CHAPTER 34

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Thoracolumbar Spine and Lower Extremity Fractures

FRACTURES OF THE THORACIC AND LUMBAR SPINE

Clinical Features. Spine fractures in children represent 1% to 2% of all pediatric fractures (1). Most of these injuries involve the cervical spine and are discussed in Chapter 21. Causes of spine injury include falls, athletic activities, and battering, but trauma due to motor vehicle accidents is most common (2–4). Thoracolumbar spine injuries are more common in older children and adolescents but less common than in adults (5). The true incidence is difficult to determine and the reported incidence may be too low because some children with trauma severe enough to cause spinal fracture may die from associated injuries (6). Approximately two-thirds of thoracolumbar spine fractures in adults are in the region of T12–L2, but the distribution of pediatric and adolescent spine fractures is more uniform throughout the thoracic and lumbar spine (7).

There is a 50% incidence of associated injuries in children who sustain spine trauma from motor vehicle crashes (3). Complete examination is essential when evaluating a child with multiple injuries because spine fractures are occasionally overlooked (8, 9). Physical examination has a high sensitivity when diagnosing spine fractures (5). Examination may reveal tenderness, swelling, ecchymosis, or a palpable defect posteriorly along the spinous processes. A seat belt mark across the abdomen or injury of an abdominal organ should increase the index of suspicion. Any loss of sensory or motor function should be accurately documented.

Spinal cord injury is less frequent in children than in adults. Perhaps this is because the pediatric spine is much more flexible than the adult spine, allowing greater deformation without fracture. This increased musculoskeletal elasticity is not shared by the spinal cord and may lead to a clinical entity known as spinal cord injury without radiographic abnormality (SCIWORA) (10). The disproportionately large head size and other structural features in children place the cervical and upper thoracic regions at greatest risk for spinal cord injury. Trauma to the lower thoracic or lumbar spine in children is rarely associated with spinal cord injury. The prognosis for recovery from incomplete neurologic injury is better in children than in adults, but complete lesions rarely improve (3).

Plain radiographs should be obtained when spine trauma is suspected, but these may be difficult to interpret. Multilevel injuries are common so imaging of the entire spine is recommended (2). A computed tomography (CT) scan or an MRI or both are indicated for evaluation of most patients when thoracolumbar injuries are suspected or known to be present (9). A CT scan is especially helpful to evaluate the bony structures. Sagittal and coronal reconstruction can be used to evaluate alignment and spinal canal encroachment. MRI is more useful than CT scan to evaluate the spinal cord, intervertebral discs, and other soft-tissue structures (9). An MRI is indicated in all cases with neurologic deficit.

Anatomy and Classification. The thoracic and lumbar vertebrae develop form three main ossification centers, one each for the left and right sides of the neural arch and one for the body. The junction of the arches with the body occurs at the neurocentral synchondrosis. This junction is visible radiographically until the age of 3 to 6 years. It lies just anterior to the base of the pedicle and can be misinterpreted as a congenital anomaly or a fracture in younger children. Secondary centers of ossification occur in flattened, disc-shaped epiphyses superior and inferior to each vertebral body. These centers provide longitudinal growth but do not cover the entire vertebral body (11). Ossification of these growth plates at the age of 7 to 8 years creates the radiographic impression of a groove at the corner of each vertebral body. This groove is circumferential around the upper and lower end plates of each vertebra. The ligaments and discs attach to this groove, which is therefore an apophyseal ring. The ring apophysis develops its own ossification center by the age of 12 to 15 years and fuses with the remainder of the vertebra at skeletal maturity (12).

Classification systems for thoracolumbar spine fractures in children have not been proposed. The three-column theory of Denis (13) allows classification of adult fractures and also has relevance for the pediatric population. According to this theory, the thoracolumbar spine consists of anterior, middle, and posterior columns. The anterior column includes the anterior longitudinal ligament, the anterior half of the vertebral body, and the anterior portion of the annular ligament. Middle column structures are the posterior half of the vertebral body, the posterior annulus, and the posterior longitudinal ligament. The posterior column includes the neural arch, the ligamentum flavum, the facet joint capsules, and the interspinous ligament. Spinal stability is primarily dependent on the status of the middle column (14).

Denis (13) applied this three-column theory to classify minor or major thoracolumbar fractures. Minor injuries include isolated fractures of the posterior elements. Major fractures are subdivided into compression fractures, burst fractures, seatbelt-type injuries, and fracture dislocations. Compression of the anterior column is usually stable and results from axial loading in flexion. Lateral compression fractures of the vertebral body may also occur. Further compression results in a burst fracture that is unstable because the middle column becomes involved. Lap-belt injuries (Chance fractures) are unstable because they disrupt the posterior and middle columns by flexion and distraction forces. Fracture dislocations usually involve all three columns and result from various combinations of forces.

Certain types of thoracolumbar injuries are unique to children; these include most cases of SCIWORA, posterior limbus or apophyseal fractures, and fractures associated with child abuse.

Treatment of Thoracolumbar Fractures. Older adolescents sustain injuries similar to those seen in adults and should be managed accordingly (15). Most thoracolumbar spine fractures in children and younger adolescents are minor, stable, and without neurologic deficit. Symptomatic treatment and gradual resumption of activities are generally sufficient for management of these injuries. In the active athlete with an acute fracture of the pars intra-articularis, a thoracolumbar-sacral orthosis is recommended for 6 to 8 weeks in an attempt to obtain union.

Compression Fractures. Most compression fractures in children occur in the thoracic spine. Underlying causes of bone fragility, such as leukemia, should be considered when trauma has been minimal. Multiple compression injuries are not uncommon. Remodeling with restoration of anterior vertebral height has been observed in children younger than 13 years (4, 7). When wedging of a thoracic or lumbar vertebra is <10 degrees, symptomatic treatment is recommended until the patient is comfortable, followed by gradual resumption of activities. When wedging is >10 degrees and the Risser sign is <3, immobilization in hyperextension is recommended for a period of 2 to 3 months (4). Surgical stabilization is recommended when compression is >15 degrees, or approximately 50% compression of the anterior vertebra, compared to posterior vertebral height. Surgical stabilization is also recommended when lateral compression is >15 degrees (6, 15). The authors follow these guidelines, although prolonged bracing after initial treatment is usually avoided.

Burst Fractures. Treatment guidelines for burst fractures are similar to those for compression fractures in children and adolescents. These injuries may be managed nonoperatively when the posterior column is intact, deformity is minimal, and there is no neurologic injury (4, 16–18). However, progressive kyphosis has been noted in some patients treated nonoperatively (18). Nonsurgical treatment usually consists of hyperextension casting for 2 to 3 months and bracing for an additional 6 to 12 months. Surgical decompression and instrumentation are recommended for patients with greater degrees of deformity or with neurologic compromise (16, 17). Posterior distraction and instrumentation may achieve decompression by ligamentotaxis with reduction of the retropulsed fragments (19). Anterior decompression has been recommended in the presence of multiple nerve root paralysis, but the role of anterior decompression and instrumentation remains controversial (20).

Lap-belt Fractures (Chance-type Fracture). This flexion distraction injury has been associated with the use of lap-belt restraints, when the lap belt slides up the torso and rests over the abdomen instead of the proximal thighs and hips (20). The incidence of Chance fractures in children has increased since the introduction of mandatory seat-belt laws. Fortunately, this injury has a better prognosis in children than in adults (21). Neurologic deficits are infrequent, but intra-abdominal injury is common and obscures the diagnosis of spine trauma.

A flexion distraction injury is unstable in most patients. Treatment consists of cast immobilization for 8 to 10 weeks when there is minimal displacement and the fracture line goes through bone. Posterior surgical stabilization is indicated in the presence of displacement, neurologic deficits, or when there is a significant ligamentous disruption. Instrumentation and fusion one level above and one level below the fracture may be required. In some patients one-level posterior fusion is sufficient (8, 20), typically with pedicle screw fixation in older children (Fig. 34-1).

Limbus Fracture (Apophyseal Fracture). This fracture is typically seen in the adolescent or young adult and presents clinically like a herniated nucleus pulposus.

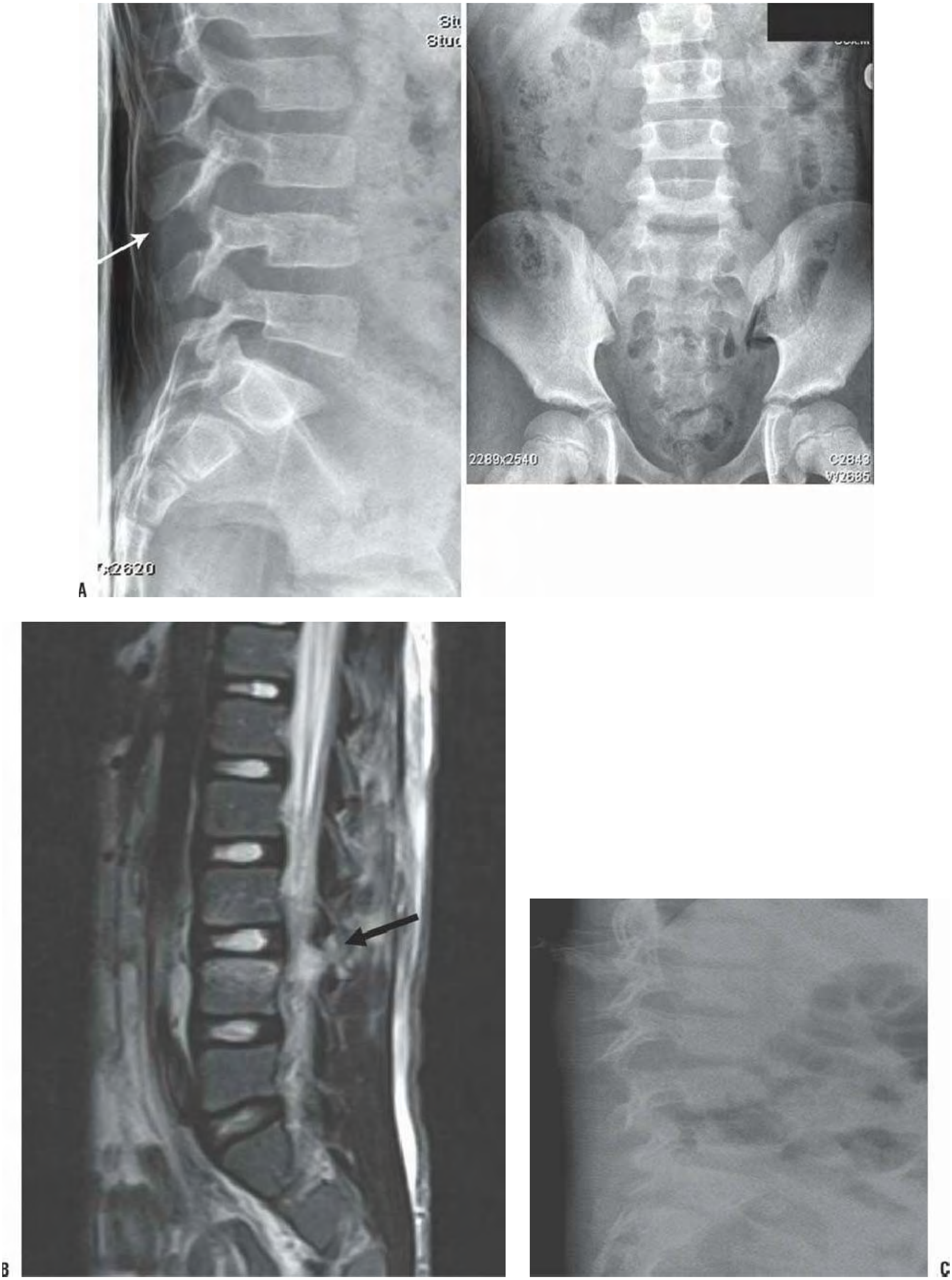

FIGURE 34-1. **A:** Anteroposterior and lateral lumber spine radiographs of an 8-year-old with a lap-belt injury. There is slight distraction of the spinous processes and posterior swelling. There was also an abdominal injury **B:** MRI with posterior ligamentous increased signal. **C:** Close observation with extension cast immobilization as the original treatment revealed the unstable ligamentous characteristics of the Chance injury. A two-level posterior fusion was thus performed.

It often results from the patient's lifting a heavy object, but may result from falls or twisting injuries. The patient may describe a "pop" at the time of injury, followed by radiculopathy. Delayed diagnosis is common (22). Takata et al. (23) described four types of growth-plate injuries to the spine. Nonoperative management is rarely successful regardless of the type (17, 22). MRI, CT scan, or both should be used to determine the exact location and configuration of the lesion. Surgical excision is then performed by piecemeal excision of the limbus fragment. In order to completely remove bony impingement, the authors recommend laminectomy with direct exposure rather than relying on minimally invasive techniques.

Complications. Complications of thoracolumbar fractures in children are uncommon unless there is an accompanying neurologic deficit. Inadequate stabilization or late deformity may be problematic when there is an associated neurologic deficit, or after wide laminectomy (24, 25). In the absence of spinal cord injury, remodeling is more likely in younger children, particularly when the iliac apophysis is incompletely ossified (Risser sign <3) (4, 7). However, remodeling can occur in older children. Spontaneous remodeling and redevelopment of the spinal canal has been observed in adults after burst fractures with canal encroachment (26). End-plate injury has been correlated on MRI with disc degeneration, but back pain is uncommon after spine fractures in children (27).

PELVIC FRACTURES

Clinical Features. Fractures of the pelvis are less common in children than in adults and represent only 0.2% of all pediatric fractures (28). The immature pelvis is more malleable than that of an adult, largely because of the lower modulus of elasticity of pediatric bones, and the greater flexibility of adjacent joints. More energy is required to cause a fracture in the immature pelvis. The greater energy absorption also means that associated injuries are common and the greatest cause of morbidity. Motor vehicle–related accidents are the most common cause of pediatric pelvic fractures (29–31). Most unstable pelvic fractures are caused when a motor vehicle strikes a pedestrian (31, 32). Pediatric pelvic fractures include avulsion fractures (usually sports injuries, covered in Chapter 31, stable and unstable pelvic ring fractures, and acetabular and triradiate cartilage injuries. Most pediatric pelvic fractures are stable and minimally displaced.

Approximately 20% of polytraumatized children have pelvic fractures (33), and approximately 58% to 87% of children with pelvic fractures have associated injuries (31, 32). These associated injuries include head injuries, intra-abdominal trauma, urologic disruptions, and fractures. There is little to no difference in mortality rates or injury severity as measured by the ISS between adults and children (34). Death occurs in 3% to 5% of children with juvenile pelvic trauma (28, 31, 32). Death is most frequently related to head injury and mortality related to exsanguination due to the pelvic fracture alone is rare (34). Yet, exsanguination from fractures or visceral injuries can occur, and the risks of hemorrhage and associated visceral injuries correlate with fracture patterns. Patients with bilateral anterior and posterior fractures are at greatest risk, whereas isolated pubic ramus fractures have the lowest risk of hemorrhage and intra-abdominal injury (35, 36).

Evaluation includes a careful physical examination for associated injuries, including neurologic deficits. Any laceration should be inspected to determine whether an open fracture has occurred. Rectal examination is indicated to look for hemorrhage signifying bone penetration into the rectum and to verify intact perineal sensation (i.e., sacral plexus function). Pelvic stability should be tested with anterior and lateral compression of the pelvis. Peripheral arterial circulation should also be noted. A single anteroposterior plain radiograph can provide key information about the pelvic ring and is useful for initial screening. If there are indications of a more unstable injury, these other views should be obtained once the patient is stable: pelvic inlet (40 degrees caudal), outlet (40 degrees cephalad), and Judet (45 degrees oblique) views. These views can help define the fracture pattern and the potential involvement of the acetabulum and triradiate cartilage injury. These views have largely been replaced with CT scan, with or without three-dimensional reconstruction. CT scan, often routinely obtained looking for visceral injury, can diagnose minor fractures in the pelvic ring and assist with classification and decision making when operative intervention is indicated.

Anatomy and Classifications of Pelvic Fractures. The pelvis is formed from three ossification centers: the ischium, the pubis, and the ilium. These come together at the acetabulum to form the triradiate cartilage. Secondary ossification centers can be confused with fractures. These appear at the apophyses in patients between 13 and 16 years of age. The apophyses that are principally associated with avulsion injuries are located on the ischial tuberosity, the anterior inferior iliac spine, and the anterior iliac crest. Secondary centers of ossification can also develop along the pubis and the ischial spine. Several other normal variants can also be confused with fractures. An area of particular confusion is at the junction of the inferior pubic ramus and the ischium. Before ossification, this junction can have the appearance of a fracture, especially when ossification is asymmetric. A swelling may also occur in this area and can simply be observed when asymptomatic.

Several classifications have been proposed for pelvic fractures (37); however, the key features for decision making include (i) whether the pelvis is mature or immature (38) and (ii) if the fracture is stable or unstable. Mature patients with a closed triradiate are managed according to adult treatment classification and guidelines. Plain radiographs can allow reliable determination of fracture types, although CT scanning may be helpful in questionable cases or when surgical intervention is anticipated (39). The authors prefer the classification proposed by Watts (40):

1. Avulsions
2. Fractures of the pelvic ring (stable and unstable)
3. Fractures of the acetabulum

Pelvic fracture stability can be subclassified using the AO/ASIF classification of adult pelvic fractures (30). This classification is based on both the mode of injury and the resulting characteristics of the fracture.

Type A: Stable Injury. Stable injuries include fractures of the pubic ramus (Fig. 34-2) or iliac wing. The ramus fractures may be isolated or may involve both the superior and the inferior rami. It should be noted that, because of the elasticity of the child's pelvis, diastasis of the pubic symphysis can occur in children without instability of the sacroiliac joint posteriorly. In young children, this fracture usually represents separation at the bone-cartilage junction rather than joint disruption. This "single ring" fracture that is stable without anterior symphysis or ramus injury may also occur near the sacroiliac joint.

Type B: Rotationally Unstable Fractures. This is a pelvic ring disruption that is stable in the vertical plane but unstable in the transverse plane. Mechanisms include lateral compression causing, for instance, pubic and ischial ramus fractures with contralateral sacral fracture. Alternatively, anterior compression may cause an "open-book" type of injury with pubic diastasis.

Type C: Rotationally and Vertically Unstable Fractures. This group includes bilateral pubic rami fractures (straddle injuries), which rarely displace in children; vertical shear fractures through the ipsilateral anterior and posterior pelvic rings; and anterior ring fractures with acetabular disruption.

Treatment of Pelvic Fractures

Pelvic Ring Fractures. Regardless of how the fracture is classified using the many different classification schemes, the assessment and treatment of pediatric pelvic fractures is dependent on two factors: whether the fracture is stable or unstable. A stable fracture is a single ring injury or multiple fractures with displacement of <1 cm. An unstable injury has an anterior and posterior ring fracture with displacement >1 cm.

Most pelvic fractures in children are stable injuries and have a favorable result with symptomatic treatment and weight-bearing restrictions with close follow-up. Unstable pelvic fractures with minimal displacement (<1 cm), which do not involve the acetabulum, can be managed with weight-bearing restrictions and close radiographic follow-up. There has been a trend toward a more aggressive operative approach in displaced unstable fractures. Historically, a nonoperative approach to unstable fractures has been acceptable due to the belief that the pelvis would remodel and there was minimal long-term morbidity. Recent literature suggests that residual deformity can lead to long-term morbidity of leg-length discrepancy, back pain, pelvic asymmetry, and sacroiliac arthritis (41).

The authors recommend fracture reduction of unstable fractures that are displaced >1 cm. The challenges include determining instability and reduction and stabilization in the pediatric pelvis. Anterior stabilization can be performed with external fixation or symphysis plating (Fig. 34-3). Unstable fractures may require internal fixation of posterior injury, in addition to anterior stabilization with external fixation or other means. Posterior stabilization can be achieved with a combination of

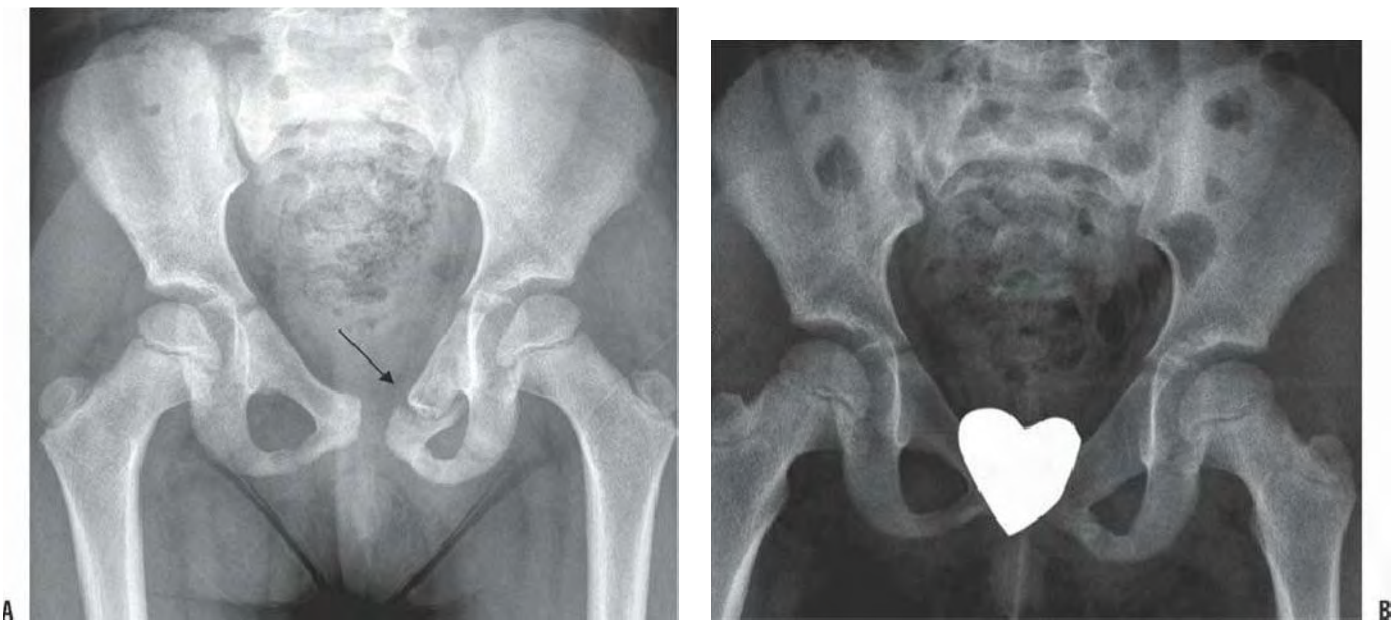

FIGURE 34-2. Example of a stable ramus fracture (*arrow* in **A**) and a fracture union with no posterior injury **(B)**.

plates and screws through a posterior or an iliac fossa approach. Sacroiliac screws can be used in the immature pelvis as long as the S1 body is large enough. Careful fluoroscopy, surgeon expertise, and CT scanning can facilitate SI screw fixation (Fig. 34-3) (30, 37, 42). Traction and spica casting is an option in the patient where size may limit internal fixation. A multispecialty approach is recommended to improve outcomes. In the urgent situation, all the specialties should work together to stabilize the patient. Temporary pelvic wrapping or anterior external fixation can help the hemodynamic status and assist with patient mobilization.

Acetabular Fractures. Watts (40) classified acetabular fractures into four types. This classification has been used to guide

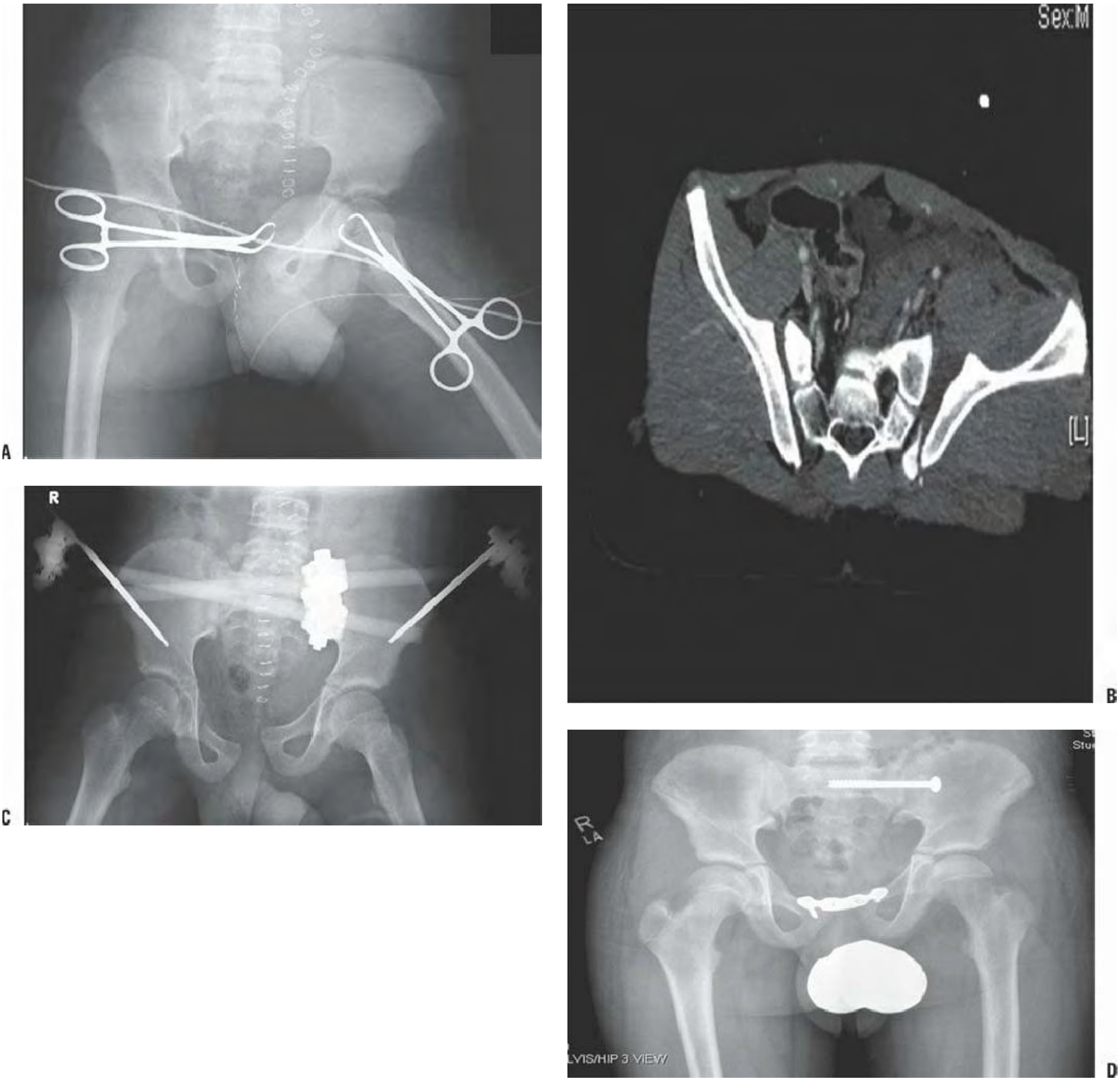

FIGURE 34-3. Radiograph (**A**) and CT scan (**B**) of a 12-year-old male with an unstable pelvic fracture. A pelvic band with a sheet was placed around the pelvis to temporarily improve hemostasis. **C:** An anterior external fixator was urgently placed to temporarily stabilize the pelvis and improve the hemodynamic status. **D:** Once the patient was stable, an anterior symphysis plate achieved anterior ring stabilization and an S1 sacroiliac screw was placed to achieve posterior stabilization. Some mild plastic deformation remains in the immature pelvis.

