removal for another reason. Dynamization with removal of the proximal or distal screw generally is not necessary.

### Complications of Locked Intramedullary Nailing

Although good results have been reported with locked intramedullary nails and patient satisfaction is high, problems with proximal femoral growth, osteonecrosis, and leg length

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**FIGURE 27-22** AP (A) and lateral (B) radiographs immediately after internal fixation of the midshaft femur fracture in a 13-year old with a pediatric locking nail that permits easy lateral entry, and requires minimal reaming of the child’s proximal femur.

**FIGURE 27-23** Preoperative (A) and postoperative (B) images showing the use of a newer generation lateral entry nail to treat a proximal third femur fracture in a 14-year-old girl.
discrepancy cannot be ignored. Fortunately, the osteonecrosis rate with newer lateral trochanteric entry nails is lower.

In a series of intramedullary nailing of 31 fractures, Beaty et al. reported one patient with segmental osteonecrosis of the femoral head (Fig. 27-25), which was not seen on x-ray until 15 months after injury. Kaweblum et al. reported a patient with osteonecrosis of the proximal femoral epiphysis after a greater trochanteric fracture, suggesting that the blood supply to the proximal femur may have been compromised by vascular disruption at the level of the greater trochanter during rod insertion. Other researchers have reported single patients with osteonecrosis of the femoral head after intramedullary nailing. A poll of the members of the Pediatric Orthopaedic Society disclosed 14 patients with osteonecrosis in approximately 1,600 femoral fractures. Despite the use of a "safe" transtrochanteric insertion site for antegrade femoral rod-

ding, a case of osteonecrosis has been reported. Buford et al. showed in their MRI study of hips after antegrade rod-
ing that subclinical osteonecrosis may be present. Antegrade rod-
ing through the trochanter or the upper end of the femur appears to be associated with a risk of osteonecrosis in children with open physes, regardless of chronologic age. Chung noted the absence of transphyseal vessels to the proximal femoral epiphysis and demonstrated that the singular lateral ascending cervical artery predominantly supplies blood to the capital femoral epiphysis (Fig. 27-26). He stated that all of the epiphyseal and metaphyseal branches of the lateral ascending cervical artery originate from a single stem that crosses the capsule at the tro-

chanteric notch. Because the space between the trochanter and

**Figure 27-24** Trochanteric entry point for intramedullary nail indicated with arrow. Entry here with smaller diameter nails limits the risk of AVN and ensures no awl in the piriformis fossa. (Reprinted from Skaggs D, Flynn J. Trauma about the pelvis/hip/femur. *Staying Out of Trouble in Pediatric Orthopaedics.* Philadelphia, PA: Lippincott Williams & Wilkins; 2006:109.)

**Figure 27-25** A: Isolated femoral shaft fracture in an 11-year old. B: After fixation with an intramedul-

ary nail, femoral head appears normal. (continues)
the femoral head is extremely narrow, this single artery is vulnerable to injury and appears to be so until skeletal maturity, regardless of chronologic age.

The proximal femoral physis is a continuous cartilaginous plate between the greater trochanter and the proximal femur in young children. Interference with the physis may result in abnormal growth of the femoral neck, placing the child at a small risk for subsequent femoral neck fracture. Antegrade nailing with reaming of a large defect also may result in growth disturbance in the proximal femur as well as femoral neck fracture. Antegrade nailing with reaming of a large defect also may result in growth disturbance in the proximal femur as well as femoral neck fracture. Beaty et al. reported no “thinning” of the femoral neck in their patients, which they attributed to an older patient group (10 to 15 years of age) and design changes in the femoral nail that allowed a decrease in the cross-sectional diameter of the proximal portion of the femoral rods.

Plate Fixation for Femoral Shaft Fractures

Submuscular Bridge Plating

Submuscular bridge plating (Fig. 27-28) allows for stable internal fixation with maintenance of vascularity to small fragments of bone, facilitating early healing.

Modern techniques of femoral plating, limiting incisions, maintaining the periosteum, and using long plates and filling only a few select screw holes, have been adopted by many pediatric orthopedic trauma surgeons as a valuable tool to manage length-unstable femur fractures. Pathologic fractures, especially in the distal femoral metaphysis, create larger areas of bone loss that can be treated with open biopsy, plate fixation, and immediate bone grafting.