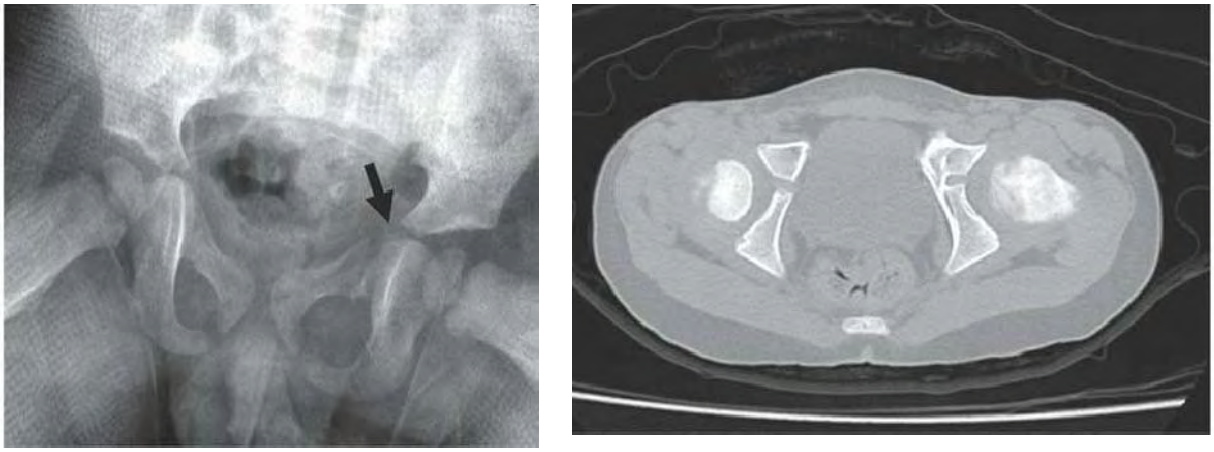

FIGURE 34-4. **A:** A 2-year-old with a minimally displaced fracture of the left superior ramus extending into the triradiate cartilage (*arrow*). Pelvis radiograph **(B)** and CT scan **(C)** 9 months after the injury showing the formation of a triradiate cartilage physeal bar. Since the patient is <10 years, bar excision is recommended to attempt to lessen future deformity of hip dysplasia.

treatment (43). Precise restoration of joint congruity is recommended except for stable posterior fracture dislocations with concentric reductions (Watts type I fractures). Nondisplaced acetabular fractures are managed by closed reduction (Watts type II fractures). Multiple fragments with instability (Watts type III) are best managed by open reduction with stable internal fixation (30, 43). Early motion is also recommended (30). Comminution is often less severe in children than in adults, and the results of surgical management are generally satisfactory. Fractures with central dislocation of the hip have a poor prognosis regardless of surgical or nonsurgical management. Traction may be utilized for these fractures, or surgical management may be attempted when comminution is minimal. Poor results after anatomic reduction may still occur with all types of acetabular fractures due to the magnitude of the initial trauma (44).

Premature closure of the triradiate cartilage is a potential complication that is unique to the immature skeleton (Fig. 34-4) (45). Fractures that cause premature closure are usually nondisplaced and do not require open reduction. Children younger than 10 years are at the greatest risk for this complication. Disturbance in growth leads to the development of a shallow acetabulum because the triradiate cartilage is responsible for growth in the height and width of the acetabulum. Hip subluxation may follow, necessitating redirectional pelvic osteotomy.

Complications. Immediate management of pelvic fractures and associated injuries can be challenging, but long-term complications are rarely attributable to the bony structures. Residual morbidity is more often due to associated injuries, especially traumatic brain injury. Untreated, displaced fractures can result in a limp, back pain, rotational deformity, or limb-length discrepancy. Acetabular injuries are at risk for developing traumatic arthritis in spite of anatomic reduction. Premature closure of the triradiate cartilage can be problematic in younger children.

FRACTURES AND DISLOCATIONS OF THE HIP

Hip Dislocation. Traumatic dislocation of the hip in children is uncommon, representing only 5% of all pediatric dislocations. Most hip dislocations are posterior, but anterior and obturator dislocations can occur (46, 47). The mechanism of

FIGURE 34-5. Traumatic hip dislocation in a 3-year-old boy. **A:** This anteroposterior pelvis radiograph was taken upon presentation of a 3-year-old boy who twisted his leg while running down the stairs. **B:** This anteroposterior pelvis radiograph was taken immediately after closed reduction in the emergency room. On long-term follow-up, there was no avascular necrosis or any other sequelae.

injury depends somewhat on the age of the child. Hip dislocations in children younger than 8 years are frequently the result of mild trauma because joint laxity is common and the acetabulum is largely cartilaginous (Fig. 34-5) (47). Dislocations in children older than 8 years are more often the result of moderate or severe trauma. Dislocation from moderate trauma may result in spontaneous, incongruous reduction and capsular interposition (48). This is rare but easily misdiagnosed in children and adolescents. Any suggestion of joint-space widening should be investigated with a CT scan. An MRI may be valuable to visualize any cartilage and labrum that may be an impediment to reduction in the immature nonossified acetabular rim (Fig. 34-6).

Treatment. Treatment consists of closed reduction with adequate muscle relaxation and analgesia. Whenever possible, closed reduction within 6 hours of injury is recommended. Reduction is rarely difficult in children, but gentle reduction is especially important in the adolescent age group. Reduction with image guidance in the operating room should be considered in the adolescent age group because occult epiphyseal injury may be present, and epiphyseal separation can occur during attempted reduction (49). The reduction technique for posterior dislocation requires hip and knee flexion, usually with adduction of the hip. Longitudinal traction is then applied while an assistant stabilizes the pelvis. The limb is then extended, internally rotated, and abducted. After the hip is reduced, the stable arc of motion should be assessed. Postreduction radiographs should include the opposite hip to confirm a concentric reduction with symmetrical joint spaces. A CT and possibly an MRI scan are recommended after hip reduction in children older than 10 years or in younger children if instability or joint-space widening is noted. A CT scan is not necessary in the younger child with a stable concentric reduction and no evidence of acetabular fracture on plain radiographs. The child younger than 8 years should be immobilized in a spica cast for 4 to 6 weeks to reduce the risk of recurrent dislocation. Stable, closed reductions in older children can be managed with activity restriction and decreased weight bearing for 6 weeks to allow capsular healing and reduction of posttraumatic inflammatory response.

The indications for open reduction include unstable closed reduction, nonconcentric reduction, bone or soft-tissue fragments within the joint, or a large acetabular rim fragment with instability. Open reduction is recommended from the direction of the dislocation, such as the posterior interval (i.e., Kocher-Langenbeck approach) for posterior dislocations. Postoperative management after open reduction is the same as that after closed reduction.

Complications. The reported incidence of avascular necrosis in children is 3% to 10%, approximately half in the rate of adults. The risk of avascular necrosis is diminished when reduction is achieved within 6 hours of injury (46, 47). Nerve injury has been reported in 5% of children with hip dislocation, but recovery occurs spontaneously in 60% to 70% of these patients (50). The long-term risk of arthritis is related to the severity of the trauma, associated fractures, and treatment delays beyond 24 hours. However, some satisfactory results have been reported when neglected traumatic dislocations have been treated by traction and open reduction (51). Coxa magna in the absence of avascular necrosis has been observed in many children after traumatic hip dislocation. The cause is probably reactive hyperemia secondary to extensive soft-tissue injury. Coxa magna does not seem to influence clinical outcome.

Hip Fractures. Hip fractures in children represent <1% of all pediatric fractures (1). In contrast to adult hip fractures, pediatric and adolescent hip fractures are usually the result of high-energy trauma because considerable force is required

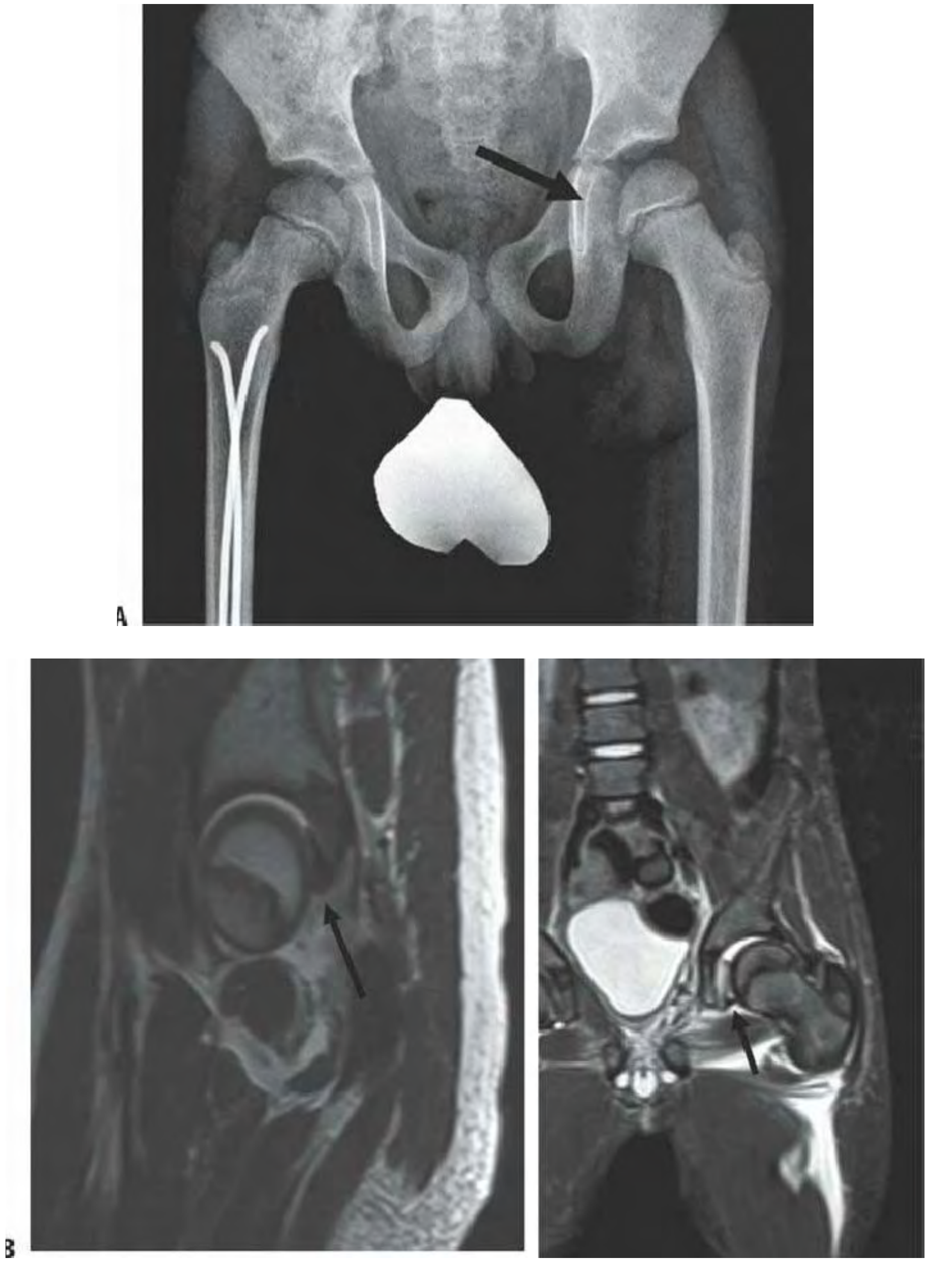

FIGURE 34-6. **A:** Pelvis x-ray of a 7-year-old. There is slight widening of the left hip joint (*arrow*) with no fracture visualized **B:** MRI of the hip showing soft tissue (labral/cartilage, *arrow*) not visible on plain radiographs entrapped in the posterior hip impeding reduction.

to produce a fracture in this age group. The exceptions to this are infants who have been subjected to child abuse, and fracture through a pathologic lesion of the femoral neck (e.g., bone cyst). Complications are frequent and have been reported in 15% to 60% of patients (52, 53). Prompt and appropriate management may reduce the risk of subsequent complications.

Anatomy and Classification. In the infant, the proximal femur is composed of a single large cartilaginous growth plate (54). The medial portion becomes the epiphyseal center of the femoral head, ossifies at around 4 months of age, and forms the proximal femoral physis. The lateral portion of the proximal femur forms the greater trochanter physis, with ossification of the epiphysis by 4 years of age. Injury to the proximal femur can affect one or both of these centers of growth. The proximal femoral physis is responsible for the metaphyseal growth of the femoral neck and provides approximately 15% of the total length of the femur. The greater trochanter helps shape the proximal femur, and damage to this apophysis in children younger than 8 to 10 years may produce an elongated, valgus femoral neck (55, 56).

The vascular supply of the growing child's proximal femur is jeopardized by these fractures, and the extent of damage greatly affects the final outcome. The dominant arterial source for the femoral head is the lateral epiphyseal vessels, which are the terminal extension of the medial femoral circumflex artery. These vessels penetrate the capsule at the base of the neck near the piriformis fossa and run along the lateral periosteum giving off several branches to the femoral neck before entering the femoral head just proximal to the epiphyseal cartilage (Fig. 34-7) (57, 58). The lateral circumflex system can supply blood to a portion of the anterior femoral head until 2 to 3 years of age, after which it primarily supplies the metaphysis. In children older than 14 to 18 months, the proximal femoral physeal plate becomes an absolute barrier to the metaphyseal blood supply and prevents direct vascular penetration of the femoral head (57, 58). Thus, the epiphyseal and metaphyseal circulation remain separate until complete physeal closure occurs. The vessels of the ligamentum teres do not contribute a significant portion of the blood supply to the femoral head, especially in children younger than 8 years.

It is postulated that some displaced fractures may leave the vascular leash intact but kinked and occluded until realignment is established (59). This has been demonstrated by arteriography before and after reduction of an unstable slipped capital femoral epiphysis (60). Vascular disruption as a cause of avascular necrosis is supported by the fact that the magnitude of displacement is a prognostic factor for the development of necrosis (61). It has also been suggested that prompt decompression of the intracapsular hematoma contributes to the restoration of normal vascular flow and reduces the incidence of femoral head necrosis (62–65).

A study of nondisplaced hip fractures in adults confirmed high intracapsular pressures with decreased blood flow on bone scan. Following aspiration and fixation, repeat bone scans demonstrated restoration of blood flow (66). Other studies have also reported high intracapsular pressures that are reduced by joint decompression (66–68). Soto-Hall et al. (69), in 1964, noted that intra-articular pressures increased when intracapsular hip fractures were manipulated by placing the leg in internal rotation and extension. The increased joint pressure during reduction of fractures in this position has been confirmed by other authors (66, 68). Reduction of intracapsular fractures may improve vascularity by restoring normal arterial position. However, fracture reduction may also lead to increased intracapsular pressure unless the hip is decompressed. Prompt anatomic reduction, internal fixation, and decompression are recommended in order to restore circulation in a timely manner. This approach to the management of hip fractures and unstable slipped capital femoral epiphyses in children has been associated with a decreased risk of avascular necrosis (62, 63, 65, 70).

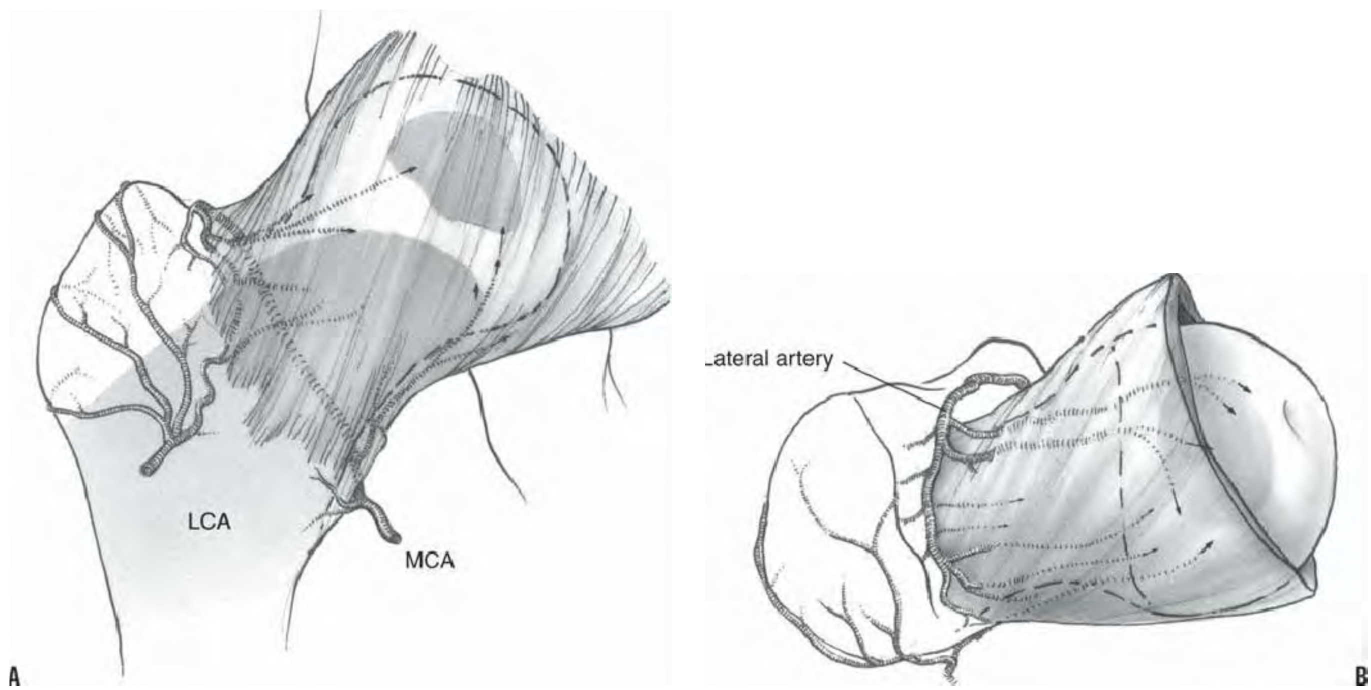

FIGURE 34-7. Arterial supply of the developing proximal femur. **A:** The anterior view demonstrates the lateral circumflex artery (LCA), which supplies the metaphysis and the greater trochanter. The medial circumflex femoral artery (MCA) is the dominant vessel to the femoral head. **B:** The superior view shows the lateral ascending artery, which sends numerous epiphyseal and metaphyseal branches (*arrows*) that supply the greatest volume to the femoral head and neck. These ascending cervical branches traverse the articular capsule as the retinacular arteries. The interval between the greater trochanter and the hip capsule is extremely narrow, and is the area where the lateral ascending cervical artery passes. This may be a site of vascular compression or injury.

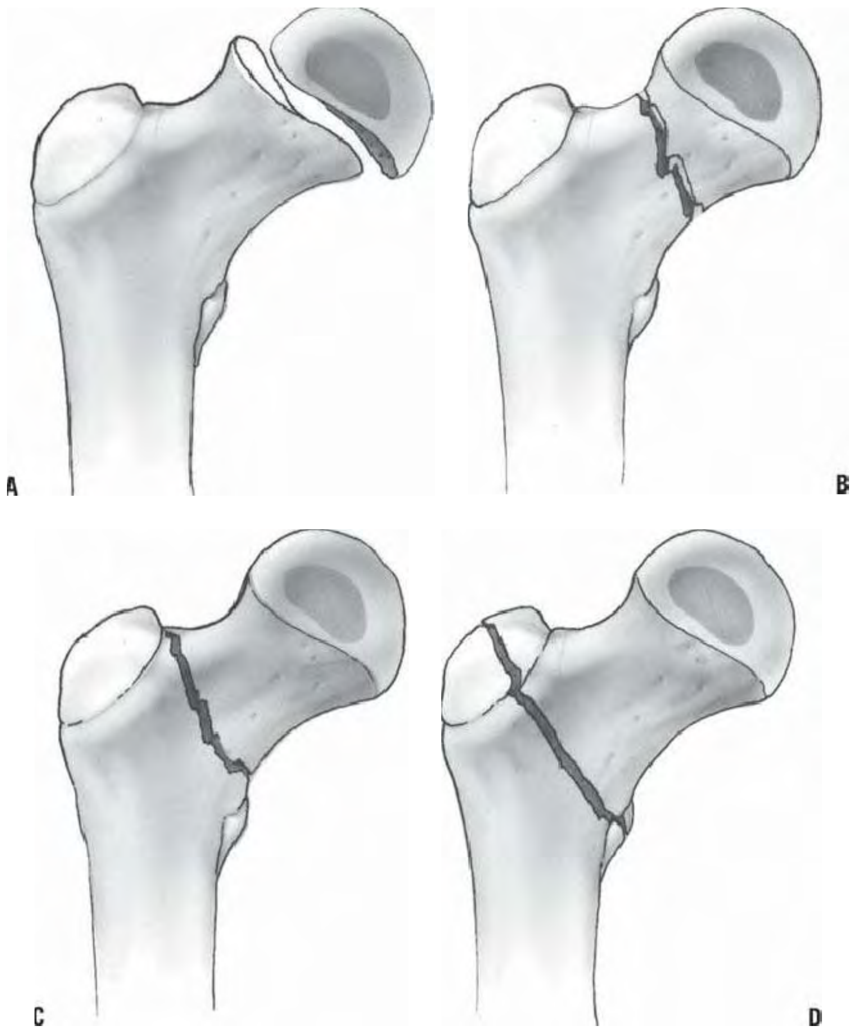

FIGURE 34-8. Delbet's classification for proximal femur fractures. **A:** Type I is a transepiphyseal fracture. **B:** Type II is a transcervical fracture. **C:** Type III is a cervicotrochanteric fracture (basicervical). **D:** Type IV is an intertrochanteric fracture.

Delbet's classification (Fig. 34-8) offers a useful system for the treatment and prognosis of proximal femur fractures (71). Type I fractures are transphyseal separations. Physeal separation in infants is occasionally seen as a birth fracture or as a result of intentionally inflicted injury. Obstetric fracture separations have excellent clinical results, without avascular necrosis, although diagnosis and treatment may be delayed (72). Children younger than 2 years with type I fracture also have a good prognosis without surgical management (73). Transepiphyseal separations in older children result from more severe trauma, but separation has been reported during reduction of hip dislocation in the adolescent age group (74). When the epiphyseal fragment is dislocated from the acetabulum, the risk of avascular necrosis approaches 100%. However, the incidence of avascular necrosis is variable when the femoral head remains within the joint (71).

Type II fractures occur in the neck of the femur between the epiphyseal plate and the base of the neck. These injuries constitute approximately 50% of all fractures of the proximal femur (71). Complications are frequent with type II fractures. The incidence of avascular necrosis approaches 50% to 60%, and the nonunion rate is 15%. Premature physeal closure may also occur, but because growth of the proximal femur is approximately 15% of the total limb (75), clinically important leg-length discrepancy is unlikely to occur in older children.

Type III fractures occur in the cervicotrochanteric, or basal neck, region of the femoral neck. This is the second most common type of hip fracture in children. Avascular necrosis occurs in 30% of displaced fractures. Malunion has been reported in 20%, and nonunion occurs in 10%, of these patients. These problems may be lessened by precise fracture reduction, combined with compression across the fracture site by means of cancellous bone screws (i.e., lag technique) (71, 76).

Type IV fractures occur in the intertrochanteric region and are associated with the least risk of damage to the femoral head vascular supply. The incidence of avascular necrosis is between 0% and 10%. Varus deformity is the most likely complication, but this may correct with growth in younger children (71, 76, 77).

Treatment. Proximal femur fractures should be treated as urgently as possible. The risk of avascular necrosis may be lower with reduction, joint decompression, and stable fixation within 24 hours of injury (53, 62, 64, 78). Delay in treatment may be necessary because of associated injuries or other considerations. A recent review of pediatric femoral neck fractures concluded that the quality of reduction and timing of surgery (<24 hours) were associated with decreasing the risk of AVN (79).

Type I Fractures. Treatment with closed reduction and casting is appropriate for minimally displaced fractures in children younger than 2 years (73). In children aged 2 to 12 years, stabilization of the reduced fracture may be accomplished with two smooth pins supplemented with spica casting. In older children, fixation across the physis is recommended. Open reduction is often necessary if the epiphysis is dislocated. This is performed through a posterior approach for posterior fracture dislocations. At the time of open reduction, curettage of the physeal plate has been recommended in an attempt to encourage revascularization of the femoral head (74).