Kanlic et al. reported a series of 51 patients using submuscular bridge plating with up to 10-year follow-up. Fifty-five percent had unstable fracture patterns. There were two significant complications: One plate breakage (3.5 mm) and one fracture after plate removal. Functional outcome was excellent with 8% significant leg length discrepancy. Hedequist et al. reported on 32 patients aged 6 to 15 years old. Most fractures in their series were comminuted, pathologic, osteopenic, or in a difficult location. Rozbruch et al. described modern techniques of plate fixation popularized by the AO Association for the Study of Internal Fixation that include indirect reduction, biologic approaches to internal fixation, and greater use of blade plates and locked plates (Fig. 27-29).
Figure 27-26 The single ascending cervical artery (A) is the predominant blood supply to the femoral head. The vessel is at risk during antegrade insertion of an intramedullary rod. (Reprinted from Chung S. The arterial supply of the developing proximal end of the femur. J Bone Joint Surg Am. 1976;58:961, with permission.)

Figure 27-27 Fifteen-year-old boy 3 years after intramedullary nailing of the right femur. Articulotrochanteric distance increased by 1.5 cm; note partial trochanteric epiphysiodysis (arrow) with mild overgrowth of the femoral neck. (Reprinted from Beaty JH, Austin SM, Warner WC, et al. Interlocking intramedullary nailing of femoral-shaft fractures in adolescents: Preliminary results and complications. Pediatr Orthop. 1994;14:178–183, with permission.)

Figure 27-28 AP (A) and lateral (B) radiographs showing a complex spiral distal femur fracture that extends into the joint. This is a variation of Salter IV fracture.

(continues)
Section Four
Lower Extremity

Figure 27-28 (continued) C: The fracture was managed with submuscular plating, and percutaneous lag screw fixation of the distal femoral condyle fractures.

Sink et al.\textsuperscript{186} reported on their center’s transition to treating unstable femur fractures with submuscular plating and trochanteric entry nails, and reserving elastic nailing for stable fractures. Their complication rate declined sharply with this change in treatment philosophy.

In very rare situations, such as when there is limited bone for fixation between the fracture and the physe, locked plating techniques may be valuable. This technique provides greater stability by securing the plate with a fixed-angle screw in which the threads lock to the plate as well as in the bone. This effectively converts the screw-plate to a fixed-angle blade plate device. In using this type of device, one should lock first, then compress, and finally lock the plate on the opposite side of the fracture. The locked plate can be used with an extensile exposure or with submuscular plating, but the latter is more difficult and should only be attempted when the technique is mastered.

We do not routinely use locking plates unless pathologic lesions, severe osteopenia, or severe comminution is present. Locking screws can “cold weld” to the plate, later turning a simple implant removal into a very difficult exercise involving large exposures, cutting of the implant, and possibly locally destructive maneuvers to remove the screws.

Technique: Submuscular Bridge Plating. The technique for submuscular bridge plating of pediatric femur fractures has been well described in recent publications.\textsuperscript{103,187,188} The patient is positioned on a fracture table, and a provisional reduction is obtained with gentle traction. In most cases, a 4.5-mm narrow, low-contact DCP plate is used. In osteopenic patients, or when there is proximal or distal fracture, locking plates may be used. A very long plate, with 10 to 16 holes, is preferred; the plate selection is finalized by obtaining an image with the plate over the anterior thigh, assuring that there are six screw holes proximal and distal to the fracture (although in some more proximal and distal fractures, only three holes will be available). Depending on the fracture location and thus the position of the plate, the plate will need to be contoured to accommodate the proximal or distal femur. The table-top plate bender is used to create a small flare proximally for the plate to accommodate the contour of the greater trochanter, or a larger flare to accommodate the distal femoral metaphysis. The plate must be contoured anatomically, because the fixed femur will come to assume the shape of the plate after screw fixation. A 2- to 3-cm incision is made over the distal femur, just above the level of the physis. Exposure of the periosteum just below the vastus lateralis facilitates the submuscular passage of the plate.

A Cobb elevator is used to dissect the plane between the periosteum and the vastus lateralis. The fracture site is not exposed, and, in general, a proximal incision is not required. The plate is inserted underneath the vastus lateralis, and the femoral shaft is held to length by traction. The plate is advanced slowly, allowing the surgeon to feel the bone against the tip of the plate.

Fluoroscopy is helpful in determining proper positioning of the plate. A Kirschner wire is placed in the most proximal and most distal hole of the plate to maintain length (Fig. 27-30). Fluoroscopy is used to check the AP and lateral views and be...
survival. The bone is at appropriate length at this point. A third Kirschner wire may be used to provide a more stable reduction of the femoral shaft. Although screws can be used to facilitate angular reduction to the plate, length must be achieved before the initiation of fixation.

The principles of external fixation are used in choosing sites for screw fixation. Greater spread of screws increases the stability of fracture fixation. We generally place one screw through the distal incision under direct visualization. At the opposite end of the femur, the next most proximal screw is placed to fix length and provisionally improve alignment. Central screws are then placed, using a free-hand technique with the “perfect circle” alignment of the plate over the fracture fragments. Stab holes are made centrally for drill and screw insertion. Rather than using a depth gauge directly, because the bone will be pulled to the plate, the depth gauge is placed over the thigh itself to measure appropriate length of the screw. When screws are inserted, a Vicryl tie is placed around the shank to avoid losing the screw during percutaneous placement. Self-tapping screws are required for this procedure. Six cortices are sought on either side of the fracture.

The postoperative management includes protected weight bearing on crutches with no need for cast immobilization, as long as stable fixation is achieved. At times, there is benefit to a knee immobilizer; however, in general, this is not required. Early weight bearing in some series of plate fixation has resulted in a low but significant incidence of plate breakage and non-union. These complications should be decreased by a cautious period of postoperative management.

There are occasional cases with sufficient osteopenia or comminution to require a locked plate to provide secure fixation. In using a locked plate submuscularly, a large enough incision must be used to be sure the bone is against the plate when it is locked. The articular fragment is fixed first to ensure that the angular relationship between the joint surface and the shaft is perfect.

**Complications of Plate Fixation**

Refracture is rare at the end of the plate or through screw holes, and whether bone atrophy under a plate is caused by stress shielding or by avascularity of the cortex is unknown. Although still somewhat controversial, the plate and screws may be removed at 1 year after fracture to avoid fracture at the end of the plate.

Plate removal can be difficult after submuscular plating; in fact, the problems with plate removal keep some surgeons from using the technique routinely. Pate et al. reviewed a series of 22 cases of plate removal after submuscular plating for femoral shaft fracture. In 7 of the 22 cases, the incision and surgical dissection was more extensive in the plate removal than in the initial insertion. The authors alert the reader that bone can form on the leading edge of the plate, complicating plate removal.

Quadriceps strength after plate fixation appears not to be compromised, relative to intramedullary fixation or cast immobilization.
For stable femur fractures in children under 6 months of age, we use a Pavlik harness. Webril is gently wrapped around the thigh before placing the Pavlik. Abuse and metabolic bone disease must be considered in an infant with a femoral fracture. If the fracture is unstable, usually the proximal fragment is flexed and a Pavlik harness is the ideal device for reducing and holding the fracture. The use of a Pavlik harness requires an attentive and compliant caregiver. A Gore-Tex-lined spica is an alternative, especially for the bigger, older baby. Traction with a spica cast is rarely used if ever needed in this group.

For children 6 months to 5 years of age with an isolated femoral fracture, an early spica cast is usually the treatment of choice. In the typical low-energy toddler femur fracture, we have noted similar clinical results, but much happier families and children, when we use a one-leg “walking spica,” so this has become our choice for this age group. Some children with a walking spica benefit from cast wedging 1 to 2 weeks after injury, so we prepare families for this possibility as we consent for the procedure. A Gore-Tex liner, if available, markedly improves skin care. If length or alignment cannot be maintained in an early spica cast (this is rare in low-energy fractures), traction followed by casting can be used. We typically use a distal femoral traction pin and place the child in a 90°/90° or oblique position in the bed for traction. We must emphasize that over 95% of infants and toddlers can be managed without traction with a low complication rate and low cost. In children with multiple-system trauma, either flexible intramedullary nailing or external fixation is often a better choice, based on the fracture anatomy and the soft tissue injury. Traction is very rarely used in the setting of multiple-system trauma.

In children 5 to 11 years of age, retrograde flexible intramedullary nailing is generally the safest and best option for length-stable fractures (and many length-unstable fractures). Submuscular bridge plating or external fixation is used for unstable fracture patterns, comminuted fractures, and fractures with severe soft tissue injury. Early spica casting may be used for nondisplaced or minimally displaced fractures in this age group. In very large or obese children (greater than 50 kg) who are 9 to 11 years of age, we may use a small diameter locked trochanteric entry nail. In certain situations, the family and surgeon prefer a “nonsurgical” option; in such cases, spica casting, usually with traction, may be used in these school-aged children.