Type II and III Fractures. If the fracture is stable and nondisplaced, and the patient is younger than 6 years, a spica cast alone can yield good results (80). Displaced fractures can usually be reduced by closed methods, but a capsulotomy may decrease the risk of avascular necrosis (62–65). Ng and Cole (64) studied the effect of early hip decompression on the frequency of avascular necrosis. It had no apparent value in type I fractures. For the type II and III fractures, 41% of 54 patients treated without hip decompression developed avascular necrosis, whereas only 8% of 39 patients with hip compression developed avascular necrosis. As previously discussed, a prompt anatomic reduction, internal fixation, and decompression are recommended by the present authors in an attempt to restore circulation in a timely manner. Fixation is achieved by the percutaneous insertion of two or three cannulated bone screws into the metaphyseal portion of the proximal fragment. If the proximal metaphyseal fragment is too small for secure fixation, smooth pins can be placed across the physis to allow subsequent growth. Stable fixation of the fracture should be given priority over preservation of the proximal femoral physis (71). Spica cast immobilization is used to augment fixation in children, especially when smooth pins have been used. In patients aged 12 years or older, threaded screws may be placed across the physis for better fixation and to avoid the use of a spica cast. Alternatively, a hip screw with a supplemental pin to control rotation may be used in older children. Caution is advised when using compression hip screws in children because dense bone may generate heat necrosis of the femoral neck during reaming. An additional smooth pin is recommended to improve rotational stability. The authors recommend an open reduction if suitable alignment is not obtained by closed means. The quality of reduction is associated with outcomes (79). An anterolateral (Watson-Jones) approach is recommended for type II fractures (Fig. 34-9).

Type IV Fractures This fracture does not require prompt stabilization except when surgical fixation improves general management. Nondisplaced fractures in this region can be managed by spica cast immobilization and close follow-up in younger children. Displaced fractures in infants and toddlers may be treated with early closed reduction and casting so long as the neck-shaft angle does not decrease to <115 degrees. Displaced fractures in older children can also be managed by skeletal traction followed by cast immobilization. However, the authors recommend surgical stabilization in children older than 6 years to reduce the risk of malunion and avoid prolonged immobilization. Interfragmentary screws may provide sufficient stability when combined with cast immobilization, but a pediatric-sized hip screw with side plate, or an angled blade plate, is preferred (Fig. 34-10). Adolescents are treated in the same manner as adults, with stable fixation across the physis using a sliding hip screw or an angled blade plate. This avoids the need for a supplemental spica cast for adolescent patients.

Complications. The most frequent complications after fracture of the proximal femur in children are osteonecrosis of the femoral head, malunion, and nonunion. Other complications include infections, premature closure of the proximal femoral growth plate, and chondrolysis. Exact complication rates are difficult to determine because of changing patterns of treatment. Prompt treatment, accurate reduction, joint decompression, and appropriate internal fixation and immobilization reduce all of these complications (53, 64).

Avascular necrosis in children may involve a portion of the femoral head, just the portion of the femoral neck between the fracture and the physis, or the entire femoral neck and head (81). Necrosis of the femoral head occurs in approximately 30% of all hip fractures in children and often leads to poor results (71). Diagnosis of avascularity can be reliably determined by MRI as early as 2 weeks following the fracture (82), or by isotope bone scan 4 months after the fracture. Children with osteonecrosis who are younger than 12 years can be treated with containment, with or without prolonged non–weight-bearing activities. These patients have a possibility of recovering satisfactory function (83, 84). The outcome for older children with osteonecrosis of the femoral head is poor. The authors recommend treating adolescents in a manner similar to that for adults, with early detection and core decompression before the occurrence of subchondral fracture (85).

Nonunion occurs in 6% to 10% of pediatric fractures of the proximal femur (71). Treatment is recommended as soon as the diagnosis is established. Subtrochanteric valgus osteotomy is preferred, with bone grafting, internal fixation, and application of a spica cast (71, 86). Supplemental vascularized bone grafting with a vascular-pedicle graft from the iliac crest should be considered when there is a large defect in the femoral head or neck (87).

Malunion and coxa vara occur in approximately 20% of reported patients, but this complication has a lower incidence when internal fixation is used (71). Remodeling may occur in younger patients (77). Subtrochanteric osteotomy is recommended for persistent deformity.

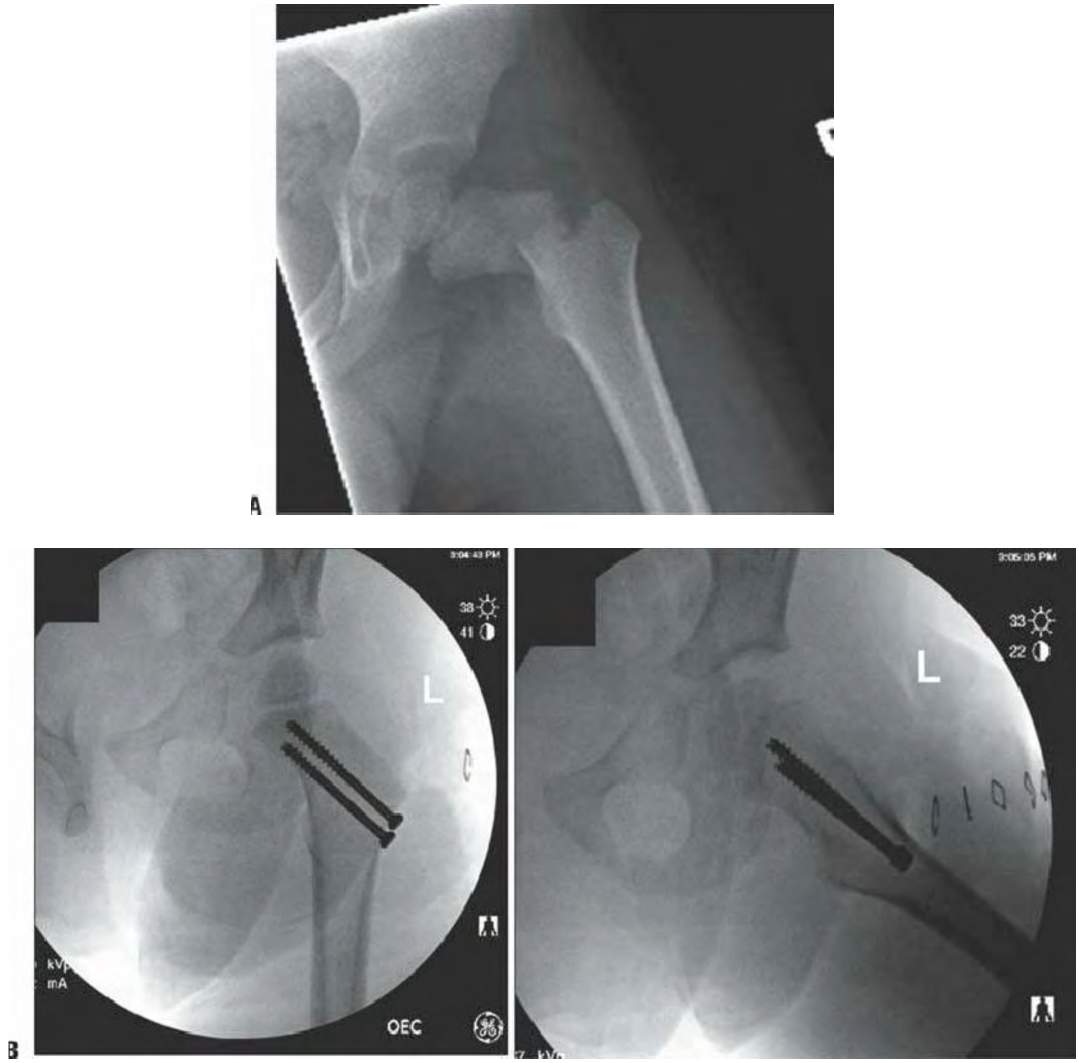

FIGURE 34-9. **A:** A 3-year-old with a displaced femoral neck fracture. **B:** Intraoperative images after an open reduction via an anterior-lateral approach as closed reduction was not successful to obtain anatomic reduction. The screws do not cross the physis so a spica cast was used.

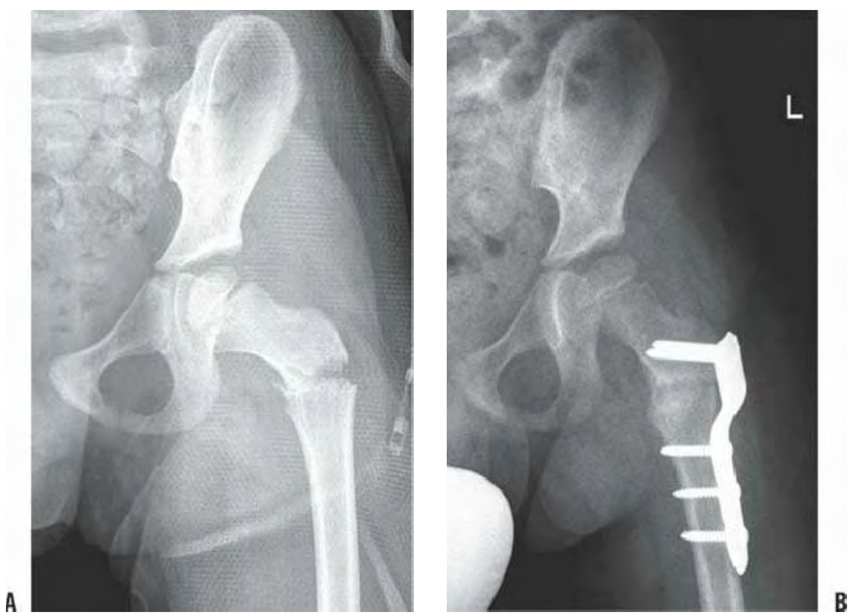

FIGURE 34-10. Type IV (intertrochanteric) hip fracture in a 4-year-old fixed with a screw and a side plate. **A:** At injury, displaced fracture in varus. **B:** At 4 weeks after internal fixation with screw and side plate, early callus is seen.

FEMORAL SHAFT FRACTURES

Femoral shaft fractures account for 1% to 2% of all fractures in childhood (1, 88). There is a bimodal age distribution, with a peak incidence at 2 to 3 years of age and another peak in adolescence. The cortical thickness of the femur increases rapidly after 5 years of age, and this may explain the decreasing incidence of femur fracture in late childhood. Intentional injury should always be considered in children who are not yet walking, but there are no distinguishing age, clinical parameter, or fracture patterns to help determine which injuries are inflicted and which are accidental (89). In infants younger than 1 year, child abuse has been identified as a cause in 65% of patients when obvious causes such as motor vehicle accidents are eliminated (89). Abuse should be indicated in any child with a femur fracture from 0 to 3 years with the greatest incidence in those younger than 1 year or walking age. Children in the toddler age group may sustain fractures with relatively minor trauma from causes such as falling from a low height or tripping while running. In the 4- to 7-year age group, approximately half of the femoral shaft fractures are caused by bicycle accidents. In the adolescent age group, motor vehicle accidents account for most of the femur fractures.

As stated by Rang (90), "It does not require a physician to diagnose a fractured femur." However, the physician must carefully examine the patient completely. Children and adolescents with femur fracture have a 35% to 40% incidence of associated injuries. Some of these injuries are occult, such as femoral neck fracture, hip dislocation, ligamentous instability of the knee, and visceral injuries (91, 92). Hemodynamic instability or steadily declining hematocrit does not occur because of an isolated, closed femur fracture. Other sources of blood loss must be sought in these patients (92).

Treatment of Femoral Shaft Fractures

Principles of Management. A wide variety of management options are currently available for femur fractures in children and adolescents. Each of these options can yield satisfactory results when used properly (93). The surgeon managing femoral fractures in children and adolescents is expected to select and perform the technique that is most appropriate under a variety of circumstances. As long as proper technique is used, there may be more than one acceptable option for treatment.

The age of the child and the fracture characteristics are the principal determinants of management. At one end of the spectrum, there are low-energy injuries in young children that are managed with closed reduction and immediate spica casting. At the other end of the spectrum, high-energy injuries in adolescents are managed with early surgical stabilization. Occasionally, however, infants with severe trauma require surgical stabilization of femoral fractures to facilitate management.

Anatomical Considerations and Remodeling Potential. Proximal fractures in all age groups are more difficult to control, but residual deformity is better tolerated because of multidirectional hip motion. Deformity is also less obvious with proximal fractures because thick thigh muscles hide residual angulation. Proximal fragments tend to flex, abduct, and externally rotate because of the unopposed action of the iliopsoas, hip abductor, and external rotator muscles. The proximal fragment of a midshaft fracture also tends to flex, abduct, and externally rotate, but the deformity is less extreme because of adductor and hamstring attachments to the proximal fragment. More distal fragments are easier to control and produce little proximal fragment angulation, except for supracondylar fractures, which tend to hyperextend because of the posterior pull of the gastrocnemius muscle on the short distal fragment. Fractures of the distal femur require more precise alignment because the deformity is more visible and remodeling in the coronal plane is limited. Supracondylar fractures of the femur require management that is similar to that for distal femoral physeal separations (94).

Children have remarkable remodeling potential until approximately 10 years of age in girls and 12 years of age in boys. Long-term studies have demonstrated that up to 25 degrees of midshaft angulation in any plane can be expected to correct satisfactorily in children younger than 13 years (95). Remodeling continues for up to 5 years following fracture. Approximately 25% of remodeling occurs at the fracture site, whereas 75% is attributed to physeal reorientation and longitudinal growth (96, 97). Fracture translation may also contribute to realignment of the mechanical axis. Rotational remodeling may also occur, but the precise amount is unpredictable (98, 99). Clinically significant rotational deformity is uncommon, even when failure of remodeling has been documented (100, 101).

Stimulation of growth after femoral fracture occurs routinely in the 2- to 9-year age group (102, 103). Unfortunately, most authors reporting the overgrowth phenomenon do not distinguish between "catch-up growth," which compensates for fracture overriding; and true overgrowth, which results in the fractured femur being longer than normal. Growth stimulation is greater when overriding is greater and may continue for 5 years after fracture. Average total growth stimulation is approximately 1 cm. In a prospective study of children younger than 12 years, Hougaard observed that all fractures of the femur healing with 3 cm or less discrepancy with the contralateral leg spontaneously recovered to <2 cm discrepancy (103). Therefore, any femoral fracture that heals in a shortened position should be observed for several years to determine the final outcome. True overgrowth has been reported after reduction with internal fixation, but the risk of overgrowth in this circumstance has not been clearly defined (93).

Management Guidelines by Age. Age or weight is the first determinant of treatment choices. Age is used here with the understanding that the children are of average weight and maturity.

Infants to 6 months. Infants younger than 1 year often sustain femur fractures because of birth trauma or abuse. The incidence of child abuse in femur fractures is up to 14% in this age group (104–106). Osteogenesis imperfecta and other metabolic disorders should also be suspected. Thick periosteum and rapid hematoma consolidation usually prevent worrisome shortening or angulation. Healing is rapid, and remodeling potential is great. Infants may be treated with application of a Pavlik harness or a conventional spica cast (107). Both methods provide patient comfort and minimal complications (107). Immobilization for 2 to 3 weeks is usually sufficient for infants <4 months, and 4 to 6 weeks for infants aged 6 to 12 months.

Age 6 months to 5 Years. Isolated femur fractures in children between the ages of 6 months and 5 years are usually treated with early spica cast application. In low-energy fractures with minimal shortening, a walking spica (cylinder long leg cast, 30 to 40 degrees of hip and knee flexion, with a pelvic band and the uninjured leg free) works well and is easier on the patient and the family. All aspects of spica cast treatment are easier for preschool children than for older children (108). Children in this age group also heal rapidly; thus, immobilization time is brief. The spica cast may be applied in the operating room or emergency department under conscious sedation. Splinting may be used for comfort until a spica cast can be applied within 48 hours after injury. Careful cast application is indicated to prevent compartment syndrome. Compartment syndrome can occur if significant pressure is placed on the calf with excessive traction especially if a short leg cast applied first and used to pull 90/90 traction while applying the remainder of the spica (109). Alignment in the cast should be as close to normal as possible, but full functional recovery can be expected in this age group if shortening at the time of union is >3 cm and angulation is <20 degrees in any plane. Fractures in the distal third should be angulated no more than 15 degrees. Close radiographic follow-up is required in the first 2 to 3 weeks to evaluate for unacceptable shortening or angulation. Other techniques should be considered if the fracture shortens >3 cm and angulation cannot be corrected with cast wedging. These techniques may be traction, temporary external fixation, or elastic nails. Other treatments such as elastic nails may be chosen in these younger preschool years dependent on fracture shortening and social concerns (110, 111).

Age 5 to 11 Years. Children between the ages of 5 and 11 years may be managed by a wide variety of methods depending on the fracture characteristics and surgeon preference. Flexible intramedullary nails are a common and proven successful method for treatment in this age group especially for stable transverse diaphyseal fractures. Historically, skeletal traction followed by spica casting has been used and is still an acceptable option for treatment. However, children treated with flexible elastic nails have a more rapid return to walking and school (112) and less hospital costs than traction and casting (113). High-energy unstable fractures with severe displacement and comminution are more challenging to treat. Flexible nails can be used with good technique, yet other methods such as submuscular plating (Figs. 34.11 to 34.17) or external fixation are good alternatives in the unstable fracture patters (114). A final option in unstable fractures that is rarely used is incorporating a traction pin in the spica cast or by traction for 2 to 3 weeks before cast immobilization to keep the fracture aligned and out to length during the period of early callus formation (115–117). Although it has been demonstrated that up to 25 degrees of angulation in any plane will remodel in this age group (118), recommended guidelines for alignment in this age group are up to 15 degrees varus or valgus, 15 degrees of anterior and/or posterior angulation, and up to 20 mm of shortening.

Age 11 Years to Maturity. Children older than 11 years are generally managed by surgical stabilization with internal or external fixation (93). Accurate restoration of length and alignment is desirable in older children because of limited remodeling potential. No more than 10 degrees of varus or valgus, 10 degrees of anterior or posterior angulation, and 15 mm of shortening should be accepted in this age group. Surgical stabilization permits early mobilization and return to school and social activities. The various techniques for stabilization include trochanteric entry nailing, submuscular plating, and flexible intramedullary nails. Flexible intramedullary nails (Figs. 34-18 to 34-22) have a slightly higher complication rate in this age group than the younger ages (119). It is generally agreed that rigid, reamed intramedullary nailing through a piriformis fossa should be avoided because of the risk of iatrogenic avascular necrosis of the femoral head (120). The risk of this complication is present as long as the proximal femoral physis remains open.

SUBMUSCULAR PLATING (FIGS. 34-11 TO 34-17). This procedure is indicated for patients ≥5 years until skeletal maturity. Submuscular plating is ideally suited for comminuted or long-oblique length unstable femur fractures. Submuscular plating is also a good option for proximal or distal one-third femur fractures. In the proximal and distal one-third fractures, there needs to be enough room for two to three screws in the proximal or the distal diaphysis.

FLEXIBLE INTRAMEDULLARY NAILING OF FEMORAL SHAFT FRACTURES (FIGS. 34-18 TO 34-24). The idea of internal stabilization of femoral shaft fractures in children is not new, having been performed by Kuntscher more than 50 years ago. Several factors, however, have brought about a renewed interest in this technique: realization of the factors that lead to a bad result with closed treatment, successful application and improvement of internal fixation of these fractures in adults, and inexperience in casting techniques among orthopaedic physicians. Cost, however, is not a factor that merits consideration. There is little difference in the cost of treating a child with flexible intramedullary rods, external fixation, or traction for 2 weeks in the hospital followed by spica cast (93, 121).

Factors that lead to a bad result with closed reduction and casting form the basis for understanding the indications for closed reduction and flexible intramedullary nailing of femoral shaft fractures in children. In children older than 9 or 10 years of age, it is often difficult to maintain acceptable alignment of the fracture because of the child's size, and this has led to the preferable use of some alternative to cast treatment in the adolescent (122–124).

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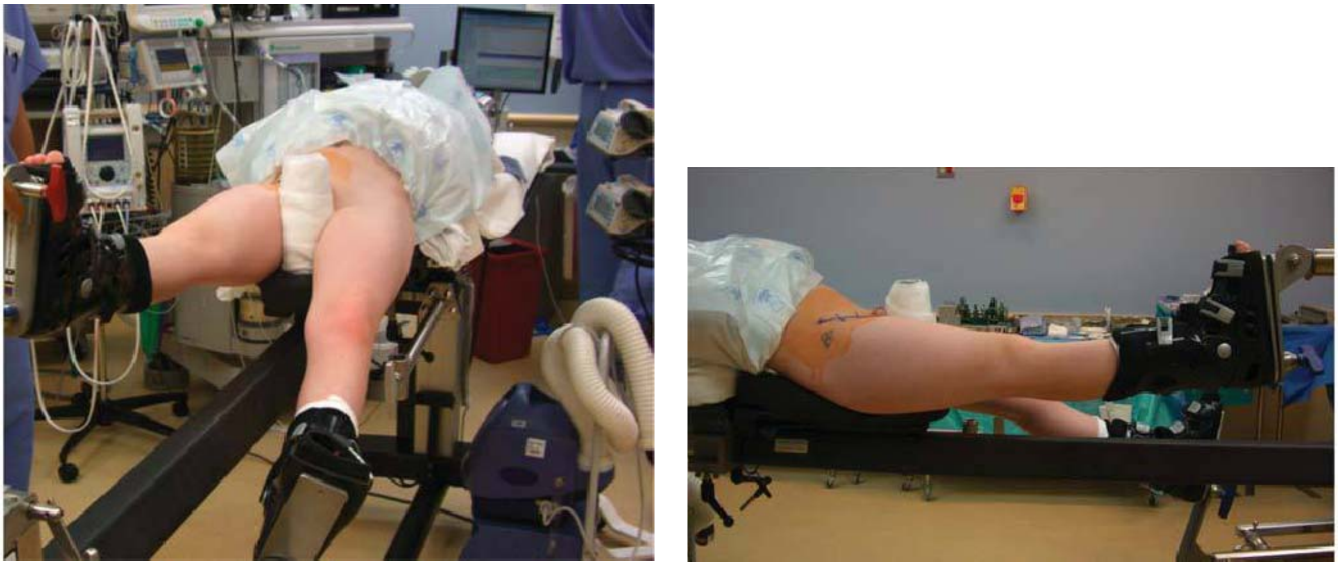
Submuscular Plating (Figs. 34-11 to 34-17)



A B

FIGURE 34-11. **Submuscular Plating. A:** Patients are positioned supine on a fracture table. The well leg is extended and slightly abducted to allow a true lateral fluoroscopic image of the fractured femur. **B:** Alternatively, a "well leg" holder may also be used. Provisional reduction restoring femoral length and rotation is obtained with boot traction and verified fluoroscopically. In comminuted fractures, special attention should be given to rotation using fluoroscopy and the well leg as a guide. Final alignment is performed with plate fixation as described later.

A B

FIGURE 34-12. **A:** A small (4 to 7 mm) incision is performed at the distal lateral thigh. The incision is midway anterior/posterior and as distal as the proximal pole of the patella. The incision is similar to the lateral incision for retrograde insertion of elastic nails. This location will expose the distal fibers of the vastus lateralis muscle. **B:** As the dissection is advanced through the tensor fascia, the distal oblique fibers of the vastus lateralis muscle will be exposed. Blunt dissection is performed deep to the distal muscle fibers to enter the plane between the vastus lateralis and the lateral femur periosteum. This plane is easily entered and allows proximal plate advancement with minimal force.

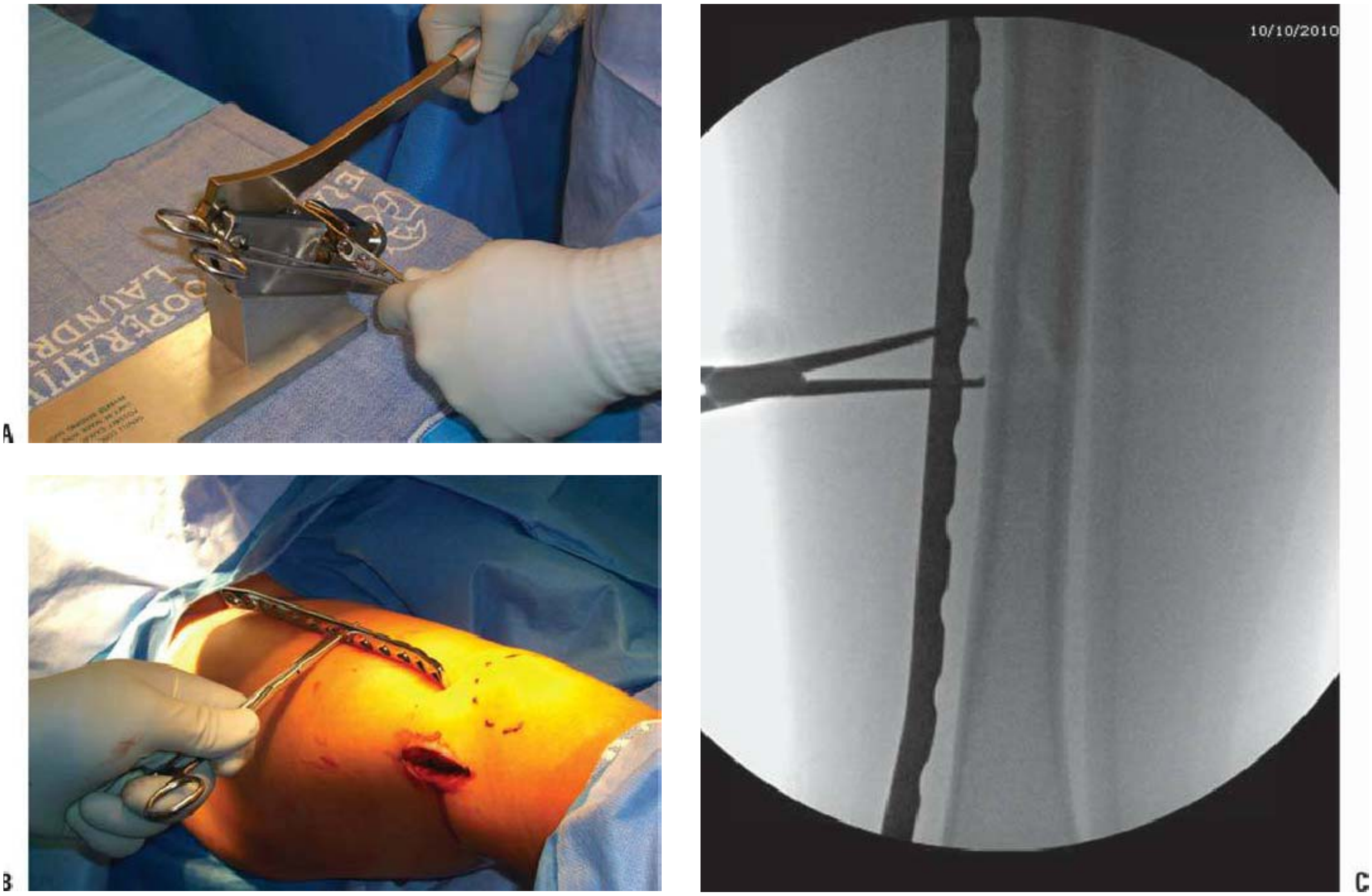


FIGURE 34-13. A long-narrow 4.5-mm plate with no staggering of screw holes is most often used. This plate is easy to contour, is readily available in many different lengths, and percutaneous screw fixation is forgiving. In smaller patients, a 3.5-mm plate may be used although a 4.5-mm plate fits most femurs in children. Having the 4.5-mm self-tapping screws allows easier percutaneous screw insertion and implant removal as the larger screw head is easier to engage with the screw-driver in a percutaneous manner. Historically a nonlocking stainless steel plate has been used. Our experience is that the nonlocking plate achieves enough stability in this age group. Also, percutaneous screw insertion and fracture reduction to the plate, is easier in a nonlocking plate. A locked plate may also be used depending on surgeon preference, in osteopenic patients, or very proximal or distal fractures where there is little available room for screws. If a locking plate is used, the surgeon should use a combination of locking and nonlocking screws to reduce the fracture to the precontoured plate. Also with a distal metaphyseal bend in the plate, the surgeon should avoid the possibility of a locking screw trajectory crossing the distal femoral physis. The plate length chosen is normally 10 to 16 holes. The plate should span from just below the greater trochanteric apophysis to the metaphysis of the distal femur. If possible, the plate should allow for six screw holes above and/or below the fracture margins to allow a large screw spread. Frequently the fracture location allows for only three screw holes which is adequate as long as a long plate is chosen. A key determinate to stability is plate length. A long plate is more important to stability than the number of screws. Once the appropriate length is chosen, it is necessary to use a table plate bender to contour the plate to accommodate the proximal and the distal metaphyseal flares **(A)**. Since the screws "pull" the femur to the precontoured plate, the final varus/valgus alignment will be that of the precontoured plate. Therefore, it is important to contour the plate as close to anatomic as possible **(B)**. Once the plate is contoured, we place it on the anterior thigh and use an anterior–posterior c-arm image to shadow the lateral aspect of the femur to check the contour and the length **(C)**.