In children 11 years to maturity, we generally prefer a trochanteric entry locked IM nail or submuscular bridge plating. Flexible intramedullary rods can be effective in this age group (Fig. 27-31), especially for midshaft transverse fractures in petite teens. The surgeon should be aware that the complication rate rises with flexible nailing in this older group. External fixation is occasionally valuable in the 11- to 15-year-old population.

**Figure 27-31** Successful use of titanium elastic nails in older teenager. This 15-year old sustained a minimally displaced midshaft femur fracture. **A:** AP and **B:** lateral views at presentation. **C:** This radiograph, taken 3 months after injury, shows that the fracture healed in perfect alignment with abundant callous.
16-year-old group, particularly in complex proximal or distal fracture. Healing is slow, however, and the full treatment course may take 4 months or more. Submuscular plating is also valuable for subtrochanteric and supracondylar fractures of the femur, whereas intramedullary nails are ideal for midshaft fractures. If antegrade rodding is chosen, a transtrochanteric approach is used. There is a limited role for retrograde-locked intramedullary nailing in adolescents approaching skeletal maturity.

**Complications of Femoral Shaft Fractures**

**Leg Length Discrepancy**

The most common sequela after femoral shaft fractures in children is leg length discrepancy. The fractured femur may be initially short from overriding of the fragments at union; growth acceleration occurs to “make up” the difference, but often this acceleration continues and the injured leg ends up being longer. 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.

**Overgrowth and Shortening**

Overgrowth after femoral fracture is most common in children 2 to 10 years of age. The average overgrowth is 0.9 cm, with a range of 0.4 to 2.5 cm. Overgrowth occurs when the fracture is short, at length, or overpulled in traction at the time of healing. In general, overgrowth occurs most rapidly during the first 2 years after fracture and to a much lesser degree for the next year or so. Because the average overgrowth after femoral fracture is approximately 1 cm, shortening of 2 to 3 cm in the cast is the maximal acceptable amount.

Truesdell reported the phenomenon of overgrowth in 1921, and many researchers since have verified the existence of growth stimulation after fracture. The relationship of the location of the fracture to growth is somewhat controversial. Staheli and Malkawi et al. reported that overgrowth was greatest if the fracture occurred in the proximal third of the femur, whereas Henry stated that the most overgrowth occurred in fractures in the distal third of the femur. Other investigators have found no relationship between fracture location and growth stimulation. The relationship between fracture type and overgrowth also is controversial. In general, most researchers believe that no specific relationship exists between fracture type and overgrowth, but some have reported overgrowth to be more frequent after spiral, oblique, and comminuted fractures associated with greater trauma.

**Angular Deformity**

Some degree of angular deformity is frequent after femoral shaft fractures in children, but this usually remodels with growth. Angular remodeling occurs at the site of fracture, with appositional new bone formation in the concavity of the long bone. Differential physal growth also occurs in response to diaphyseal angular deformity. Wallace and Hoffman stated that 74% of the remodeling that occurs is physal, and appositional remodeling at the fracture site occurs to a much lesser degree. However, this appears to be somewhat age dependent. It is clear that angular remodeling occurs best in the direction of motion at the adjacent joint. That is, anterior and posterior remodeling in the femur occurs rapidly and with little residual deformity. In contrast, remodeling of a varus or valgus deformity occurs more slowly. The differential physal growth in a varus or valgus direction in the distal femur causes compensatory deformity, which is usually insignificant. In severe varus bowing, however, a hypoplastic lateral condyle result, which may cause a distal femoral valgus deformity if the varus bow is corrected.

Guidelines for acceptable alignment vary widely. The range of acceptable anterior and posterior angulation varies from 30 to 40 degrees in children up to 2 years of age (Fig. 27-32), decreasing to 10 degrees in older children and adolescents. The range of acceptable varus and valgus angulation also becomes smaller with age. Varus angulation in infants and children should be limited to 10 to 15 degrees, although greater degrees of angulation may have a satisfactory outcome. Acceptable valgus angulation is 20 to 30 degrees in infants, 15 to 20 degrees in children up to 5 years of age, and 10 degrees in older children and adolescents. Compensation for deformity around the knee is limited, so guidelines for the distal femoral fractures should be stricter than proximal femoral fractures.

Late development of genu recurvatum deformity of the proximal tibia after femoral shaft fracture has been most often reported as a complication of traction pin or wire placement through or near the anterior aspect of the proximal tibial physis, excessive traction, pin track infection, or prolonged cast immobilization. However, proximal tibial growth arrest may complicate femoral shaft fracture, presumably as a result of occult injury. 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 1 or 2 fingerbreadths 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 markedly 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 often preferable.

Distal femoral angular malunion is being recognized after submuscular plating. Care in plate contouring and postoperative monitoring are recommended.

**Rotational Deformity**

According to Verbeek, rotational deformities of 10 degrees to more than 30 degrees occur in one-third of children after...
conservative treatment of femoral shaft fractures. Malkawi et al.\textsuperscript{126} found asymptomatic rotational deformities of less than 10 degrees in two-thirds of their 31 patients. Salem and Keppler\textsuperscript{179} noted a 47\% incidence of torsional malunion $\geq 15$ degrees in the patients they treated with elastic nails at one center in Germany. Torsional deformity usually is expressed as increased femoral anteversion on the fractured side compared with the opposite side, as demonstrated by physical examination; a difference of more than 10 degrees has been the criterion of significant deformity. However, Brouwer et al.\textsuperscript{23} challenged this criterion, citing differences of 0 to 15 degrees in a control group of 100 normal volunteers. The accuracy of measurements from plain x-rays also has been disputed, and Norbeck et al.\textsuperscript{155} suggested the use of computed tomographic (CT) scanning for greater accuracy.

Rotational remodeling in childhood femoral fractures is another controversy in the search for criteria on which to base therapeutic judgments. According to Davids\textsuperscript{44} and Braten et al.\textsuperscript{22} up to 25 degrees of rotational malalignment at the time of healing of femoral fractures appears to be well tolerated in children. In their patients with more than 25 degrees of rotational malalignment, however, deformity caused clinical complaints. Davids\textsuperscript{44} found no spontaneous correction in his study of malunions based on CT measurements, but the length of follow-up is insufficient to state that no rotational remodeling occurs. Brouwer et al.\textsuperscript{23} and others\textsuperscript{15,72,157,206} reported slow rotational correction over time. Buchholz et al.\textsuperscript{26} documented five children with increased femoral anteversion of 10 degrees or more after fracture healing in children between 3 and 6 years old. In three of five children there was full correction of the rotational deformity but the oldest of the children failed to correct spontaneously.

Certainly, in older adolescents, no significant rotational remodeling will occur. In infants and juveniles, some rotational deformity can be accepted\textsuperscript{55} because either true rotational remodeling or functional adaptation allows resumption of normal gait. Up to 30 degrees of malrotation in the femur should result in no functional impairment unless there is pre-existing rotational malalignment. The goal, however, should be to reduce a rotational deformity to 10 degrees, based on alignment of the proximal and distal femur radiographically, interpretation of skin and soft tissue envelope alignment, and correct positioning within a cast, based on the muscle pull on the proximal fragment. The distal fragment should be lined up with the position of the proximal fragment determined by the muscles inserted upon it (Fig. 27-3).
Delayed Union

Delayed union of femoral shaft fractures is uncommon in children. The rate of healing also is related to soft tissue injury and type of treatment. The time to fracture union in most children is rapid and age dependent. In infants, fracture can be healed in 2 to 3 weeks. In children under 5 years of age, healing usually occurs in 4 to 6 weeks. In children 5 to 10 years of age, fracture healing is somewhat slower, requiring 8 to 10 weeks. Throughout adolescence, the time to healing continues to lengthen. By the age of 15 years, the mean time to healing is about 13 weeks, with a range from 10 to 15 weeks (Fig. 27-33). Application of an external fixation device appears to delay callus formation and slow the rate of healing. Flexible nailing allows some motion at the fracture site, promoting extensive callus formation. Bone grafting and internal fixation with either a compression plate or locked intramedullary nail is the usual treatment for delayed union in older children and adolescents. Delayed union of a femoral fracture treated with casting in a child 1 to 6 years of age is probably best treated by continuing cast immobilization until bridging callus forms or (rarely) by additional bone grafting.

Nonunion

Nonunions of pediatric femoral fractures are rare. They tend to occur in adolescents, in infected fractures, or in fractures with segmental bone loss or severe soft tissue loss. Tibial fractures are the most common source of pediatric nonunions; femoral fractures account for only 15% of nonunions in children. Even in segmental fractures with bone loss, young children may have sufficient osteogenic potential to fill in a significant fracture gap (Fig. 27-34). For the rare femoral shaft nonunion in a child 5 to 10 years of age, bone grafting and plate-and-screw fixation have been traditional treatment methods, but more recently insertion of an interlocking intramedullary nail and bone grafting have been preferred, especially in children over 10 to 12 years of age. Aksoy et al. reported a small series of nonunions in malunions salvaged with titanium elastic nails. Union was achieved in 6 to 9 months in most cases.