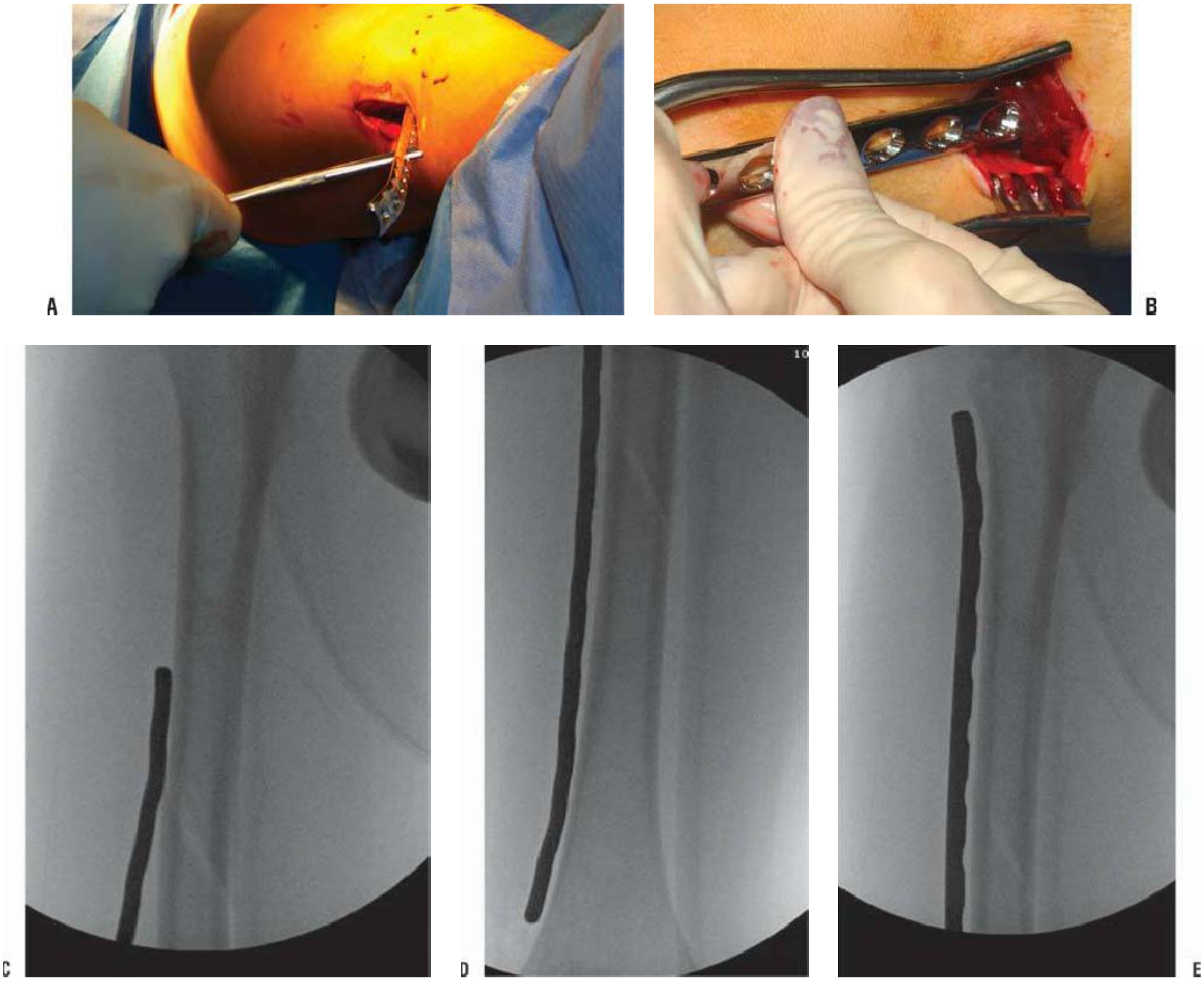
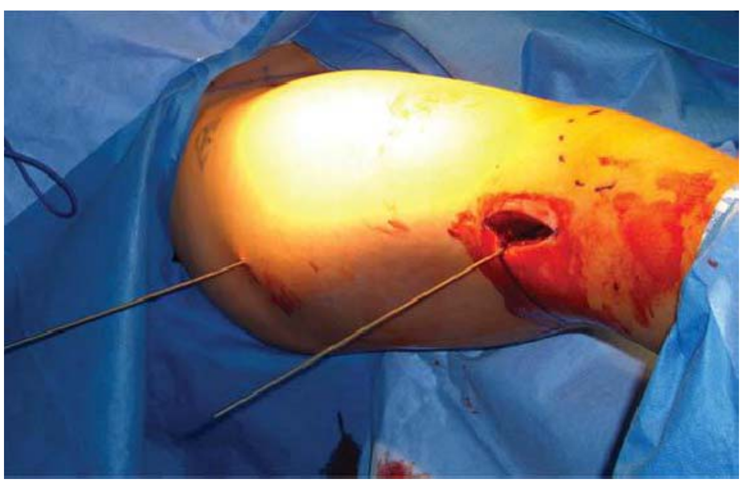
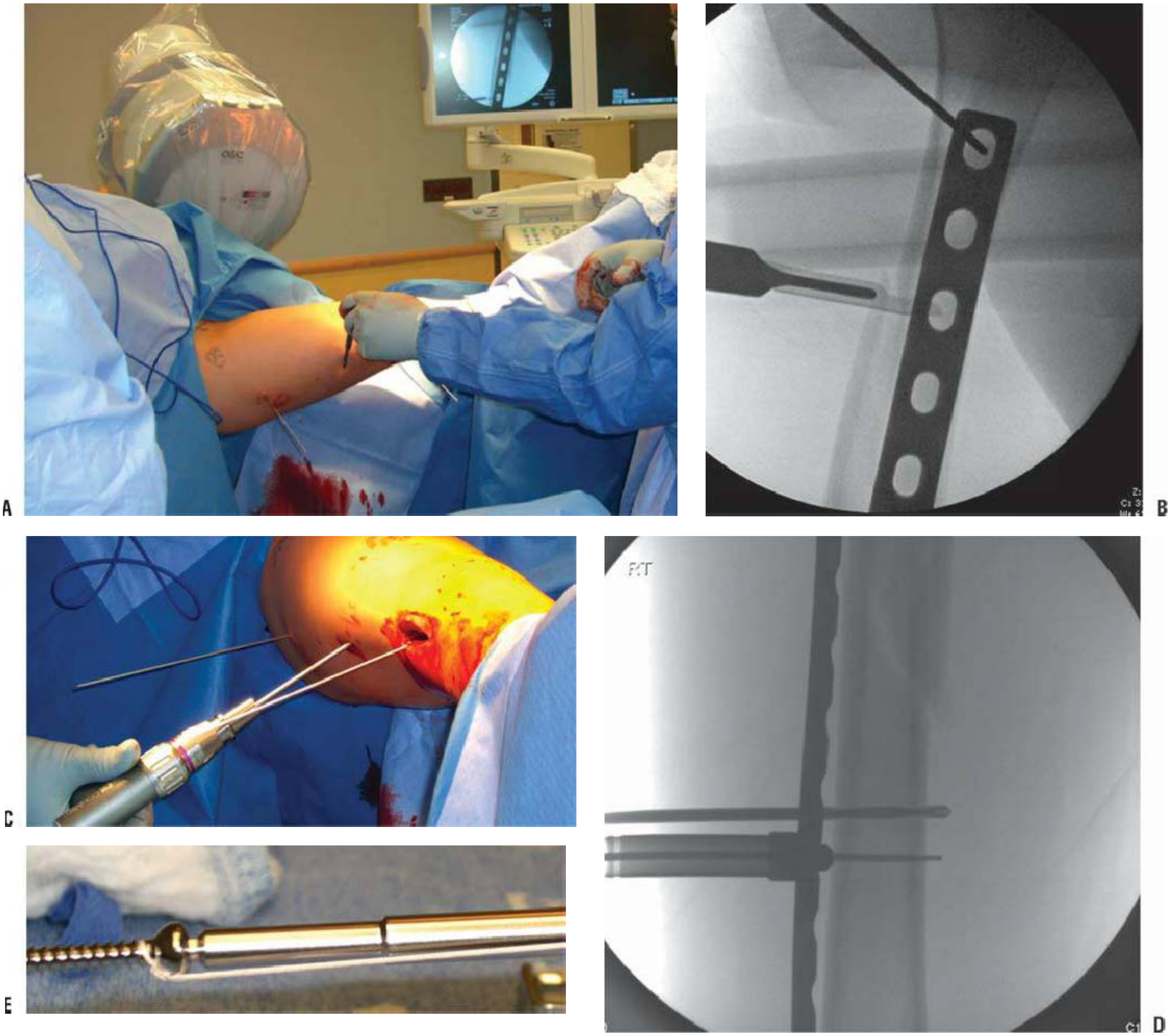


FIGURE 34-14. **A–B:** The plate is then slowly tunneled proximally along the lateral femur in the subvastus plane. A Kocker clamp may be used to grasp the distal aspect of the plate for guidance. Care is taken to keep the plate on the lateral femur as it is advanced proximally past the fracture to the region of the greater trochanteric apophysis. The plate may be more difficult to pass along the lateral femur as it passes the fracture. The surgeon may facilitate plate advancement by pulling the plate back and redirecting it using C-arm guidance **(C–E)**.

FIGURE 34-15. Once the plate is fully advanced it is provisionally secured with a Kirschner wire in the most proximal and distal screw holes. The position of the plate on the femur can be adjusted with the placement of the Kirschner wires. Once the plate is secured, an anteroposterior and lateral fluoroscopic image is performed to confirm the position of the plate on the femur.





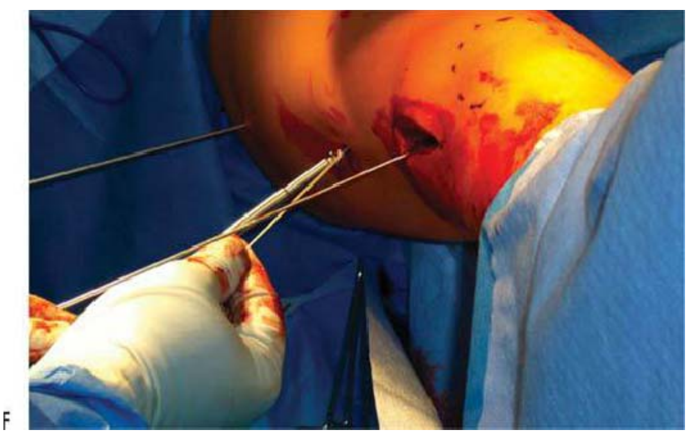
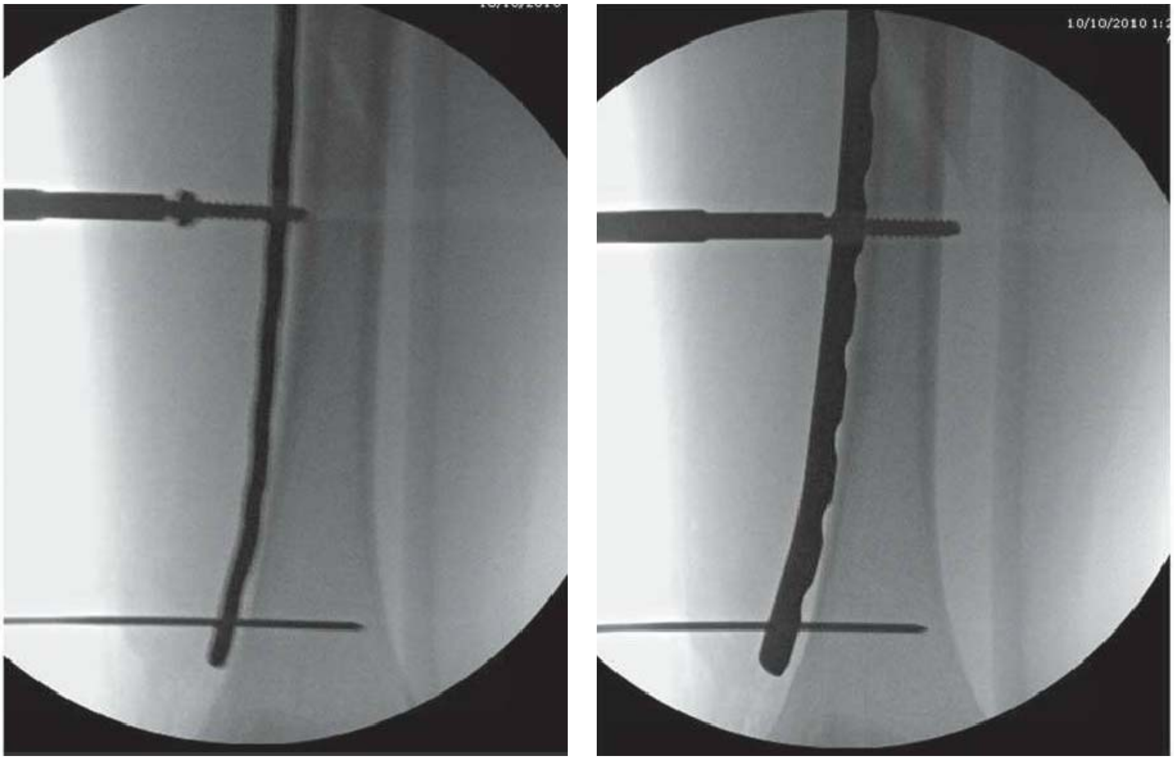
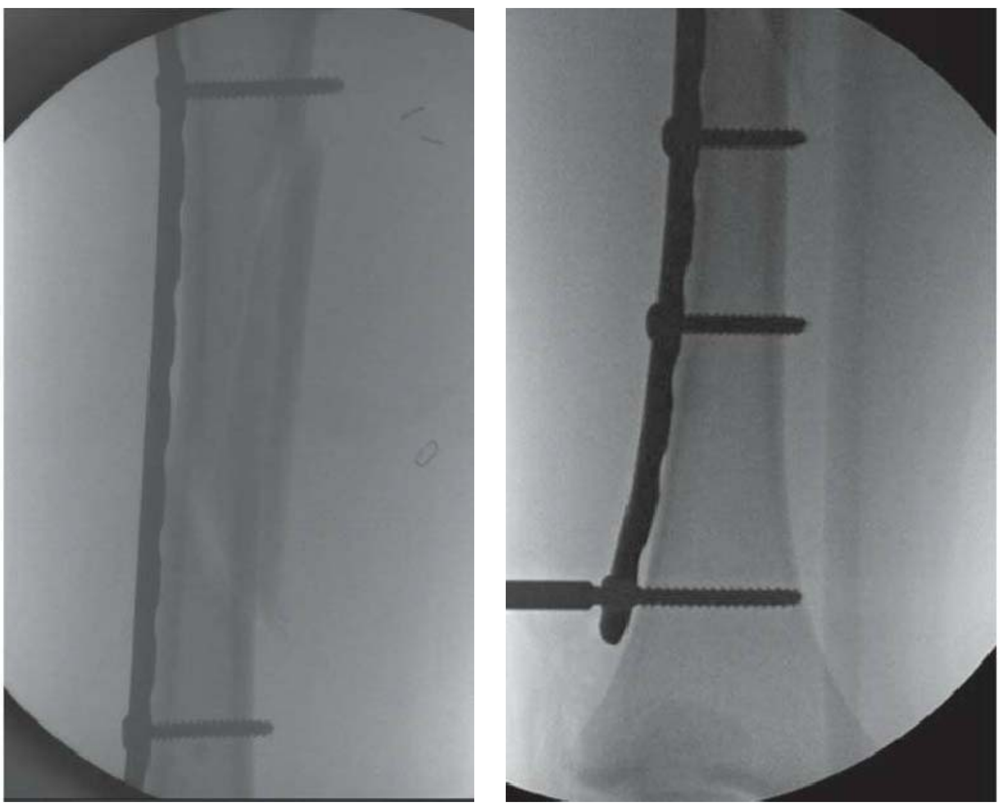


FIGURE 34-16. The screws are place with "freehand perfect circles technique." The first screw placed should be near the proximal or the distal extent of the fracture where the femur is furthest from the plate. This screw will reduce the femur to the precontoured plate and act as a "reduction screw." Screws are placed using "perfect circles" technique. Using the fluoroscopic image in the lateral plane, a no. 15 blade scalpel is placed on the skin over the desired hole then rotated horizontal to the beam through the skin, tensor fascia, and vastus fascia **(A, B)**. A 3.2-mm drill is placed in this small incision, and its location in the desired hole is confirmed with fluoroscopy. The hole is then drilled through both cortices **(C)**. The length of the screw is approximated by placing the depth gage on the anterior thigh as the c-arm is used in the anterior-posterior position **(D)**. It is important to tie a 0-vicryl suture around the 4.5-mm fully threaded cortical screw head, so it will not be lost in the soft tissue if the screw inadvertently disengages from the screwdriver **(E)**. The screw is then placed through the plate and across the femur. As the screw engages the far cortex, the femur will be reduced to the precontoured plate **(F–H)**.



G H

FIGURE 34-16. *(continued)*



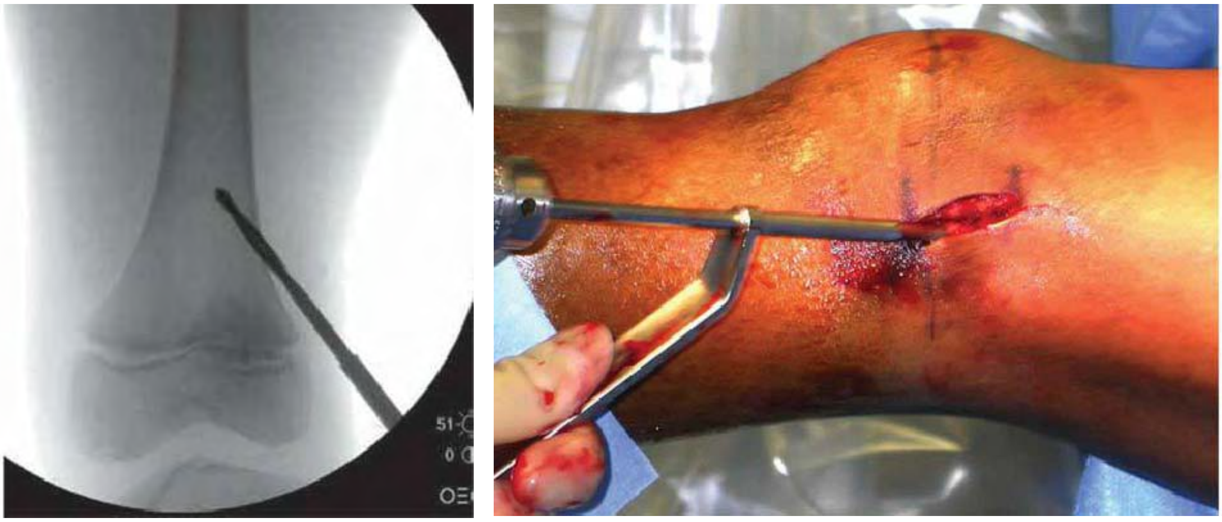
A B

FIGURE 34-17. The second screw is placed on the other margin of the fracture as the fracture is bridged. **A:** The remaining screws are spread as far apart as possible. **B:** Once all the screws are placed, the sutures are cut. A soft dressing is applied. Patients are allowed to be touchdown weight bearing until about 6 weeks when early callus is visualized on radiographs. At that time, weight bearing can be progressed as tolerated.

Flexible Intramedullary Nailing of Femoral Shaft Fractures (Figs. 34-18 to 34-24)

FIGURE 34-18. Flexible Intramedullary Nailing of Femoral Shaft Fractures. The patient may be placed on either a fracture table or a radiolucent table. What is important is that the surgeon be able to reduce the fracture while driving the rods across the fracture fragment. The legs, especially the contralateral leg, are abducted or extended to allow the surgeon to stand on the medial as well as the lateral side of the leg. This facilitates insertion of the nail(s) from the medial side. Particular attention to rotation should be given at the time of reduction and insertion of the nails into the proximal fragment. This is most easily judged by the skin lines. The limb is prepared and draped to give access to the entire femur and knee joint and to permit manual manipulation of the thigh.

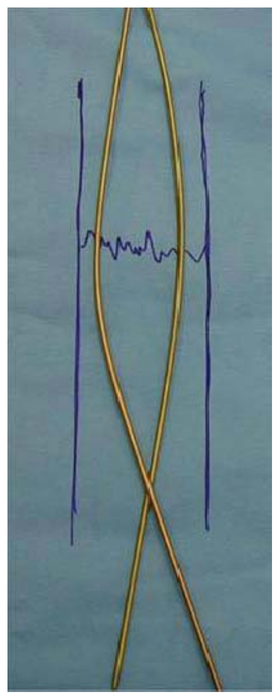
FIGURE 34-19. The insertion point for the nails is medial and lateral at the top of the flare of the medial and the lateral condyles so that after insertion they will tend to bind against the flare of the condyle. If the nails are started too low, they will tend to back out, a troublesome complication. The insertion should be posterior to the midlateral line so that, if the nails back out, they will be less likely to enter the synovial pouch. An incision is made on the lateral side of the leg extending about two finger breadths above the superior pole of the patella. (The superior pole of the patella lies slightly above the level of the physis.) **A:** The fascia lata is incised, and the vastus lateralis muscle is retracted dorsally. A drill hole is made with a 4.5–6.4 mm drill bit at the level of the upper metaphyseal flare **(B)**. The drill hole is made oblique or a rongeur, is used to elongate the hole and avoid cracking of the cortex when the rod is inserted **(C, D)**



C D

FIGURE 34-19. *(continued)* **C, D.** The insertion point on the medial side is made in the same manner by elevating the vastus medialis muscle.

FIGURE 34-20. Whether using titanium of elastic nails, the nail diameter chosen should be the largest diameter possible for the specific femoral diameter. The nail diameter should be at least 40% of the canal diameter. Therefore, two nails would fill at least 80% of the canal diameter. The two nails should be the same diameter to prevent deformation once the nails are inserted. Both nails should be precontoured into a gentle "C" shape to maximize the stability of the fracture. Newer nails are of standard length and are cut in situ to the correct length. Ideally, the lateral nail should extend to the level of the greater trochanter and the medial nail into the femoral neck. Assuming a midshaft diaphyseal fracture, if both nails reach above the level of the lesser trochanter, the fixation will be adequate.



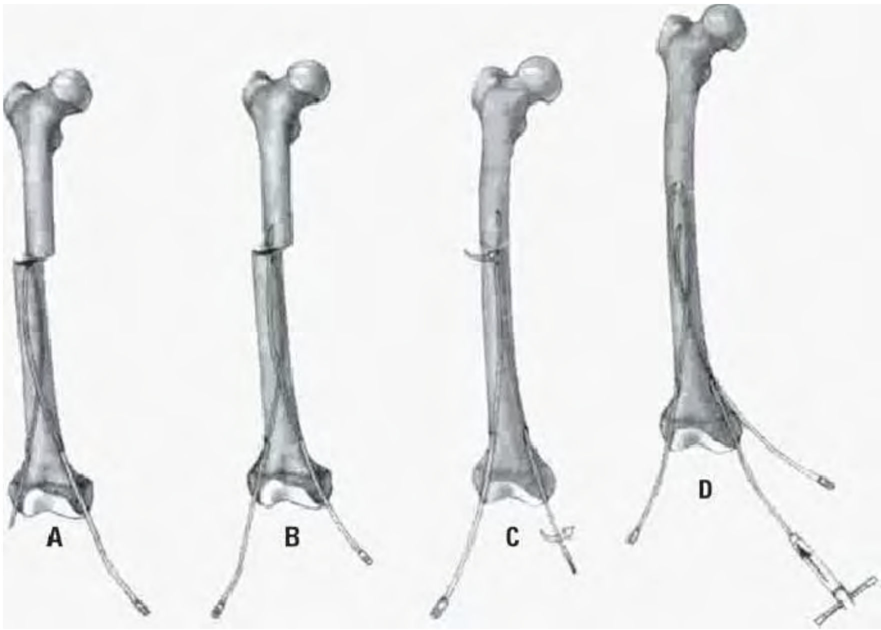


FIGURE 34-21. Drawing highlighting the strategy for mail insertion.