Robertson et al. reported the use of external fixators in 11 open femoral fractures. The time to union was delayed, but a satisfactory outcome occurred without subsequent procedures. This supports the belief that the rates of delayed union and nonunion are low in pediatric femoral fractures, because open fractures would have the highest rates of delayed union.

Muscle Weakness

Weakness after femoral fracture has been described in the hip abductor musculature, quadriceps, and hamstrings, but persistent weakness in some or all of these muscle groups seldom causes a long-term functional problem. Henrikus et al. found that quadriceps strength was decreased in 30% of his patients and 18% had a significant decrease demonstrated by a one-leg hop test. Thigh atrophy of 1 cm was present in 42% of patients.
of patients. These deficits appeared to be primarily related to the degree of initial displacement of the fracture. Finsen et al. found hamstring and quadriceps deficits in patients with femoral shaft fractures treated with either rods or plates.

Damholt and Zdravkovic documented quadriceps weakness in approximately one-third of patients with femoral fractures, and Viljanto et al. reported that this weakness was present when patients were treated operatively or nonoperatively. Byami et al. found that hip abductor weakness was related to ipsilateral fracture magnitude, long intramedullary rods, and, to a lesser degree, heterotopic ossification from intra-medullary rodding. Hedin and Larsson found no significant weakness in any of 31 patients treated with external fixation for femoral fractures based on either Cybex testing or a one-leg hop test. He felt that the weakness seen in other studies may be related to prolonged immobilization.

Injury to the quadriceps muscle probably occurs at the time of femoral fracture, and long-term muscle deficits may persist in some patients regardless of treatment. Severe scarring and contracture of the quadriceps occasionally require quadricepsplasty.

**Infection**

Infection may rarely complicate a closed femoral shaft fracture, with hematogenous seeding of the hematoma and subsequent osteomyelitis. Fever is commonly associated with femoral fractures during the first week after injury, but persistent fever or fever that spikes exceedingly high may be an indication of infection. One should have a high index of suspicion for infection in type III open femur fractures. A series of 44 open femur fractures reported no infection in type I and II fractures, but a 50% (5 of 10) of type III fractures developed osteomyelitis. Presumably this occurs because of the massive soft tissue damage accompanying this injury.

Pin track infections occasionally occur with the use of skeletal traction, but most are superficial 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.

**Neurovascular Injury**

Nerve and vascular injuries in children are uncommonly associated with femoral fractures. An estimated 1.3% of femoral fractures in children are accompanied by vascular injury. Such injuries result in the formation of pseudoaneurysms. Vascular injury occurs most frequently with displaced Salter–Harris physeal fractures of the distal femur or distal femoral metaphyseal fractures. If arteriography indicates that vascular repair is necessary after femoral shaft fracture, open reduction with internal fixation or external fixation of the fracture is usually recommended first to stabilize the fracture and prevent injury of the repair. Secondary limb ischemia also has been reported after the use of both skin and skeletal traction. Documentation of peripheral pulses at the time of presentation, as well as throughout treatment, is necessary.

Nerve abnormalities reported with femoral fractures in children include those caused by direct trauma to the sciatic or femoral nerve at the time of fracture and injuries to the peroneal nerve during treatment. Weiss et al. reported peroneal nerve palsies in 4 of 110 children with femoral fractures treated with early 90/90 hip spica casting. They recommended extending the initial short leg portion of the cast above the knee to decrease tension on the peroneal nerve.

Riew et al. reported eight nerve palsies in 35 consecutive patients treated with locked intramedullary rodding. The nerve injuries were associated with delay in treatment, preoperative shortening, and boot traction. Resolution occurred in less than 1 week in six of eight patients.

Many peroneal nerve deficits after pediatric femoral shaft fractures will resolve with time. In infants, however, the development of an early contracture of the Achilles tendon is more likely. Because of the rapid growth in younger children, this contracture can develop quite early; if peroneal nerve injury is suspected, an ankle-foot orthosis should be used until the peroneal nerve recovers. If peroneal, femoral, or sciatic nerve deficit is present at initial evaluation of a closed fracture, no exploration is indicated. If a nerve deficit occurs during reduction or treatment, the nerve should be explored. Persistent nerve loss without recovery over a 4- to 6-month period is an indication for exploration.

**Compartment Syndrome**

Compartment syndromes of the thigh musculature are rare, but have been reported in patients with massive thigh swelling after femoral fracture and in patients treated with intramedullary rod fixation. If massive swelling of thigh musculature occurs and pain is out of proportion to that expected from a femoral fracture, compartment pressure measurements should be obtained and decompression by fasciotomy should be considered. It is probable that some patients with quadriceps fibrosis and quadriceps weakness after femoral fracture had intracompartmental pressure phenomenon. Mathews et al. reported two cases of compartment syndrome in the “well leg” occurring when the patient was positioned for femoral nailing in the hemilithotomy position. Vascular insufficiency related to Bryant traction may produce signs of compartment syndrome with muscle ischemia. Janzing et al. reported the occurrence of compartment syndrome using skin traction for treatment of femoral fractures. Skin traction has been associated with compartment syndrome in the lower leg in both the fractured and nonfractured sides. It is important to realize that in a traumatized limb, circumferential traction needs to be monitored closely and is contraindicated in the multiply injured or head-injured child. As noted in the spica cast section, several cases of leg compartment syndrome have been reported after spica cast treatment in younger children with femur fractures.

**Special Fractures of the Femoral Shaft**

Subtrochanteric Fractures

Subtrochanteric fractures generally heal slowly, angulate into varus, and are more prone to overgrowth. These fractures offer a challenge, as the bone available between the fracture site and the femoral neck limits internal fixation options. In younger
Children, traction and casting can be successful. Three weeks of traction is usually necessary, and the surgeon should place a good valgus mold at the fracture site, and monitor the fracture closely in the first 2 weeks after casting. When the patient returns for follow-up and the subtrochanteric fracture has slipped into varus malangulation, the cast can be wedged in clinic or casting can be abandoned for another method. Parents should be warned that loss of reduction in the cast is quite common, and wedging in clinic is a routine step in management.

An external fixation strategy can be quite successful if there is satisfactory room proximally to place pins. Once there is satisfactory callus (about 6 weeks), the fixator can be removed and weight bearing allowed in a walking spica (long leg cast with a pelvic band—place a valgus mold to stabilize fracture in the first few weeks after external fixator removal). Flexible nailing can be used, with a proximal and distal entry strategy (Fig. 27-35). A pitfall in this fracture is thinking the proximal fragment is too short to use flexible IM nails on the AP radiograph because the proximal fragment is pulled into flexion by the unopposed psoas muscle. Pombo and Shilt reported a series of 13 children, averaging of 8 years old with subtrochanteric fractures, treated with flexible nailing. Results were excellent or satisfactory in all cases. Submuscular plating can also produce satisfactory results. In adolescents, there is insufficient experience with this fracture to determine at what age intramedullary fixation with a reconstruction-type nail and an angled transfixion screw into the femoral neck is indicated. Antegrade intramedullary nail systems place significant holes in the upper femoral neck and should be avoided. Unlike subtrochanteric fractures in adults, nonunions are rare in children with any treatment method.

**Supracondylar Fractures**

Supracondylar fractures represent as many as 12% of femoral shaft fractures and are difficult to treat because the gastrocnemius muscle inserts just above the femoral condyles and pulls the distal fragment into a position of extension (Fig. 27-36), making alignment difficult (Fig. 27-3). The traditional methods of casting and single-pin traction may be satisfactory in young children (Fig. 27-37). As mentioned in the external fixation section above, supracondylar fractures through a benign lesion are safely and efficiently treated with a brief period (4 to 6 weeks) of external fixation (Fig. 27-38), followed by a walking cast until the callus is solid and the pin sites are healed. In other cases, internal fixation is preferable, either with submuscular plating (Figs. 27-28 and 27-39) and fully threaded cancellous screws (if there is sufficient metaphyseal length) or with crossed smooth K-wires transfixing the fracture from the epiphysis to the metaphysis, as described for distal femoral physeal separations. If there is sufficient metaphyseal length, flexible nailing can be used, so long as fixation is satisfactory. The flexible nails can be either placed antegrade as originally described, or a retrograde if there is satisfactory distal bone for fixation near the nail entry site. Biomechanically, retrograde insertion is superior. Pathologic fractures in this area are common, and an underlying lesion should always be sought.

**Open Femoral Fractures**

Open femoral fractures are uncommon in children because of the large soft tissue compartment around the femur. Proper wound care, debridement, stabilization, and antibiotic therapy are required to reduce the chance of infection. In a study by Hutchins et al., 70% of children with open femoral fractures had associated injuries and 90% were automobile related. The average time to healing was 17 weeks, and 50% of the Gustilo type III injuries developed osteomyelitis.