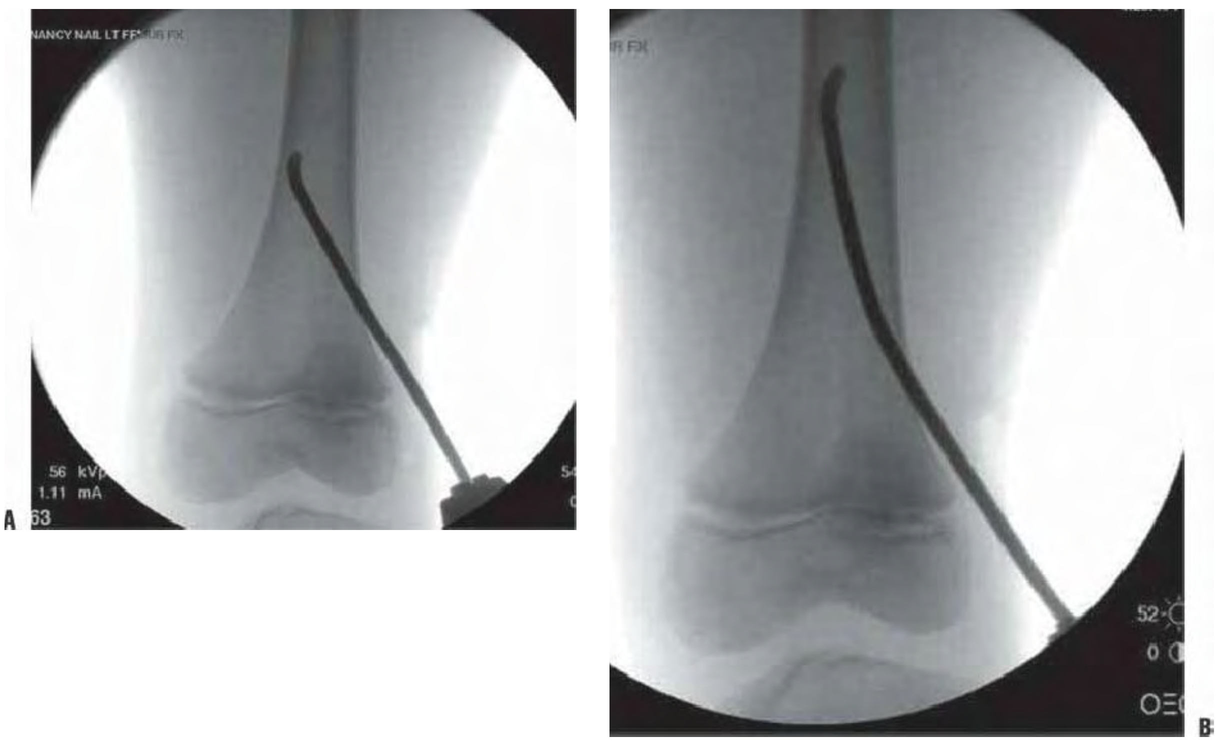
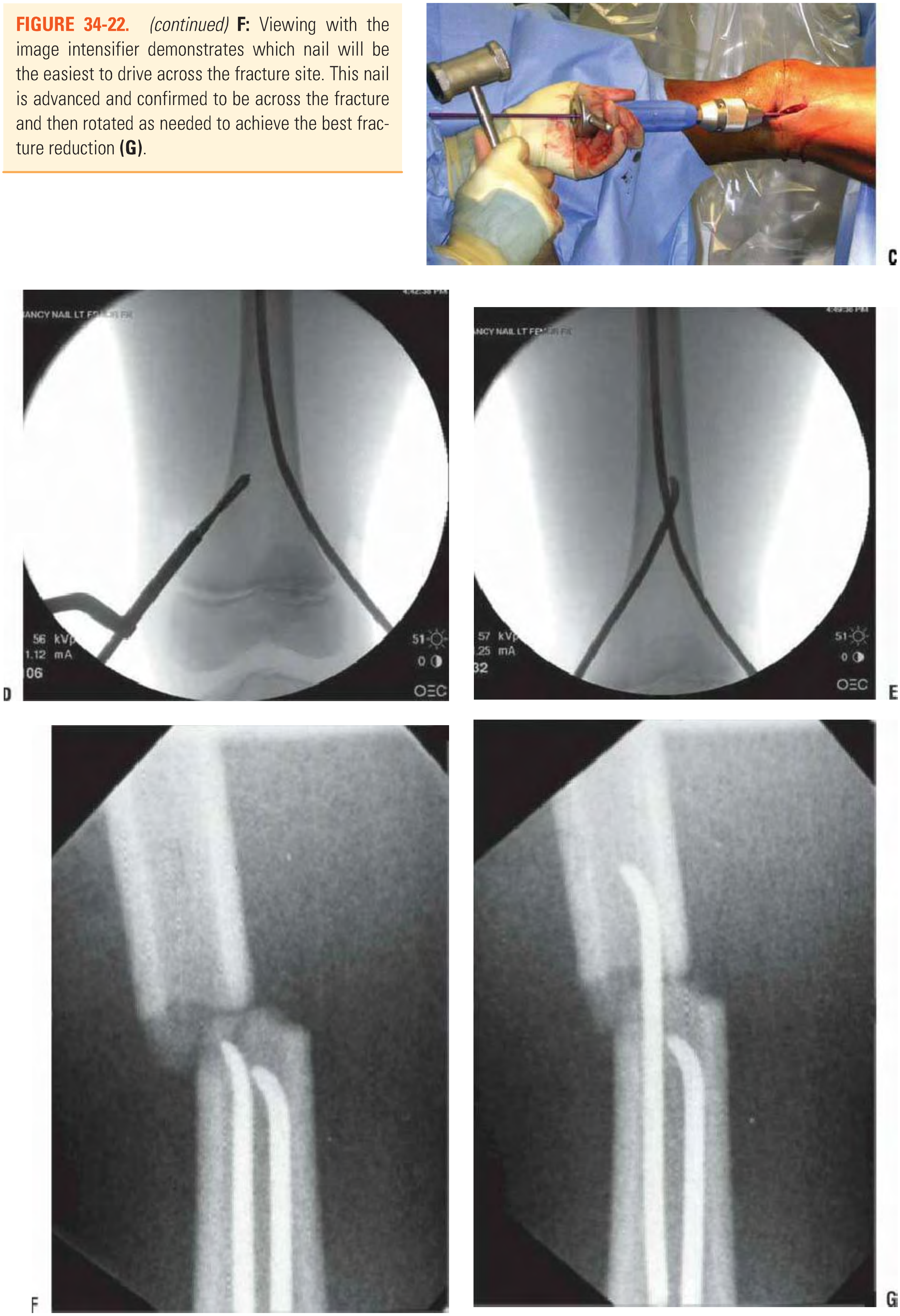


FIGURE 34-22. Nail insertion **(A–K)**. In many cases, the fracture fragments will not be reduced perfectly, making it more difficult to pass the nails into the proximal fragment. Also if one nail is inserted completely past the fracture, the ability to manipulate the fracture into a more anatomic alignment with the nail tips will be difficult. Therefore, it is recommended to insert and advance both medial and lateral nails sequentially to the level of the fracture prior to crossing the fracture **(F)**.

FIGURE 34-22. *(continued)* **F:** Viewing with the image intensifier demonstrates which nail will be the easiest to drive across the fracture site. This nail is advanced and confirmed to be across the fracture and then rotated as needed to achieve the best fracture reduction **(G)**.



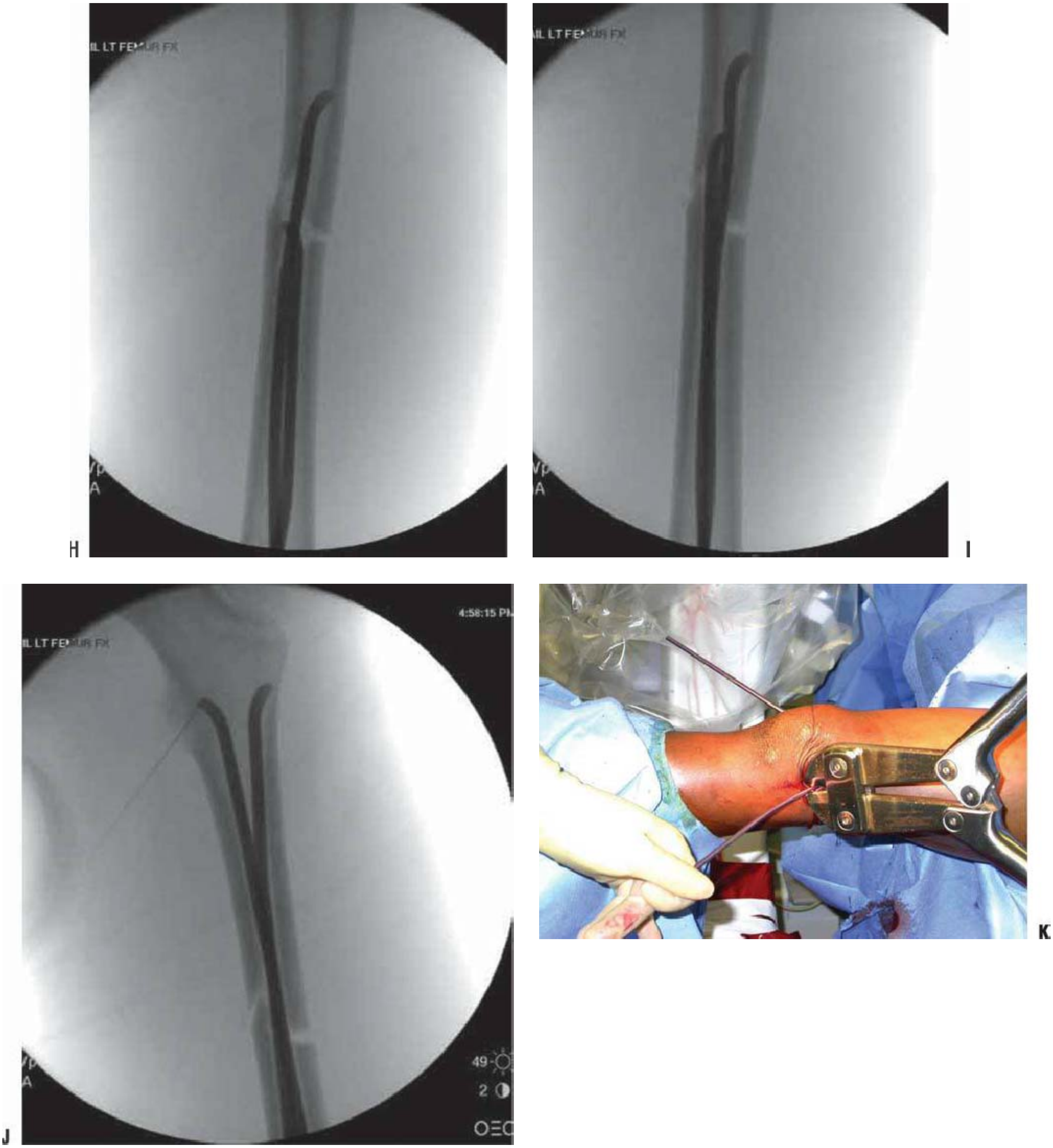
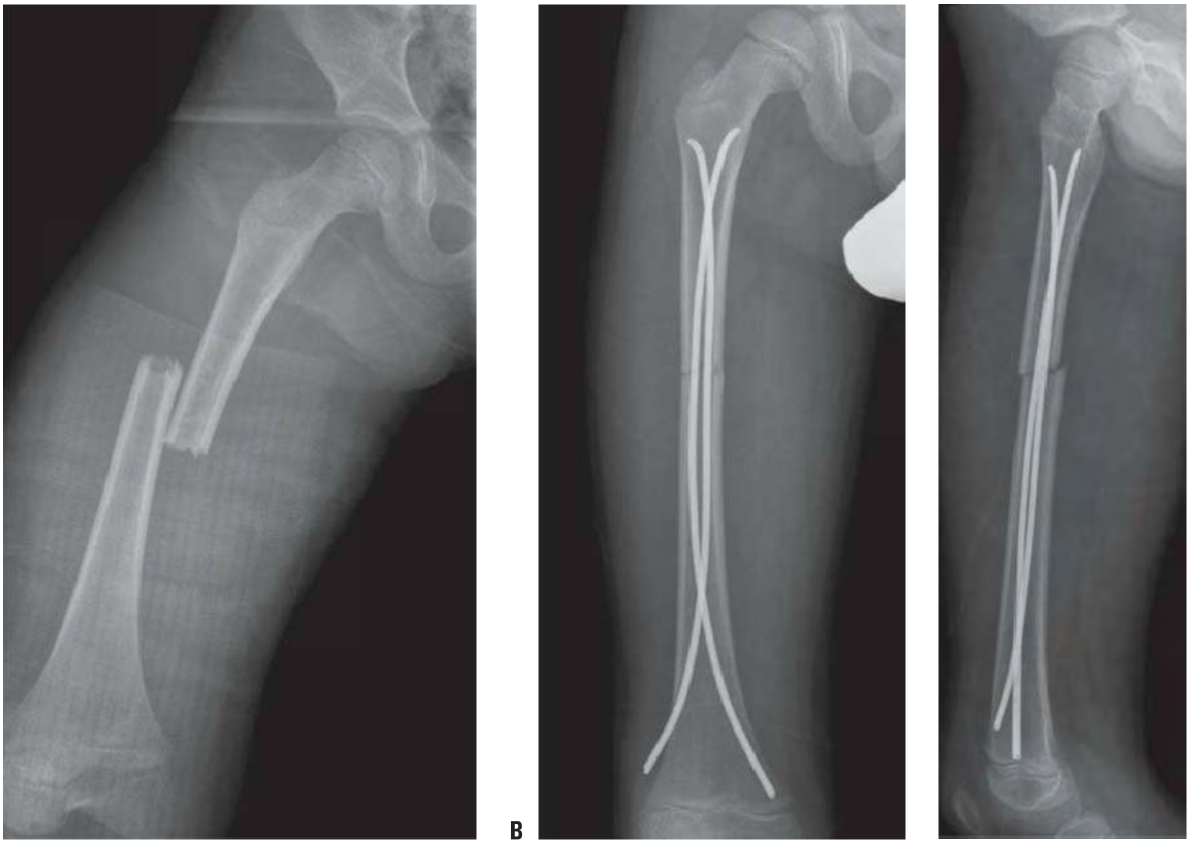


FIGURE 34-22. *(continued)* Motion of the proximal fragment demonstrates that the nail is in the proximal fragment. At this point, the second nail is advanced past the fracture and rotated as needed to further reduce the fracture **(H)**. It is important not to advance the first rod far past the fracture site until the second rod has passed the fracture site **(I)**. If the first rod is advanced too far, it will shift the fragments and make passing of the second rod difficult or impossible. The traction is released, and both nails are advanced to their full length **(J)**. The entire femur is seen with the image intensifier to ensure that the fracture is reduced and not distracted and that the nails are properly positioned. In rare instances to achieve further stability, it is possible to insert a third nail. Inserting a third nail is most easily accomplished if it is inserted before either of the other two nails are fully advanced. This has the advantage of providing more rotational and slip stability by filling the canal and enhancing cortical contact. Prior to the final advancement of the nails, they are rotated so the "c" contour is opposite each other and the nails are cut outside the skin. After the nails are cut **(K)**, the final advancement is then performed with the tamp present in the nail set **(L)**.

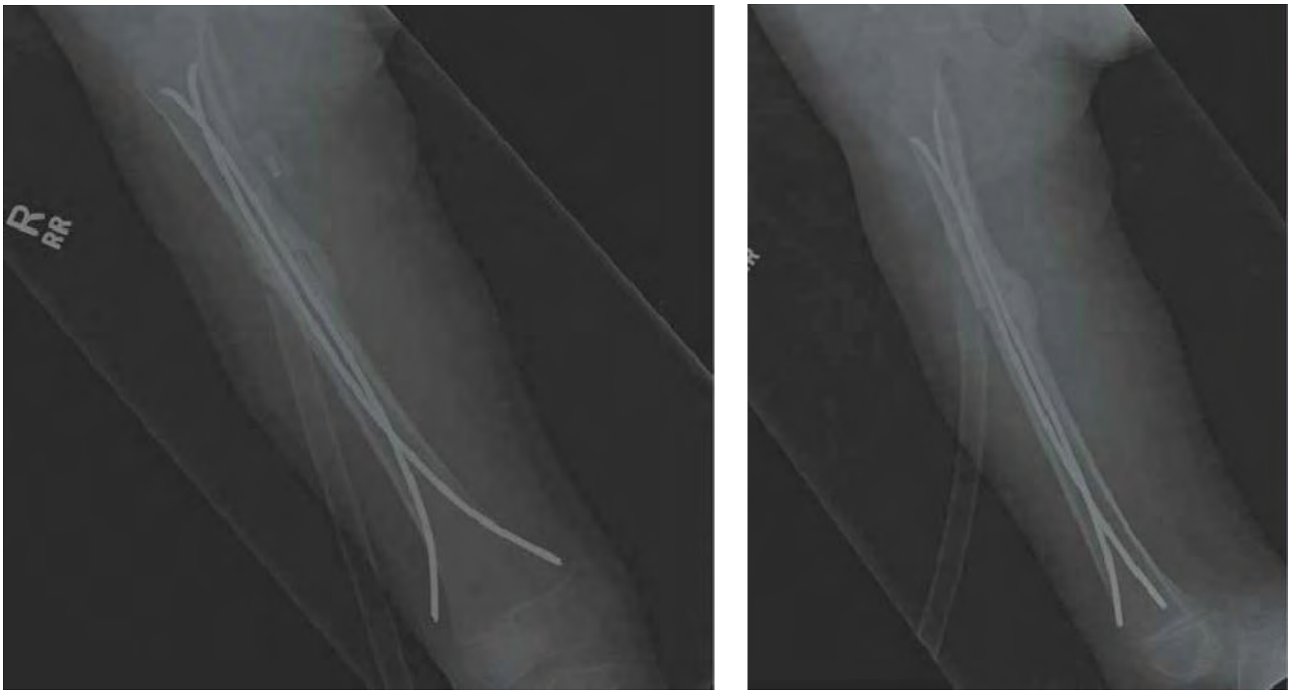
L

FIGURE 34-22. *(continued)* The nails should rest against the flare of the metaphysis but rest just above the level of the physis, so they are not prominent. The nails should not be bent away for the bone and should be only 1 to 2 cm outside the bone proximal to the level of the physis to prevent nail prominence. Nail removal is still possible with a small length of nail left outside the canal. After insertion of the nails, the wounds are closed and a soft dressing is applied. A knee immobilizer may be used for postoperative comfort. In rare instances, a supplemental spica can be applied, but if needed for stability, other fixation options should be considered. Weight bearing is advanced as tolerated once callus is observed around 4 to 6 weeks postoperative.



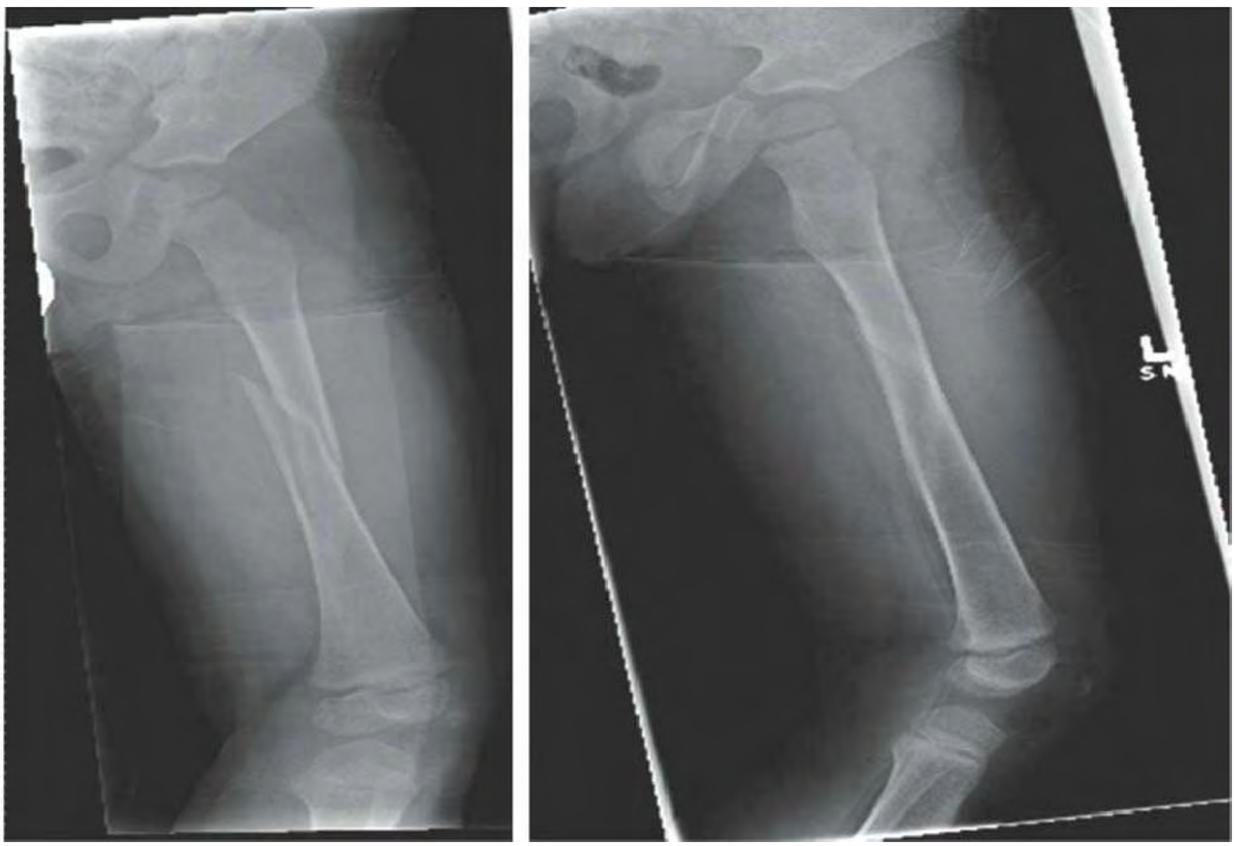
A B C

FIGURE 34-23. **A–E:** Anteroposterior radiographs of the left femur of a 10-year-old boy who sustained a femur fracture in an automobile accident. He had flexible intramedullary nailing with retrograde rods with good canal fill. The apex of the rod contour is opposite each other at the fracture site allowing the optimal mechanical stability. Six weeks after injury, healing of the fracture is demonstrated with a large surrounding callus typical of the dynamic nature of this fracture fixation.



D E

FIGURE 34-23. *(continued)*



A

FIGURE 34-24. **A:** A 3-year-old with a spiral midshaft diaphyseal femur fracture.

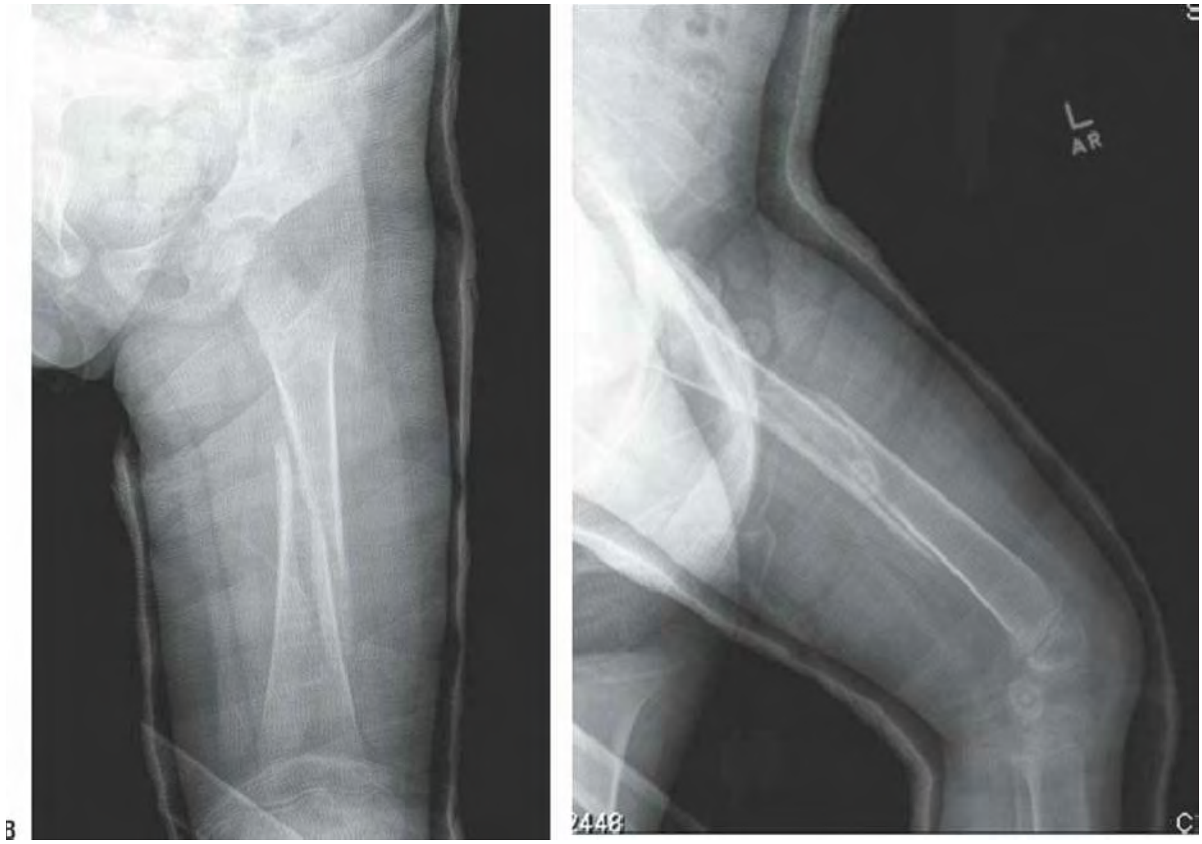


FIGURE 34-24. *(continued)* **B:** Early spica treatment is chosen for this fracture. This highlights the common fracture overriding and slight angulation that will remodel and respond to overgrowth.

With proper technique of closed reduction and early spica cast immobilization, however, most younger children are treated successfully (125–127). Nevertheless, there are certain circumstances even in these young children—including children with multiple system injury, multiple fractures, ipsilateral tibial fracture, head injury with coma, and some pathologic fractures—in which this form of treatment does not produce consistently good results or makes the treatment of concomitant conditions difficult. These circumstances constitute the solid indications for some form of fixation. A new indication is mentioned increasingly in the literature: social indication (121, 128). This is explained as "conservative treatment alternatives unacceptable to the patient's parents" (129).

Having decided on an alternative to closed reduction and cast immobilization, there are many alternatives, such as external fixation, open reduction and plating (130), and intramedullary nailing with flexible or rigid rods. The ideal indications for intramedullary fixation are a child with open growth plates and a transverse uncomminuted diaphyseal fracture that, for any reason, is unsuitable for early cast treatment. External fixation has the disadvantage, in this particular fracture configuration, of lack of callus formation, slow healing, and incidence of refracture (93, 131). Reports of avascular necrosis in children 12 years of age and below, treated with rigid intramedullary rods, should promote caution in the use of these devices in this age group (120, 132). In older children, rigid rods are preferable to flexible rods.

Several reports in the literature record the experience with the use of flexible intramedullary rods in children's femoral shaft fractures (121, 133–137). Flexible intramedullary rods come in stainless steel or titanium in a variety of sizes.

It is important to understand the mechanics of internal fixation with flexible intramedullary rods. These rods permit a greater degree of bending at the fracture site than conventional intramedullary rods and thereby avoid rigid fixation of the fracture. This may be the advantage they offer, with early callus formation and healing, as compared to the more rigid forms of fixation (138). In addition, they provide little in torsional stiffness and allow considerable slip of the fragments on the rods. What they do provide is axial stability. This form of fixation works best when there is good cortical contact at the fracture site.

Management Techniques Techniques for management are selected according to the principles and the guidelines discussed in the preceding paragraphs. Age and fracture characteristics are key determinants when selecting the appropriate treatment.

Early Fit Spica Cast The typical candidate for early cast immobilization is a child younger than 6 years (Fig. 34-24). Children up to 10 years of age may also be treated by early spica casting for low-energy, closed femur fractures that have <2 cm overriding at rest (139–141). Under anesthesia, gentle longitudinal compression may be applied to verify that the fracture does not shorten more than 3 cm (telescope test) (139). If the fracture shortens more than 3 cm, then surgical stabilization, use of traction, or pins and plaster may be more appropriate than early spica casting. After fracture alignment is obtained, the popliteal area and all bony prominences should be well padded prior to cast application. The authors recommend hip and knee flexion with gentle fracture reduction while the hip and knee are held in slight abduction with less than 90 degrees of flexion at the hip and knee (142, 143). Care must be taken to avoid excessive traction in order to avoid peroneal nerve palsy and posterior compartment syndrome of the leg (141, 144). Applying a short leg cast and pulling traction to place the patient in 90/90 position should be avoided due to the risk of compartment syndrome (109). (Applying the long leg portion of the cast as an initial step may facilitate cast application and maintenance of alignment.) A single-leg walking spica cast is a good alternative in simple fractures that may allay some of the social concerns since the patient may have easier mobilization (145). After casting, patients are usually discharged within 24 hours. Follow-up visits to monitor alignment are recommended at 1 and 2 weeks after reduction.

Skeletal Traction Skeletal traction is a safe, reliable, and easily instituted form of management for almost any femur fracture in any age group. However, skin traction is sufficient for children of average weight who are younger than 8 years (116). Traction and casting are rarely the treatment of choice today, however, because excellent results can be obtained from early spica casts in children younger than 6 years, or internal and external fixation in the older child.

There are several ways in which traction can be constructed (146, 147). The simplest is the 90–90 position. Skeletal traction entails insertion of a pin into the metaphysis of the distal femur, using a medial-to-lateral direction to avoid potential injury to the femoral artery. Local anesthesia and intravenous sedation provide sufficient analgesia for pin insertion. Proximal tibial pins are avoided due to the risk of growth arrest. However, proximal tibial growth arrest is more likely to result from the mechanism of injury than from pin insertion (148). Optimal femoral pin placement is approximately 2 cm proximal to the distal femoral growth plate and is aligned parallel to the knee joint to reduce the risk of malalignment (149). A traction bow is attached to the pin, and traction is applied. Periodic radiographs are obtained to guide the weight and the direction of traction vectors needed to restore alignment. After relative fracture stability has been obtained (17 to 21 days) and callus formation is confirmed on radiographs, a cast is applied for an additional 4 to 8 weeks.

External Fixation The prime indications for external fixation are length-unstable fracture patterns (i.e., significant comminution), some very proximal or distal fractures, or soft-tissue damage as in open fractures or burn (133). Other relative indications include polytrauma, in which the child's general medical condition favors rapid and bloodless stabilization, which is possible with this technique. It may be considered as a form of ambulatory traction enabling the child to be partially weight bearing and independent several days after sustaining the injury. Some authors report few complications with this method, whereas others report many complications (93, 150–152).

The technique involves the sequential insertion of pins above and below the fracture site and attaching them to an external frame. Preferred pin location should be far enough away from the fracture site for the pins to avoid the fracture hematoma. However, the pins should also avoid penetrating the cortex of the femoral neck or the distal femoral physis. Under fluoroscopic guidance, final alignment can be adjusted as the pins are secured to the body of the fixator.

The most frequent problems encountered with the use of external fixation are pin-track infections, delayed union, and refracture after device removal. Pin-track inflammation and superficial infection requiring oral antibiotics are common (150, 151). Rarely, deep infection may require intravenous antibiotics or pin removal. In this instance, fixator removal before complete union can be managed by application of a cast. Delayed union and refracture are more frequent with fracture sites that have been opened, or with transverse and short, oblique, midshaft fractures that are anatomically reduced (153, 154). Delayed healing has also been associated with excessively rigid constructs, lack of dynamization, and premature removal of the fixation device (151, 155). Removal of the external fixation should occur only after complete union to prevent refracture. With careful attention to indications, surgical technique, and postoperative management, external fixation may be successfully used to treat pediatric femoral fractures.

Elastic Intramedullary Fixation Flexible or elastic intramedullary nails have the advantage of being applicable to the small, young child without risking damage to the trochanter, the femoral neck, or the vascular supply to the femoral head (112). A transverse or stable fracture pattern in ages 5 to 11 years is the best indication for this method of internal fixation. Flexible rods are commonly inserted retrograde from the distal femoral metaphysis toward the proximal end of the femur. Two nails, precontoured into a C-shape with one inserted medially and one laterally, usually provide sufficient stability when three-point intramedullary contact is obtained (156, 157) (Fig. 34-25). The size of the titanium nail should be approximately 40% of the diameter of the femoral canal at its most narrow point. Other options for insertion include a unilateral approach proximal or distally, inserting one C-shaped nail and one S-shaped nail. When the fracture is very distal, nails may be introduced proximally in the region of the greater trochanter. Additional nails may be added for stability. Flexible nail fixation is less reliable in heavier (>50 kg), older children (>11 years), and for comminuted fractures (119, 156, 158–161). The addition of a cast can supplement unstable internal fixation, but this partially defeats the advantages of surgical

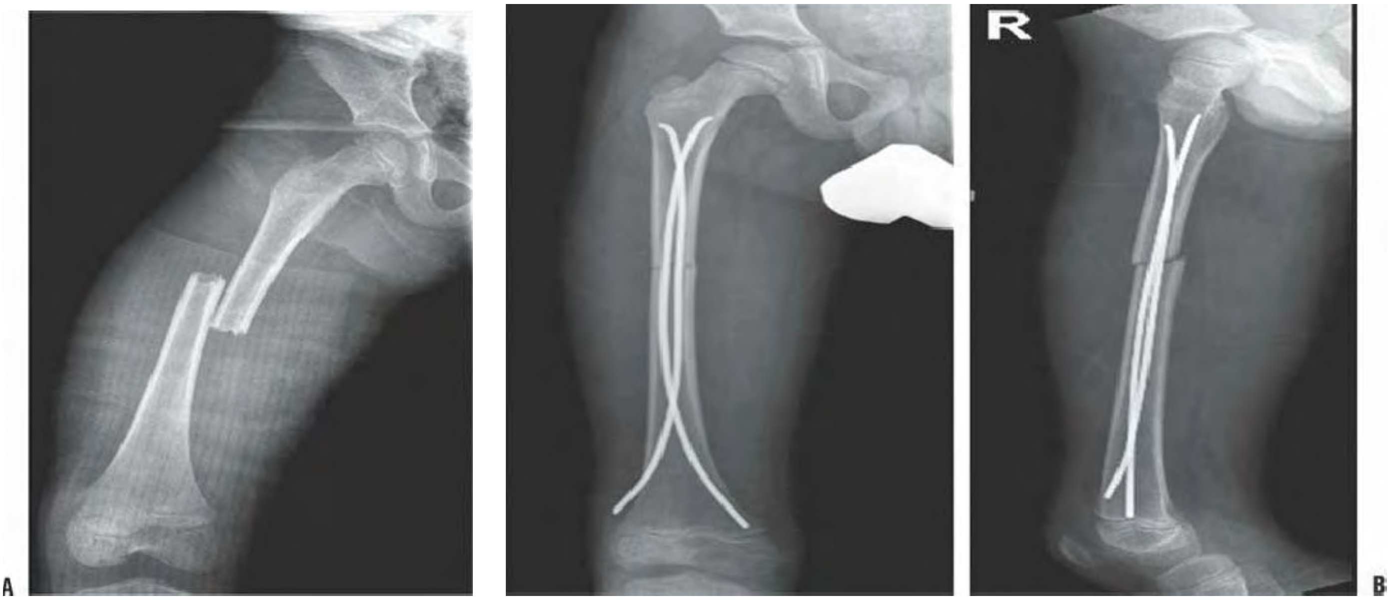


FIGURE 34-25. **A:** A transverse diaphyseal stable femur fracture in a 7-year-old. This is an ideal fracture and age for elastic intramedullary nail fixation **B:** Postoperative radiographs after stabilization with titanium elastic nails.

stabilization. New types of flexible nails that allow proximal and distal locking are currently being developed to help manage unstable fractures (162). Elastic intramedullary nails are either stainless steel or titanium. The titanium models are common and easy to insert, but there may be some benefit of stainless steel in unstable fractures (163, 164).

Submuscular Plating/Plate Fixation Traditional open femoral plating has not been widely used for pediatric femur fractures (130) although several authors have reported successful results with conventional compression plating (130, 165). Disadvantages of conventional compression plating include extensive dissection with additional blood loss, device failure, and the risks associated with plate removal. Open plating techniques may be used in the very proximal or distal fractures. Submuscular bridge plating, and subcutaneous, minimally invasive percutaneous osteosynthesis with locking compression plates are newer techniques that are being utilized for pediatric femur fractures (114, 166, 167) (Fig. 34-26). One of the advantages of submuscular plating is the soft-tissue envelope is left intact to allow rapid synthesis, which avoids the large dissection. Leaving the soft-tissue envelope intact will allow for more rapid osteosynthesis lessening the chance of plate failures reported with conventional plating. The indications for submuscular plating are length unstable comminuted or long oblique fractures, or proximal and distal fractures that may be more challenging with elastic nails.

Trochanteric Intramedullary Fixation Two devices used for intramedullary fixation are rigid nails and flexible, unreamed nails (132, 168, 169). Rigid nails are ideally suited for adults because they can be locked proximally and distally to control shortening

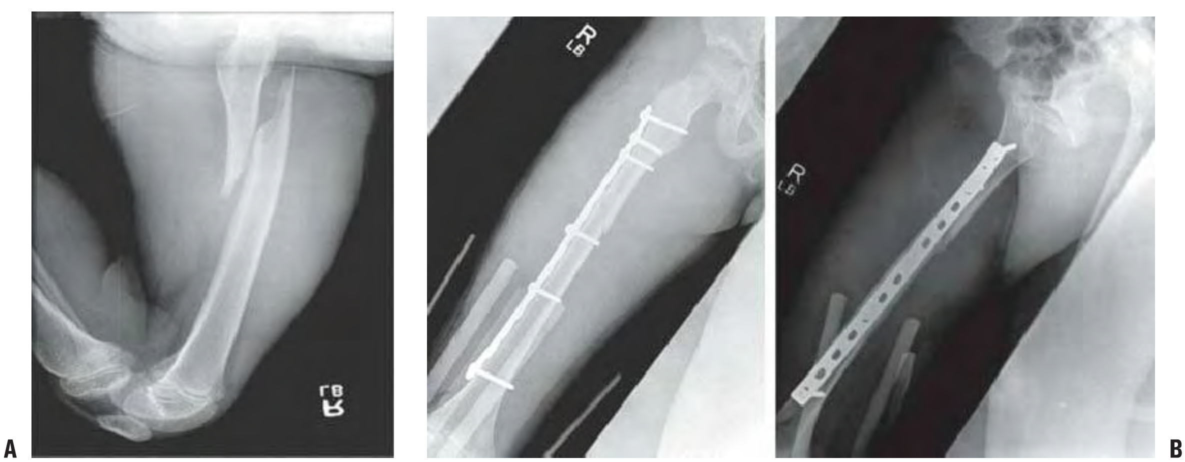


FIGURE 34-26. **A:** A 9-year-old with a proximal one-third long oblique fracture. **B:** Submuscular bridge plating was performed in this more challenging unstable proximal fracture.

and rotation. However, the use of reamed rigid nails introduced through the piriformis fossa has been associated with avascular necrosis of the femoral head in children and adolescents (170). Rigid nails in children younger than 13 years have also been associated with growth disturbance with femoral neck deformity, including coxa valga and thinning of the femoral neck (168, 169). For these reasons, it is recommended that rigid, reamed nails introduced through the pyriformis fossa should be avoided unless the proximal femoral physis is completely closed. There are many new trochanteric entry nails now available for pediatric femur fractures with the benefits of minimal dissection and stable fixation (Fig. 34-27). Trochanteric entry nails are inserted lateral to the tip of the greater trochanter, and there is theoretically less risk of avascular necrosis and proximal femoral deformity (171). The author's indications for lateral trochanteric entry nails are older patients (>11 years) with stable or unstable fractures where the intramedullary canal and proximal femur are large enough to accept the nail.

Femoral Fractures in Special Circumstances

Management of pediatric femoral fractures may be altered in complex circumstances as seen in children with head injuries, multiple trauma, open fractures, floating knee, or high subtrochanteric fractures. Children with head injuries or multiple trauma benefit from more aggressive fracture stabilization so that they can be transported and mobilized (33). The general management of open fractures is discussed earlier in this chapter. External fixation is recommended for open fractures with severe soft-tissue injury, but grade I and many grade II open femur fractures can be managed in standard fashion after appropriate wound care.

Floating Knee Simultaneous ipsilateral fracture of the femur and tibia has been termed the *floating knee* (172–174). This injury pattern has been classified by Letts et al. (174). The fracture usually is the result of high-energy trauma. Knee ligament damage occurs in approximately 10% of these patients and is better assessed after fracture stabilization. A juxta-articular fracture pattern and fractures in children older than 10 years have worse prognoses for early and late problems (173). Surgical stabilization of at least one bone is recommended in most cases (172–174).

Subtrochanteric Fractures Subtrochanteric fractures usually result from high-energy trauma. It may be difficult to maintain alignment by closed treatment because the proximal fragment flexes, abducts, and externally rotates. Union in the anatomic position is rarely achieved with closed treatment, but remodeling potential is great in this anatomic region. Fractures that are closer to the greater trochanter and fractures in children older than 8 years more often result in malunion (175, 176). Early spica cast application in the "sitting" position may suffice in very young children, but traction in the 90–90 position is frequently necessary until callus formation is visible on radiographs. Alternatively, the authors recommend that children older than 5 years, or younger children with unstable fractures, should be considered for surgical stabilization.

Complications of Femur Fractures Malunion, with or without limb-length discrepancy, is the most frequent complication of pediatric femur fractures. Compartment syndrome, neurovascular injuries, nonunion, and infections may also occur. These latter complications are more frequent after open injuries and are discussed elsewhere. Management principles are similar to those in adults. Malunion and limb-length discrepancy may resolve with remodeling so long as the deformities are within management guidelines discussed previously. Osteotomy is performed to correct persistent deformity in older children, or when remodeling is incomplete in younger children after a period of observation. Persistent limb-length discrepancy is rarely severe and is usually managed by epiphysiodesis of the contralateral extremity at an appropriate age. Overgrowth of the ipsilateral extremity is common with anatomic reduction but in most cases is not clinically relevant.

FRACTURES AND DISLOCATIONS AROUND THE KNEE

The same trauma that would cause a ligamentous injury in an adult will usually cause a fracture in a child. The attachments of the joint capsule and the surrounding ligaments expose the pediatric knee to certain characteristic avulsions and physeal injuries. The child presenting with an acute hemarthrosis of the knee may have a soft-tissue injury, a fracture, or both. MRI has been used to provide additional information, but this modality may be less accurate in children than in adults (177, 178). Radiographically silent osteochondral fractures have been noted in 7% to 67% of juvenile patients undergoing arthroscopy for acute hemarthrosis (179, 180). However, arthroscopy is rarely necessary for the initial management of acute hemarthrosis in children younger than 13 years. Arthroscopy may be useful in older children when it could lead to definitive management (181, 182). Acute patellar dislocations and soft-tissue injuries of the knee are covered in the sports medicine Chapter 31.

Distal Femoral Physeal Separations The distal femoral growth plate has a complex geometric configuration designed to resist very high shear and translational forces. A distal femoral physeal fracture, therefore, indicates that the young knee was exposed to very high forces. These fractures constitute approximately 5% of all long-bone physeal fractures and 1% to 2% of all fractures in skeletally immature patients (183, 184). Except in cases of nondisplaced fractures, the diagnosis is straightforward. Nondisplaced fractures may mimic ligamentous injuries on clinical examination. However, careful inspection will reveal that the area of tenderness and swelling is proximal to the joint line, and generally on both the medial and lateral sides at the distal femoral physeal site. Although rarely needed, stress radiographs with the patient sedated can be used to demonstrate the fracture. Hyperextension of the knee produces anterior epiphyseal displacement, and valgus or varus stress produces medial or lateral displacement, respectively. Direct impact in the knee-flexed position causes posterior displacement of the femoral epiphysis.

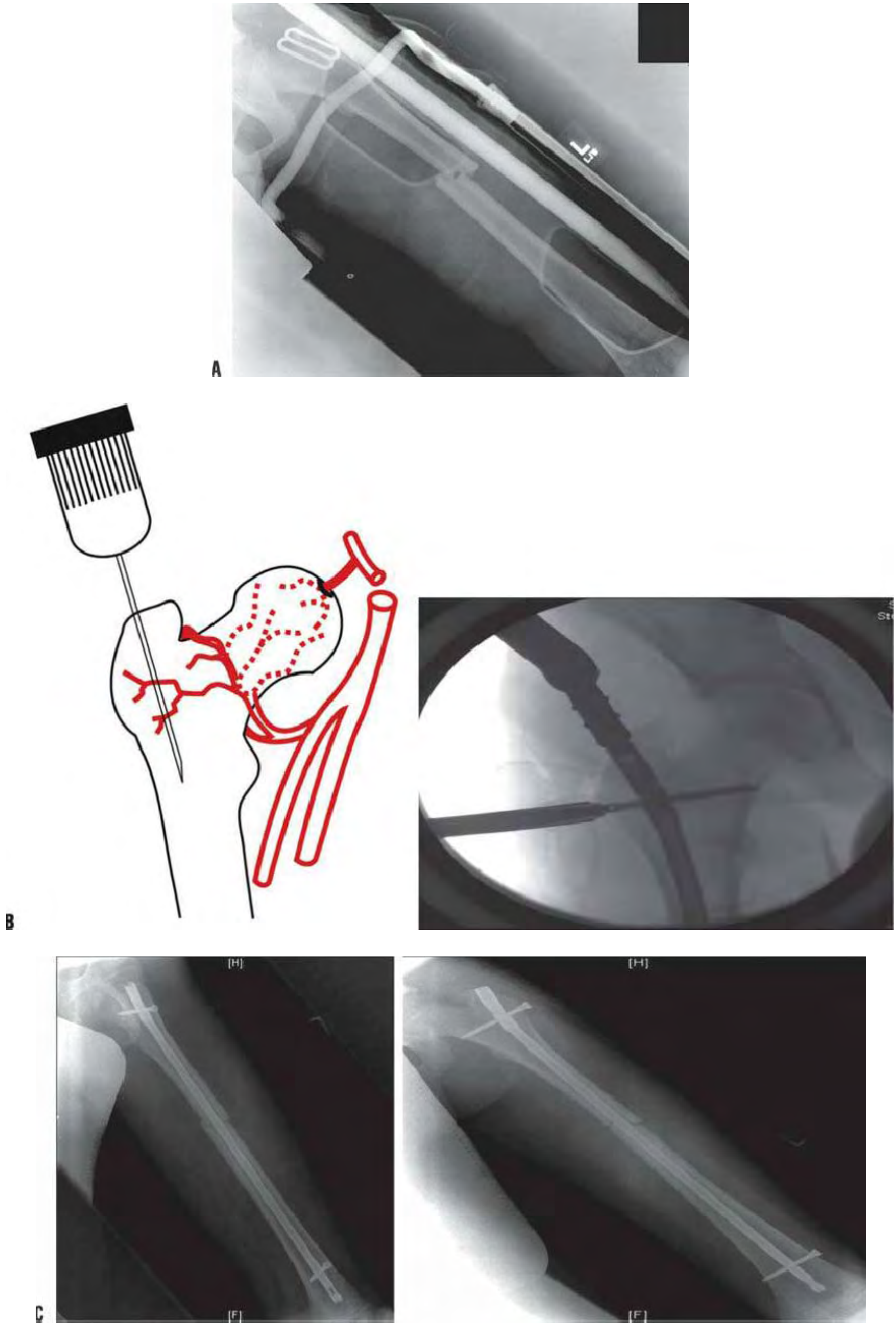


FIGURE 34-27. **A:** A 13-year-old with a transverse diaphyseal femur fracture. Since the patient is older than 11 years trochanteric entry nails were chosen. **B:** It is important to insert the nail on the lateral trochanter, lateral to the tip of the trochanter to avoid the circumflex artery near the piriformis fossa. (Credit pic to J.D. Bomar.) **C:** Postoperative radiographs after lateral trochanteric entry intramedullary nail.

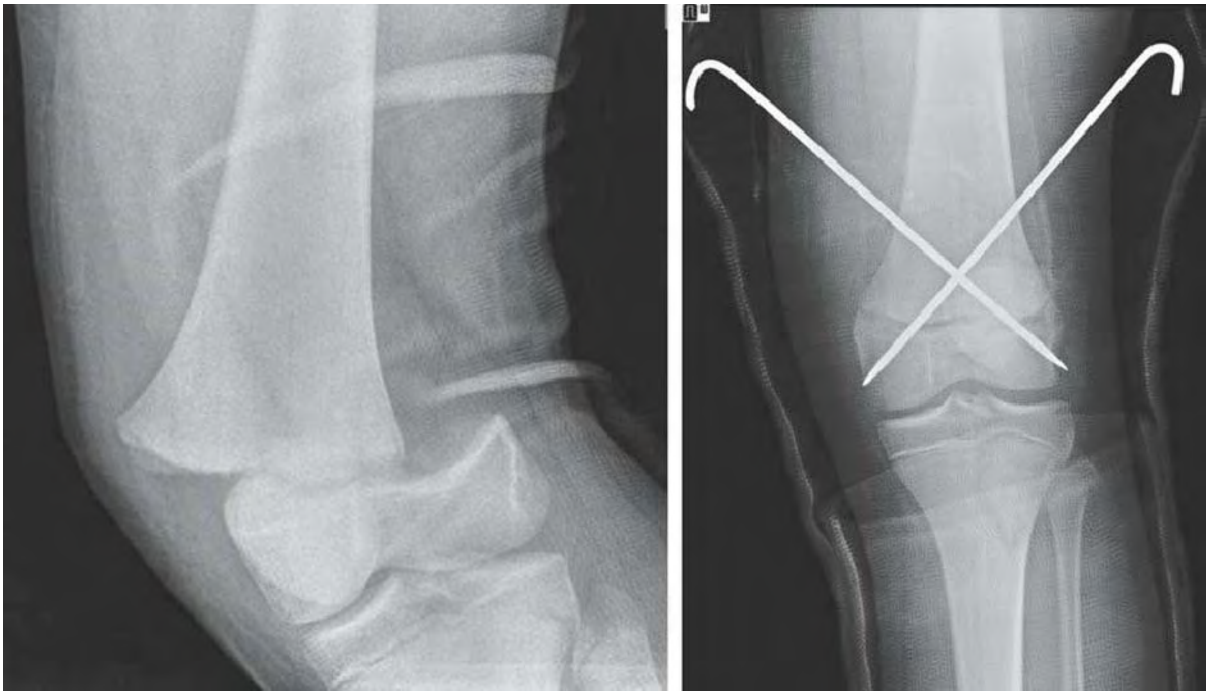


FIGURE 34-28. Antegrade internal fixation of a displaced distal femoral physeal fracture. After fixation, the fracture is protected with cast immobilization for 3 weeks.

The Salter-Harris type III fracture of the medial femoral condyle usually results from valgus force on the knee. The medial collateral ligament and joint capsule transmit this force to the condyle, producing the fracture. Spontaneous reduction is common, making diagnosis on plain radiographs difficult in many cases. The Salter-Harris type III injury to the medial condyle may appear innocuous but is often associated with cruciate ligament damage and intra-articular osteochondral fragments (185).

Most distal femoral physeal injuries are Salter-Harris type I and II fractures. These injuries carry a very high rate of subsequent growth arrest, documented by some studies to be up to 50% (186–188). Growth arrest is closely related to the severity of displacement (187–189). Metaphyseal comminution in SH II fractures may be prognostic of a higher rate of growth arrest (190). It is imperative that the treating surgeon counsel the family about this risk at the outset of care.