External fixation of open femoral shaft fractures simplifies wound care and allows early mobilization. The configuration of the external fixator is determined by the child’s size and the fracture pattern. Generally, monolateral half-pin frames are satisfactory, but thin-wire circular frames may be necessary if (text continues on page 1022)
FIGURE 27-37  A: This 6-year-old patient sustained an unstable supracondylar fracture of the femur. B: The fracture was managed with immediate spica casting with the knee in 90 degrees of flexion, mandatory in such a case to prevent posterior angulation. Bayonet apposition, as shown in this figure (C: lateral and D: AP) is acceptable in a child of this age.
Figure 27-38  AP (A) and lateral (B) radiographs showing a fracture at the junction of the distal femoral metaphysis and diaphysis. C: The fractures reduced into near-anatomic alignment and an external fixator was used to control the distal fragment. D: The fixator was removed 8 weeks after injury, and after a brief period of weight bearing is tolerated a long leg cast, the fracture has healed in anatomic alignment with no shortening.
bone loss is extensive. External fixation provides good fracture control, but, as always, family cooperation is required to manage pin and fixator care. Plate fixation also allows early mobilization as well as anatomic reduction of the femoral fracture. Wound care and treatment of other injuries are made easier in children with multiple trauma. However, this is an 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 or intramedullary fixation may be used for Gustilo–Anderson type I and II fractures; type III fractures in older adolescents are better suited for external fixation or intramedullary nailing. Plate breakage can occur if bone grafting is not used for severe medial cortex comminution.

In older adolescents, submuscular plating or trochanteric entry nailing is often the optimal treatment choice. Closed nailing after irrigation and drainage of the fracture allows early mobilization and easy wound care in patients with Gustilo–Anderson type I, II, IIIA, and IIIB injuries, but the risk of osteonecrosis must be recognized.

### Femoral Fractures in Patients with Metabolic or Neuromuscular Disorders

For patients with osteogenesis imperfecta who have potential for ambulation, surgical treatment with Rush, Bailey–Dubow, or Fassier rods (see Chapter 8) is recommended for repeated fractures or angular deformity. Cast immobilization is minimized 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 is used.

### Floating Knee Injuries

These rare injuries occur when ipsilateral fractures of the femoral and tibial shafts leave the knee joint “floating” without distal or proximal bony attachments. They are high-velocity injuries, usually resulting from collision between a child pedestrian or cyclist and a motor vehicle. Most children with floating knee injuries have multiple-system trauma, including severe soft tissue damage, open fractures, and head, chest, or abdominal injuries. Except in very young children, it is usually best to fix both fractures. If both fractures are open, external fixation of both the tibial and femoral fractures 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.

Letts et al. described five patterns of ipsilateral tibial and femoral fractures and made treatment recommendations based on those patterns (Fig. 27-40). Because of the high prevalence of complications after closed treatment, Bohn and Durbin recommended open or closed reduction and internal fixation of the femoral fracture in older children. Arslan et al. evaluated the treatment of the “floating knee” in 29 consecutive cases, finding that those treated operatively had a shorter hospital stay, decreased time to weight bearing, and fewer complications than those managed with splinting casting or traction. Arslan et al. demonstrated that open knee fracture rather than ligamentous injury was a risk factor for poor outcome and that angulation was a predictor of future compromise of function.
Bohn and Durbin\textsuperscript{19} reported that of 19 patients with floating knee injuries, at long-term follow-up 11 had limb length discrepancy secondary to either overgrowth of the bone after the fracture or premature closure of the ipsilateral physis (seven patients), genu valgum associated with fracture of the proximal tibial metaphysis (three patients), or physeal arrest (one patient). Four patients had late diagnosis of ligamentous laxity of the knee that required operation. Other complications included peroneal nerve palsy, infection, nonunion, malunion, and refracture.

Fractures in the Multiple-System Trauma Patient

In a study of 387 previously healthy children with femoral fractures, the authors evaluated the effect of stabilization on pulmonary function. Patients with severe head trauma or cervical spine trauma are at greatest risk for pulmonary complications. Timing of treatment of femoral fractures appears to not affect the prevalence of pulmonary complications in children. Mendelson et al.\textsuperscript{1910} similarly showed no effect of timing of femoral fixation on long-term outcome but early fracture fixation did decrease hospital stay without increasing the risk of central nervous system or pulmonary complications.

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