Fractures in the 2- to 11-year age group are frequently caused by severe trauma and have the greatest likelihood of physeal arrest (187). Fractures in the adolescent age group are often the result of less severe trauma but still have a 50% risk of growth disturbance. In contrast to these fractures in the juvenile and adolescent age groups, distal femoral separations in infants and toddlers have excellent remodeling potential and rarely lead to growth disturbance.

Treatment Stable, nondisplaced fractures can be immobilized in a long-leg or cylinder cast for 3 to 4 weeks, until the fracture site is nontender. Close follow-up is warranted to detect any tendency toward displacement. Displaced distal femoral physeal separations should be treated with closed reduction under general anesthesia (188). After reduction, fixation is recommended using crossed percutaneous pins to prevent redisplacement while the leg is in a cast. The preferred technique is antegrade pin placement to avoid intra-articular pins, which may become infected (Fig. 34-28).

If the metaphyseal portion of the Salter-Harris type II metaphyseal fragment is large enough, fixation can be accomplished with percutaneous insertion of one or two cancellous bone screws through this fragment (Fig. 34-29).

Indications for open reduction include entrapped periosteum or muscle blocking reduction, Salter-Harris type III and IV injuries, open injuries, and fractures associated with neurovascular disruption. Salter-Harris type III and IV injuries require precise alignment to restore the articular surface and reduce the risk of growth arrest. Because blocks to reduction are usually on the tension side, the fracture is approached from that side. At least two cannulated screws, typically 7.3 mm in diameter, are recommended to ensure stability. Cast immobilization is also used for 3 to 4 weeks, especially if there is only sufficient bone for a single screw.

Knee range of motion returns to normal rapidly in extracurricular fractures. Crosspins are typically removed 3 weeks after injury, and interfragmentary screws are removed about 4 months after injury (facilitating MRI evaluation of the physis). Plain radiographs are obtained three or four times in the first year, with close scrutiny for signs of early physeal arrest. Many centers now use MRI evaluation of the physis, with special sequences, at about 4 to 6 months after injury to determine early growth arrest (Fig. 34-30).

Tibial Spine Fracture The terms “tibial eminence fracture” and “tibial spine fracture” have been used interchangeably

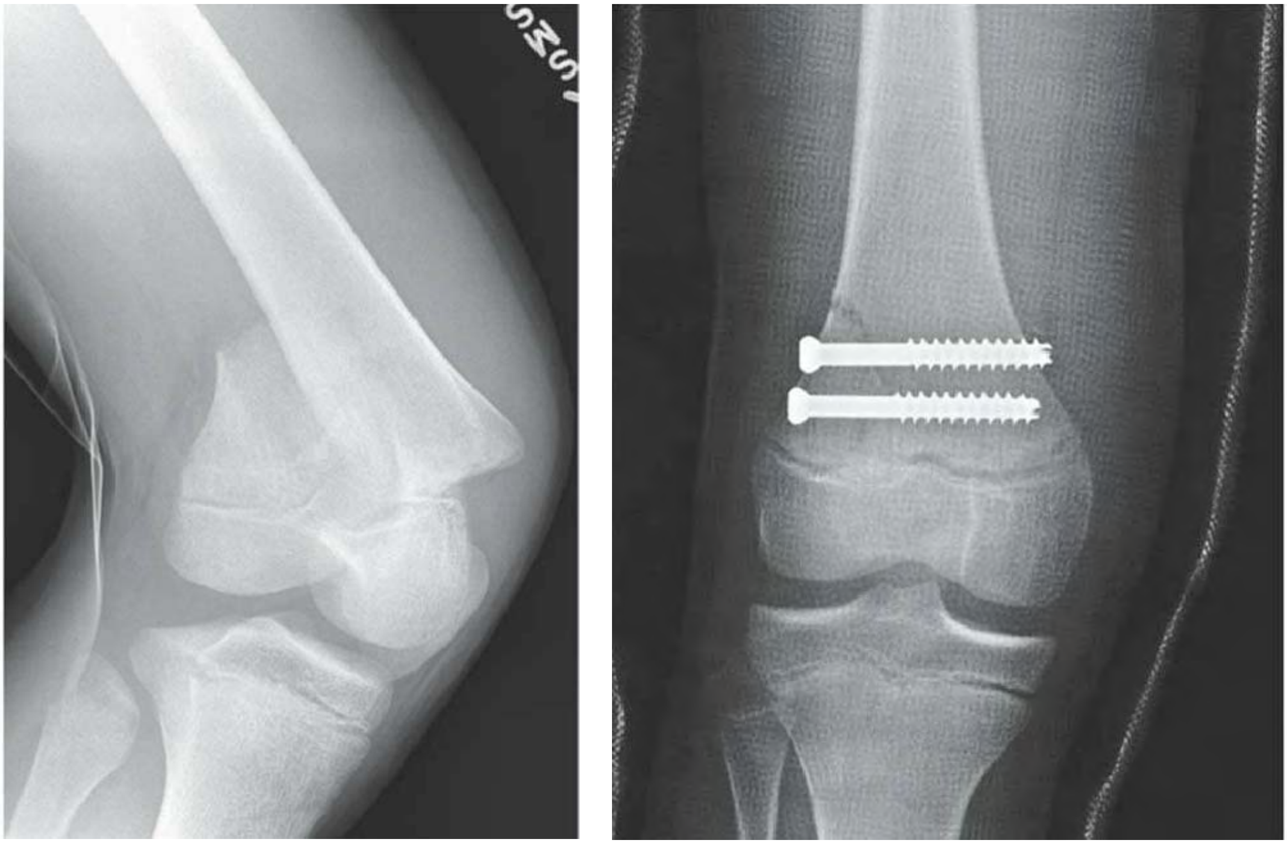


FIGURE 34-29. Internal fixation of a displaced Salter-Harris II distal femoral physeal fracture with interfragmentary screws **(A)**. **B:** Anteroposterior radiograph immediately following fixation and casting shows anatomic restoration of the physeal contour. A small incision was necessary medially to free entrapped soft tissue. **C:** Lateral radiograph shows sagittal restoration of the distal femoral anatomy.

to describe avulsion of the tibial attachment of the anterior cruciate ligament. The tibial eminence consists of two bony spines and is located between the medial and lateral plateaus of the tibia. The anterior cruciate ligament attaches to the medial spine. Between these spines are the attachments of the menisci. Avulsion of the tibial eminence in children is usually caused by a fall from a bicycle, skiing and other athletic injuries, or some other indirect trauma to the knee. The typical age range for this injury is 6 to 15 years. Meyers and McKeever (191) classified this avulsion fracture by degree of displacement:

Type I. Minimally displaced, with only slight elevation of the anterior margin.
Type II. Hinged posteriorly, producing a beak-like appearance on the lateral radiograph.
Type III. Completely displaced and elevated from its bed.

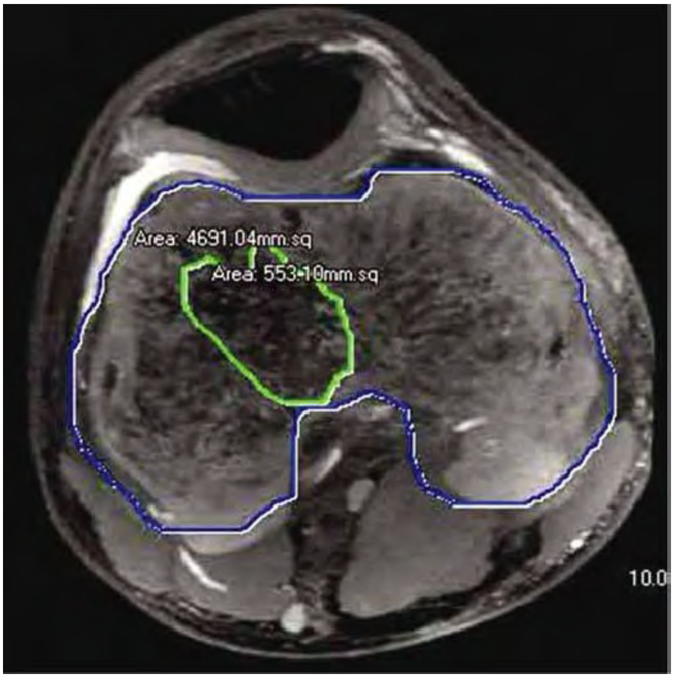


FIGURE 34-30. MRI of the distal femoral physis taken 4 months after injury reveals an 11% growth arrest on the central-lateral region of the physis.

With displacement, the meniscus may become trapped underneath the fragment and interfere with reduction (192). Long-term studies have reported some residual knee laxity despite anatomic reduction with internal fixation (193–195). This would suggest that the fibers of the anterior cruciate ligament are stretched prior to bone failure. Residual laxity has not led to functional deficits or subjective feelings of knee instability. A more troublesome problem is failure to regain full knee extension. Wiley and Baxter (195) carefully evaluated knee range of motion and determined that 60% of all patients lost more than 10 degrees of extension. This loss of motion was noted in all type III injuries that were treated with closed reduction, and in approximately one-half of the type III injuries treated with open reduction. Long-term functional results are generally excellent except for displaced type III fractures (193, 195, 196).

Treatment In type I injuries the limbs do not require reduction and can be immobilized in a cylinder cast for 4 to 6 weeks. This is followed by range-of-motion exercises, strengthening, and gradual resumption of activities.

Type II fractures may be difficult to distinguish from completely displaced fractures. Aspiration of the joint and injection of local anesthetic facilitates reduction. Reduction is attempted by fully extending the knee and applying an above-knee cast. If radiographs after reduction are inconclusive or demonstrate inadequate reduction, MRI or arthroscopic evaluation may be necessary to determine whether the posterior attachment is disrupted, and whether there is meniscal entrapment. The preferred position of immobilization after reduction is controversial. Some authors recommend immobilization in extension (197, 198), whereas others recommend immobilization with 20 to 30 degrees of knee flexion to relieve tension on the anterior cruciate ligament (197). We recommend immobilization in extension following reduction because loss of extension after union is more problematic than joint instability. Hyperextension should be avoided. When reduction cannot be achieved for type II fractures, open reduction is indicated in a manner similar to that for type III injuries.

Recommended treatment of type III fractures is open or arthroscopic reduction (199) (Fig. 34-31). Internal fixation can be achieved by using a small intraepiphyseal cancellous screw (200). Alternatively, especially in cases of comminution, sutures or wires can be passed that enter the osteochondral

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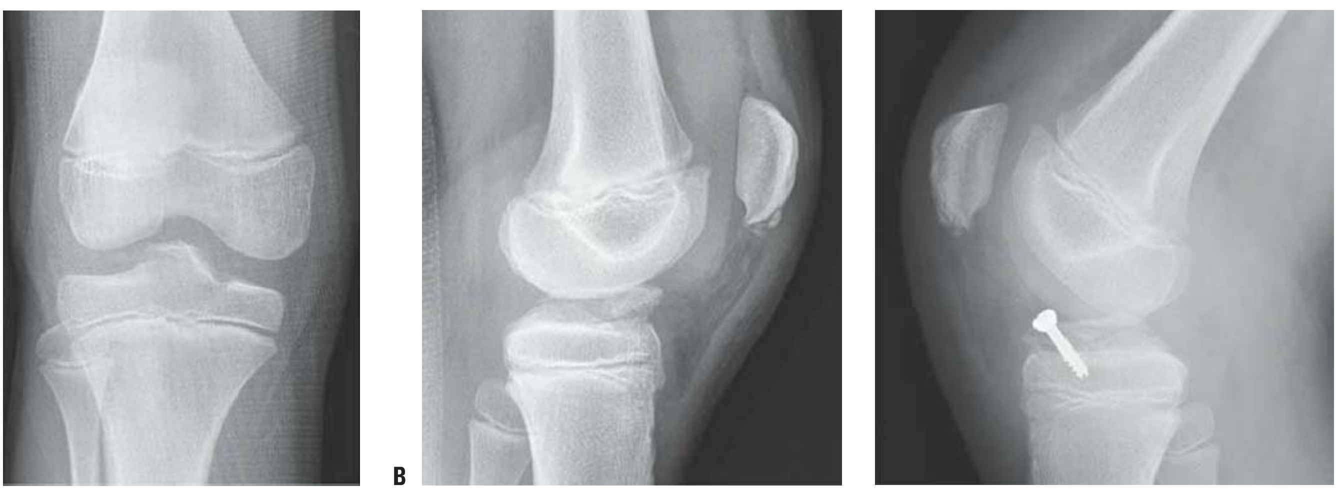


FIGURE 34-31. Type II tibial eminence fracture. The anteroposterior **(A)** and the lateral radiographs **(B)** taken on presentation demonstrate the extent of injury. The postoperative lateral x-ray **(C)** shows reduction of the fragment and fixation with an interfragmentary screw. (Images courtesy of Theodore J. Ganley, MD.)

fragment and exit through the periphery of the epiphysis (201, 202). Suture anchors can also be used to achieve excellent fixation without crossing the physis (203). Biomechanical studies demonstrate that several methods can yield satisfactory fixation (204), hence allowing early mobilization can be initiated to avoid loss of motion.

Complications Some loss of motion and ligamentous instability is common after tibial eminence fracture. These problems are usually mild and rarely interfere with function. Arthrofibrosis can also occur following arthroscopic surgical management (205). Manipulation under anesthesia should be approached with caution due to the risk of distal femoral physeal separation in skeletally immature patients. Occasionally, patients will present late with malunion that limits knee extension. This can be treated with an anterior closing wedge osteotomy and internal fixation (197, 206).

Tibial Tubercle Fracture The tibial tubercle is the anterior and distal extension of the proximal tibial epiphysis. It develops a secondary ossification center and serves as the insertion site of the patellar tendon. Fracture of the tibial tubercle is an injury of the adolescent knee joint, usually occurring in boys between 13 and 16 years of age (207). During this period of growth, the proximal tibial physis is usually in the process of physiologic closure. The tibial growth plate begins closing centrally, proceeds centrifugally, and finally proceeds distally to include the tubercle. The mechanism of injury for avulsion of the tubercle is forceful quadriceps contraction against resistance (e.g., jumping). There may be a preceding history of Osgood-Schlatter disease (208, 209).

Examination reveals swelling, deformity, and tenderness. The ability to perform a straight-leg raise should also be tested. The diagnosis is confirmed on a lateral radiograph by identifying the displaced fragment and a high-riding patella. A classification was proposed by Watson-Jones and modified by Ogden et al. (209). Type I fracture is through the distal ossification center; type II is at the junction of the tubercle and the tibial ossification centers; and type III involves the articular surface of the tibia. A type IV fracture has been suggested, consisting of avulsion of the entire proximal tibial epiphysis.

Treatment Treatment of type I minimally displaced fractures is nonsurgical, but most of the other types require anatomic reduction and internal fixation (207). This can be accomplished by open reduction and insertion of cancellous bone screws (Fig. 34-32). There is usually a large retinacular injury that should be repaired. In younger children with significant growth remaining (an unusual scenario), smooth pins placed obliquely across the fracture can be substituted for screws. This procedure can be supplemented with a tension band suture or wire to the tibial metaphysis if pin fixation is insecure. After knee immobilization for 3 to 4 weeks, active range of motion is begun. Because of the very limited subcutaneous tissue in this area, any screw heads placed in the midline are generally prominent and will be need to be removed later. In some fracture patterns, it's possible to place the interfragmentary screws off the midline, rendering them much less symptomatic in the postoperative period.

Complications Several authors have reported acute compartment syndrome of the leg after tibial tubercle avulsion fracture (210). This may be because the tubercle is near the anterior compartment fascia, and bleeding from the fracture enters this compartment. Pape et al. (210) observed that compartment syndrome may be more frequent in patients who are managed by closed reduction or by percutaneous methods. Bolesta and Fitch (208) recognized this potential complication and performed prophylactic fasciotomy when anterior compartment swelling was present.

Avulsion fractures of the tibial tubercle rarely result in tibial deformity because they occur toward the end of growth; however, posttraumatic genu recurvatum can occur in younger patients. This is caused by premature arrest of the anterior aspect of the growth plate. Patients with more than 1 year of growth remaining should be observed with serial lateral knee radiographs for development of this deformity. Bilateral proximal tibial epiphysiodesis is generally the preferred procedure when deformity is mild. Greater degrees of deformity may necessitate proximal tibial flexion osteotomy to restore normal alignment (211).

Patellar Fractures Patellar fractures are much less common in children than in adults, because the patella is largely cartilaginous until adolescence. The child's patella is also more mobile than the adult's and is subjected to less tensile force during quadriceps contraction. In adolescents, the patellar anatomy approaches that of the adult, and the patella is more likely to be damaged by direct trauma. Osteochondral fractures have also been reported in 15% to 70% of children and adolescents sustaining acute patellar dislocations (181).

The diagnosis of a patellar fracture may be more difficult in children than in adults. Palpation may reveal a defect, but palpation can be difficult to perform because of pain and tense hemarthrosis. Lack of function and abnormal movement of the extensor mechanism on physical examination are useful indicators of patellar injury. Radiographs can be difficult to interpret. Bipartite patella (i.e., secondary ossification center) may be painful and can be confused with nondisplaced fracture. The characteristic location of a bipartite patella—the superolateral portion of the patella—can be a clue to diagnosis. A fractured patella may be difficult to diagnose accurately due to incomplete ossification. The patellar sleeve fracture is a type of patellar fracture that is unique to younger children (212). The age range for patellar sleeve fracture is 8 to 12 years. This injury consists of an avulsion of the cartilaginous portion of the distal patella from the ossification center (213, 214) (Fig. 34-33). Lateral radiographs may demonstrate only patella alta and a very small fragment of bone attached to the distal unossified cartilage. MRI can be diagnostic when there is doubt regarding the nature of the injury.

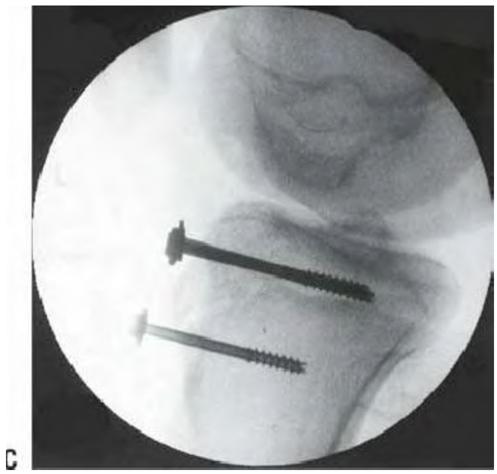


FIGURE 34-32. Type III tibial tubercle fracture. **A:** The initial lateral radiograph of a 14-year-old boy who sustained a tibial tubercle fracture after landing from a jump in a basketball game. The radiograph shows complete displacement, with the fracture line extending into the articular surface of the tibial plateau. **B:** Intraoperative photograph showing exposure through a midline anterior knee incision. The typical massive soft-tissue injury is illustrated, with tears of the medial and the lateral retinacula and stripping of the anterior surface of the tibia. **C:** Lateral image intensifier view taken immediately after open reduction and internal fixation of the fracture.

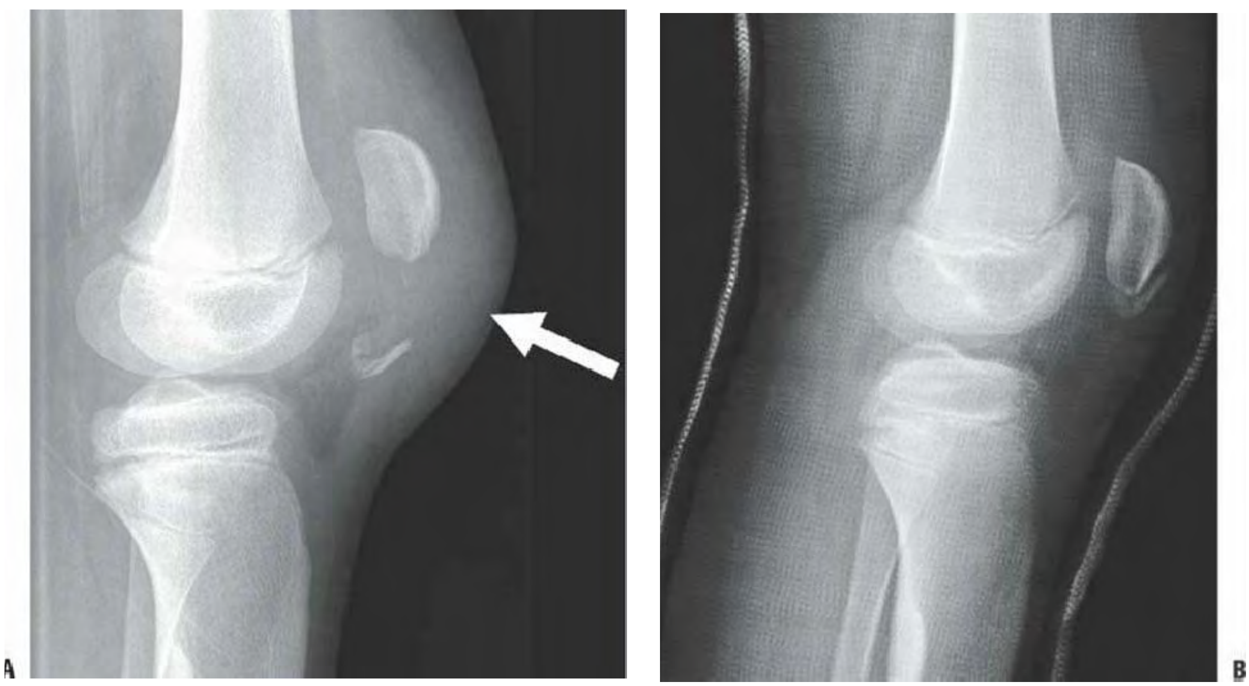


FIGURE 34-33. Preoperative **(A)** and immediate postoperative **(B)** lateral radiographs of a patellar sleeve fracture. Note the extreme soft-tissue swelling localized over the fracture site (*arrow*): this can be a valuable diagnostic sign in more subtle fractures.

Treatment Treatment of patellar fractures in children is generally the same as for adults (200). The patella is a sesamoid bone that grows by apposition, so growth disturbance is uncommon. Nondisplaced fractures with intact extensor mechanisms may be treated by immobilization in extension for 4 to 6 weeks. Open reduction with internal fixation is indicated for displaced fractures. Stability may be achieved by means of the AO tension band technique with either nonabsorbable suture or wire.

TIBIAL FRACTURES

Tibial fractures are the most common lower extremity fracture in children and account for 10% to 15% of all pediatric fractures (88, 183). Many of these are so-called *toddler's fractures,* or low-energy nondisplaced fractures occurring from minor falls or twisting injuries. Motor vehicle accidents and high-energy injuries are more common in older children. Mubarak et al. (215) have classified proximal tibial fractures in children, illustrating how mechanisms of injury and fracture patterns vary with age.

Proximal Tibial Epiphyseal Fracture Separation of the proximal tibial epiphysis is less common than distal femoral physeal injury, likely because ligamentous and physeal anatomy exerting a strong protective effect. The fibula buttresses the tibia laterally and the physis slopes downward anteriorly in the region of the tibial tubercle. The medial collateral ligament inserts on the metaphysis in addition to the epiphysis. Many of the musculotendinous units that span the knee do not insert on the proximal tibial epiphysis. Therefore, varus and valgus stresses are not transmitted to the tibial epiphysis.

The mechanism of injury to this epiphysis is usually direct force to the knee, although this area is also injured by lawn mower accidents in younger children (216, 217). Most proximal epiphyseal injuries are Salter-Harris type II fractures demonstrating posterolateral or posteromedial displacement. These are followed in frequency by type I separations. Hyperextension fractures threaten the popliteal artery because the artery is tethered to the posterior aspect of the tibia by its branches. The posterior branch passes under the arch of the fibers of the soleus muscle, whereas the anterior branch passes into the anterior compartment just distal to the growth plate (Fig. 34-34).

Treatment Management consists of closed reduction in most cases. After reduction, percutaneous pinning (Fig. 34-35) or cannulated screw fixation is recommended. Precise reduction is recommended because future growth may be impaired and residual deformity may not correct spontaneously. Displaced type III and IV fractures are intra-articular injuries. Also, precise reduction and internal fixation is advisable to preserve joint function and reduce the risk of premature physeal closure. These fractures should be followed closely for growth arrest, which occurs in 25% to 33% of patients regardless of the type of physeal separation (217).

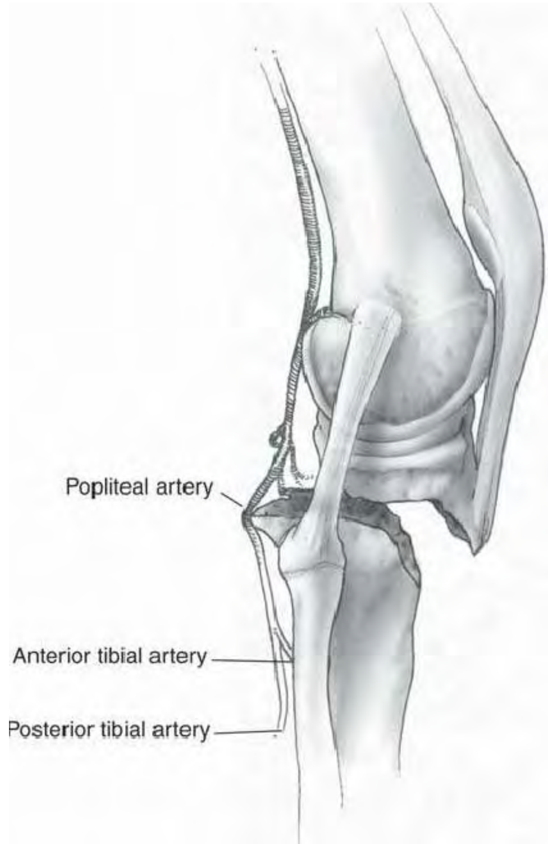


FIGURE 34-34. Proximal epiphyseal fracture. The distal tibial segment is displaced posteriorly, producing vascular occlusion of the popliteal artery.

Complications Vascular compromise requires prompt reduction and stable fixation. If pulses are abnormal, or the foot is cool or discolored, a vascular surgeon should be consulted and the fractures should be reduced promptly in the operating room, internally fixed, then the vascular status should be reassessed. The integrity of the vessels can be evaluated with an angiogram or a magnetic resonance angiography. In the absence of vascular findings, close observation after reduction is imperative. When a period of ischemia has exceeded 4 hours or vascular repair is required, prophylactic fasciotomy is recommended (218). This may prevent reperfusion compartment syndrome from developing.

Proximal Tibial Metaphyseal Fracture (Cozen Fracture) Metaphyseal fractures of the proximal tibia occur most commonly in children between the ages of 2 and 8 years. The usual mechanism of injury is a valgus force applied to the extended knee producing an incomplete fracture of the tibia, with or without fracture of the fibula. The lateral cortex of the tibia may be buckled, impacted, or may undergo plastic deformation. Pronounced displacement is uncommon except in instances of high-energy trauma. This innocuous-appearing fracture is more often in valgus than one readily appreciates from the initial radiographs. A comparison radiograph of the opposite tibia is helpful to determine the true deformity of the injured leg.

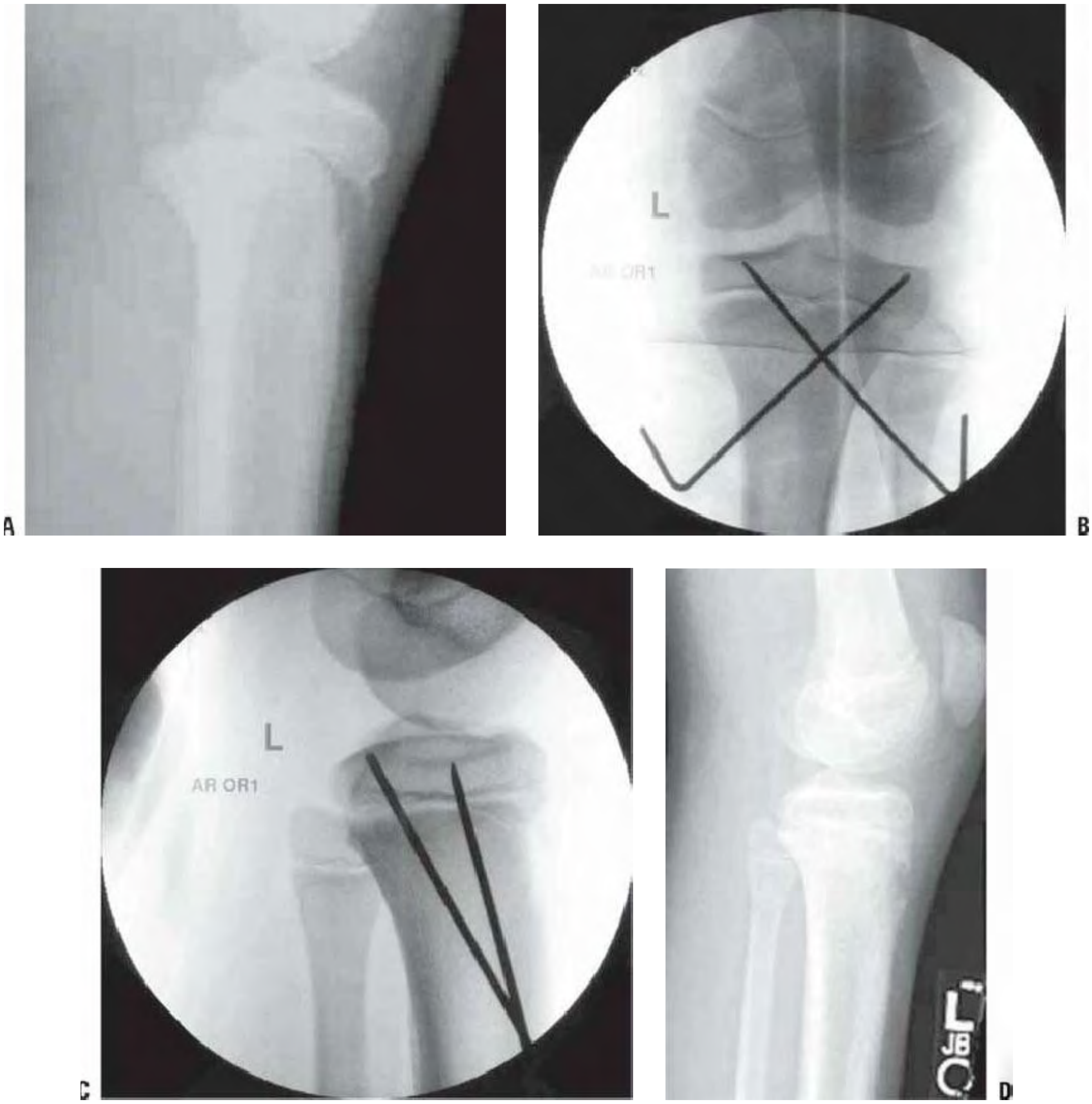


FIGURE 34-35. Proximal tibial physeal injury. **A:** This initial lateral radiograph shows a displaced proximal tibial physeal fracture. **B, C:** Intraoperative images after closed reduction and internal fixation with two Kirchner wires. **D:** Lateral radiographs 6 weeks after injury show maintenance of anatomic alignment.

Treatment Management consists of closed reduction and cast immobilization. Occasionally, open reduction is necessary to remove interposed periosteum or pes anserinus. After reduction, the knee is placed in extension. This position allows effective three-point cast molding to generate a varus force. The extension position also facilitates subsequent radiographic interpretation. The authors recommend that reduction should be within 5 degrees of the opposite intact tibia as judged by a line through the physis and a line down the tibial shaft. The cast is maintained until healing is complete, usually 6 weeks. From the time of injury, families should be counseled about the possibility of posttraumatic genu valgum. Displaced proximal tibial fractures in adolescents sometimes require surgical stabilization to control alignment and expedite mobilization. During the 48 hours after closed reduction and casting, the extremity should be closely monitored for signs of compartment syndrome.

Complications Progressive valgus deformity of the leg frequently develops in children younger than 10 years who sustain a Cozen fracture (219) (Fig. 34-36). Close review of the initial postreduction radiographs occasionally reveals that an incomplete reduction was responsible for at least part of the deformity. However, nondisplaced and anatomically aligned fractures can also develop progressive valgus deformity (219). Progressive angulation begins several weeks after fracture and usually ceases by 12 months after fracture. The cause of this problem remains somewhat obscure, but it probably results from selective overgrowth of the medial tibial physis (219). Overgrowth of the tibia with tethering by the intact fibula has also been postulated as a possible cause, but progressive valgus deformity can develop even when the fibula is fractured. Treatment of this deformity for children younger than 5 years consists of observation (220). Valgus deformity usually resolves spontaneously in this age group with the development of a slightly S-shaped tibia

A B C

FIGURE 34-36. **A:** Radiograph of a proximal metaphyseal fracture of the tibia with valgus deformity. Closed reduction was performed. **B:** Radiographic appearance at the time of union demonstrates satisfactory alignment. **C:** Radiographs 8 months later demonstrate valgus alignment attributable to asymmetrical growth stimulation.

(220–223). Tibial osteotomy and hemiepiphyseal stapling have been reported for correction of more severe deformities (220, 224). In the authors' opinion, osteotomy should be avoided because of the high risk of recurrent deformity (221). Although rarely indicated, the authors recommend temporary hemiepiphyseal stapling to correct deformity in children older than 5 years who have a deformity >15 degrees.

Tibial Diaphysis Fractures Fractures of the shaft of the tibia or fibula account for approximately 4% to 5% of all pediatric fractures (88, 183). These fractures generally fall into three categories: (i) nondisplaced, (ii) oblique or spiral, and (iii) transverse and comminuted displaced fractures (225–227). In infants and young children, the tibial cortex is weaker, and hence is more likely to bend, buckle, or sustain a nondisplaced spiral fracture than to fracture completely. The surrounding periosteum is strong and imparts stability to the fracture site. This limits displacement and shortening. In contrast, the adolescent tibial shaft is composed of very dense cortical bone and a thinner, weaker periosteum. Fractures in the adolescent age group are more often the result of high-energy trauma and are associated with greater fracture displacement, comminution, and slower healing rates than in younger children.

The remodeling potential of the tibia is limited. A recent study (228) of 48 tibia fractures in children 3 to 12 years old concluded that in the sagittal plane, acceptable critical anterior and posterior angular deformities that corrected completely were 12 and 6 degrees, respectively. In the coronal plane, acceptable angular deformities were 10 degrees varus and 8 degrees valgus. Hansen and Grieff (225) reported only 13.5% correction of angular deformity with subsequent growth. Shannak (227) demonstrated that one-third of children with more than 10 degrees of angulation at healing had persistence of the angulation at final follow-up assessment. In general, varus malalignment seems to remodel more completely than valgus deformity. Although long-term studies show that moderate angulation is well tolerated (229), the authors recommend that attempts should be made to maintain alignment within 10 degrees of angulation in any direction for children 6 years and older, and within 15 degrees of angulation for children younger than 6 years (225, 227, 229, 230). Rotational deformity may not remodel, although external rotation deformity is better tolerated than internal rotation deformity (227).

Some shortening at the fracture site can remodel, but the ability to compensate for shortening decreases with age. Children younger than 5 years show the greatest capacity. However, growth acceleration >5 to 7 mm is unusual (231). In a review of 142 tibial fractures, Shannak (227) reported an average of only 4.35 mm of growth acceleration. Comminuted and long spiral fractures displayed the greatest amount of overgrowth, including those that were treated with anatomic reduction and internal or external fixation. Overgrowth is not routinely seen in girls older than 8 years or boys older than 10 years.

Nondisplaced Fractures of the Tibial Shaft Nondisplaced tibial fractures are more common in younger children. Toddler's fracture is seen in the 1- to 4-year age group. A mildly traumatic event may have been observed, but often the child presents with an acute limp of unknown cause. A twist while descending a sliding board, with or without a parent, is a very common mechanism. Approximately 20% of these acutely limping toddlers have sustained occult fractures, and half of these fractures are in the tibia (232). Low-energy torsional forces, as when the child twists a leg, usually cause these fractures. The child limps or refuses to walk on the affected lower limb. Examination may reveal a point of tenderness or subtle swelling in the distal third of the leg, but often the examination is unremarkable. Radiographs may show a fracture, but frequently the fracture line is not initially evident. Careful examination of the entire extremity, including the hip and knee joint and the foot, should be part of every evaluation of an occult toddler's fracture. Infectious processes need to be considered in the differential diagnosis, but these can usually be diagnosed by the presence of fever and laboratory studies demonstrating increased sedimentation rate, C-reactive protein, and leukocyte count. A triphase bone scan may help establish the diagnosis when pain and limp are severe and the workup remains equivocal (233). MRI is more specific but less often used because sedation is required in these young patients. Treatment is initiated when fracture is suspected, and the diagnosis is usually confirmed 10 to 14 days later, when periosteal new bone has formed.

Treatment of nondisplaced fractures of the tibial shaft in all age groups consists of immobilization in a short-leg cast for distal fractures or long-leg cast for fractures proximal to the midshaft. A short leg walking cast, with full weight bearing permitted, is recommended for the typical stable, nondisplaced toddler's fracture of the tibia. Immobilization is continued until union has occurred, usually 3 to 4 weeks for toddlers and 6 to 10 weeks for older children.

Oblique or Spiral Fractures of the Tibial Shaft Isolated fracture of the tibia with an intact fibula is the most common tibial shaft fracture in the pediatric age group (230, 234). A rotational or twisting force results in a spiral or an oblique fracture at the junction of the middle and distal thirds of the tibial shaft. The most common mechanism of injury is indirect trauma such as sports accidents or falls. The intact fibula imparts stability, but it may have plastic deformation that interferes with reduction of displaced tibial fractures. The intact fibula may also contribute to the development of varus angulation.

Treatment consists of reduction and immobilization in an above-knee cast, with the knee flexed to 30 degrees and the ankle in 15 degrees of plantar flexion to minimize varus muscle forces and prevent recurvatum (230, 234). Unstable, displaced fractures may require surgical stabilization with external fixation or flexible nails. Angulation >10 degrees in any direction should be corrected, except in children younger than 6 years, in whom 15 degrees may be accepted (225, 227, 229, 230).

Transverse and Comminuted Displaced Fractures of the Tibia and Fibula Complete fractures of the tibia and fibula are more common in older children. These fractures result from high-energy trauma, such as a pedestrian struck by a motor vehicle. Open fractures of the tibia are not uncommon and account for 4% of all tibial fractures in children and adolescents (235). Soft-tissue damage and periosteal stripping predispose to more severe complications such as compartment syndrome, delayed union, and infection. Inherent fracture stability after reduction is variable.

Treatment of closed injuries is similar to that for oblique and spiral fractures, and is considerably more successful, and hence more widely used, than closed treatment of adult tibia fractures. Closed reduction may be easier to achieve when the fibula is fractured, but there is a tendency for the fracture to drift into valgus and procurvatum because of the greater muscle bulk posterolaterally in the leg. An above-knee cast is used for 4 to 8 weeks until initial stability has been achieved. Immobilization may then be continued with a patella-tendon-bearing cast, weight bearing as tolerated, until healing is complete. Optimal final alignment should be within 10 degrees in any direction.

Unstable fractures may require surgical stabilization to maintain alignment or facilitate rehabilitation. Most cases of operative management of pediatric or adolescent tibia fractures result from very high-energy injuries, which either displace in the initial cast, or are taken to the operating room at the time of injury to address open wounds, polytrauma, or compartment syndrome. Elastic nailing has become a popular stabilization method for high-energy pediatric tibia fractures (236–238)

FIGURE 34-37. Tibia fracture stabilized with elastic nails. **A:** Anteroposterior and **(B)** lateral of a midshaft short oblique tibia and fibula fracture on the day of injury. **C:** Anteroposterior and **(D)** lateral after internal fixation with elastic nails. The fracture was also protected in a short leg cast. Immediate partial weight bearing was permitted. **E:** Anteroposterior radiographs 1 year after injury. Nails were removed approximately 6 months after injury. Alignment is excellent.

(Fig. 34-37). Recent studies have demonstrated that elastic nailing yields slightly better results than external fixation (although each is valuable, depending on the circumstances).

Open Fractures of the Tibia The general management of open fractures has been discussed earlier in this chapter. Open fractures of the tibia in children are the result of high-energy trauma, with associated injuries in 25% to 50% of these patients (235, 239).

Treatment Initial management consists of administration of intravenous antibiotics and tetanus prophylaxis, followed by aggressive wound irrigation and debridement (235, 239–241). Clean, grade I open wounds may be loosely closed over a drain after adequate debridement, but most wounds should be left open with repeated debridement before soft-tissue coverage (240). Vacuum-assisted closure has become an invaluable tool in the management of open tibia fractures, markedly reducing return trips to the operating room and the need for soft-tissue coverage of some cases. Debridement of devitalized bone is not necessary in children if the bone is clean and can be adequately covered with soft tissue (242). Surgical stabilization facilitates wound management. External fixation is generally preferred in most cases with large open wounds (235, 239–241, 243).

Complications Open fractures in children share many of the same complications reported in the literature for fractures in adults (244, 245). Several authors have noted that age is the most significant prognostic indicator (241, 246). Children younger than 12 years require less aggressive surgical management, heal faster, have lower infection rates, and have fewer complications than older children. Children older than 12 years have fracture patterns and complications that are similar to those in the adult population. However, limb salvage and reconstruction has a higher rate of success than in the adult population (247).

Fractures of the Distal Tibial Metaphysis Distal tibial metaphyseal fractures are typically either transverse or short oblique fractures, and heal reliably after closed reduction and casting. The patterns of displacement of the distal tibial metaphyseal fractures are either valgus recurvatum and varus procurvatum (248). Fractures of the fibula always present with the same pattern as the tibia.

FRACTURES OF THE ANKLE

Ankle fractures in children constitute approximately 5% of all pediatric fractures and one out of every six physeal fractures (17%) (1, 184). The same mechanisms that produce spiral fractures of the tibial shaft in younger children may produce epiphyseal fractures of the ankle in older children. Tillaux and triplane fractures are specific injuries that occur as the distal tibial growth plate begins to close (249). Tillaux and triplane fractures are referred to as *transitional fractures* because they occur in adolescents during the transition from an open physis to skeletally mature distal tibia and fibula.

The ossification centers of the distal tibial and fibular epiphyses appear between the ages of 6 months and 2 years. The medial malleolar extension forms at around 7 to 8 years of age and is complete by the age of 10. Closure of the distal tibial growth plate begins centrally, proceeds medially, and closes last on the lateral side. This sequence of closure is responsible for transitional fracture patterns. The fibular physis lies at the level of the talar dome, and closes 1 to 2 years later than the distal tibia.

Because the ankle is a flexion/extension hinge, the region susceptible to injury from twisting or bending forces. Medial stability is provided by the deep fibers of the deltoid ligament that attach the medial malleolus to the body of the talus. The lateral ligament complex consists of anterior and posterior talofibular ligaments and the calcaneofibular ligament. Strong ligamentous structures also bind the distal tibia to the fibula at the level of the joint. The anterior tibiofibular ligament is important in the pathomechanics of transitional fractures. Ligaments around the ankle principally attach to the epiphyses distal to the level of the growth plate. This anatomic arrangement transmits injury forces to bone and results in physeal fractures in older children and adolescents.

Diagnosis can be difficult in patients with nondisplaced or minimally displaced fractures. This is particularly true for distal fibular physeal separations and Tillaux fractures. Swelling may be minimal. Careful palpation usually reveals that the most tender area is the growth plate rather than the joint or ligaments. Displaced fractures are painful, with visible deformity due to the subcutaneous nature of the ankle joint. The position of the foot relative to the tibia provides evidence of the mechanism of injury and indicates the direction of manipulation required for reduction. Motor, sensory, and vascular assessments should be performed before reduction. Plain radiographs usually confirm the diagnosis and define the fracture pattern. CT scanning, with or without three-dimensional reconstruction, is useful for evaluation and management of transitional fractures. In most cases, a CT is best performed after an initial reduction attempt because the CT can confirm satisfactory joint and physeal alignment. An MRI does not offer great advantage over plain radiography except to evaluate complications such as growth arrest (250).

Malleolar avulsion fractures are more common in younger children, whereas a variety of epiphyseal injuries may be seen in older children. Fractures with syndesmosis disruption are uncommon in children until late adolescence. The most common avulsion injury is avulsion of the tip of the lateral malleolus, followed by separation of the distal fibular physis (251).

Classifications Ankle injuries in children have been classified by mechanism of injury, type of growth-plate injury, and combinations of both systems (252, 253). Classifications based on mechanism of injury have been proposed to help guide reduction, but these classifications have been formulated independent of clinical examination. Also, children rarely have comminution or syndesmosis disruption, which have poor prognoses in adult classification schemes. In children, the steps necessary for reduction are usually evident when the clinical examination of foot position is combined with the radiographic appearance. Classifications have also been proposed that combine mechanism of injury with the type of growth-plate injury, but these classifications can be confusing and difficult to remember. The authors agree with Vahvanen and Aalto (251), who stated: "The simultaneous use of the classifications based on both type of trauma and type of epiphyseal lesion for classifying ankle fractures in children has led to unsatisfactory and unnecessarily complex groupings. In children the mechanism of trauma can often not be identified, and experimental work, such as what Lauge-Hansen did to support the mechanism-of-trauma classification in adults, is lacking in children." Those authors subsequently proposed a simple classification to guide management and predict outcome. According to their system, ankle fractures in children can be classified into two categories (251):

Group I. Low risk, including avulsion fractures and epiphyseal separations (Salter-Harris types I and II)
Group II. High risk, including fractures through the epiphysis (Salter-Harris types III, IV) and displaced transitional fractures

In this classification scheme, transitional fractures would be considered high risk. However, we prefer to consider transitional fractures as a separate category because of the distinct pathoanatomy of these injuries. Spiegel et al. (254) used a slightly different classification of high-risk and low-risk pediatric ankle fractures, with a third category for transitional fractures.

Treatment

Low-risk Fractures This category includes avulsion fractures that do not involve the physis, and all Salter-Harris type I and II physeal injuries. Nondisplaced distal fibular physeal fractures are treated with a weight-bearing short-leg cast for 4 to 6 weeks. Children with nondisplaced, low-risk ankle fractures involving the tibia are placed in a short-leg cast and limited to non–weight-bearing activities for 2 to 3 weeks; they are allowed full weight-bearing activities thereafter. Union occurs at approximately 4 to 6 weeks after injury. Follow-up radiographs in the cast are recommended 7 to 10 days after initial treatment to ensure maintenance of alignment.

Displaced low-risk fractures are usually managed by closed reduction (Fig. 34-38). This can be attempted in the emergency room, but complete muscle relaxation may be required for successful manipulation. Following reduction, a residual physeal gap of >3 mm may indicate the presence of entrapped soft tissue. This may lead to a greater risk of physeal closure unless open reduction is performed to remove interposed tissue (255). A flap of periosteum is usually found, but tendons or neurovascular structures can also become interposed. Internal fixation with smooth pins or metaphyseal screws can be used after open reduction (Fig. 34-39), but this is not required if the fracture is stable clinically. Minor amounts of displacement and angulation can be accepted, especially in children younger than 8 years, because these injuries are usually extra-articular and have good prognoses for resumption of growth. Immobilization in an above-knee cast (non–weight bearing) is recommended for the first 3 weeks after closed reduction. A below-knee, weight-bearing cast is then applied

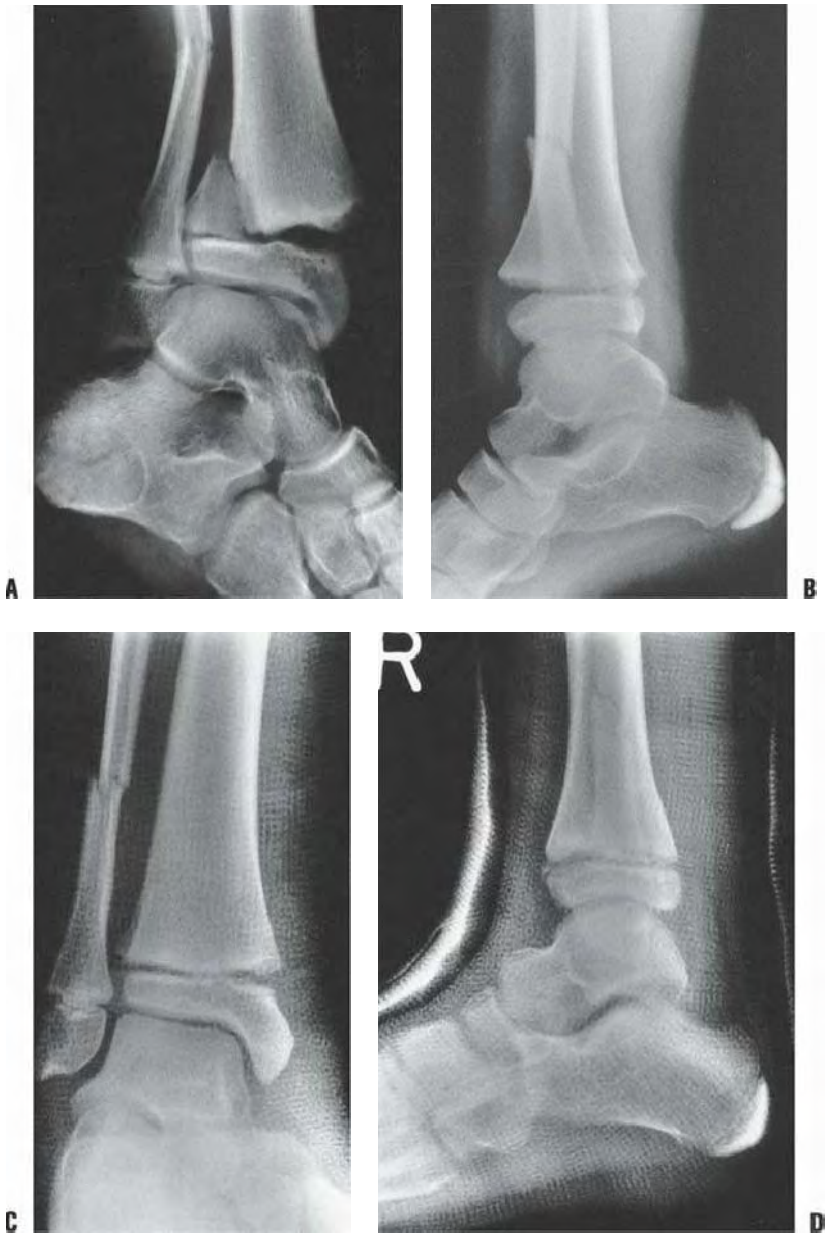


FIGURE 34-38. Pronation and external rotation ankle fracture. **A:** This anteroposterior radiograph demonstrates a Salter-Harris type II fracture of the distal tibia. The Thurston Holland fragment is lateral. The fibular fracture is transverse and located well above the fibular physis. **B:** Lateral projection of the same injury. **C:** This fracture was treated with closed reduction and application of an above-knee cast. **D:** A lateral radiograph demonstrates acceptable alignment. This fracture was managed successfully with closed reduction.

until union is obtained. A total of 6 weeks of immobilization is usually sufficient.

High-risk Fractures These fractures include Salter-Harris type III and IV fractures. They are intra-articular, usually with joint instability. "Hairline" fractures in which the fracture line is 1 mm or less on all views can be managed by immobilization in a long-leg cast with close follow-up. Greater degrees of displacement require accurate reduction. Salter and others (256, 257) have noted that reduction of these fractures must be "perfect" to restore the articular surface and minimize the risk of growth arrest. Closed reduction may be attempted for displaced fractures, but is rarely successful. Open reduction is usually performed with fixation using intraepiphyseal smooth Kirschner wires or 4.5-mm cannulated screws (Fig. 34-40). Lintecum and Blasier (258) described a technique of direct visualization and reduction through an anterior arthrotomy incision. This was accompanied by percutaneous fixation with cannulated screws inserted medially or laterally. Every effort should be made to avoid crossing the growth plate with internal fixation devices. However, restoration of articular integrity is more important than preserving growth at the ankle. The distal tibial and fibular epiphyses contribute only 5 to 7 mm of longitudinal growth per year. When unstable fractures occur in children older than 12 years, there are some circumstances where it is advisable to place internal fixation devices across the physis and perform epiphysiodesis to avoid subsequent angular deformity if sufficient growth remains.

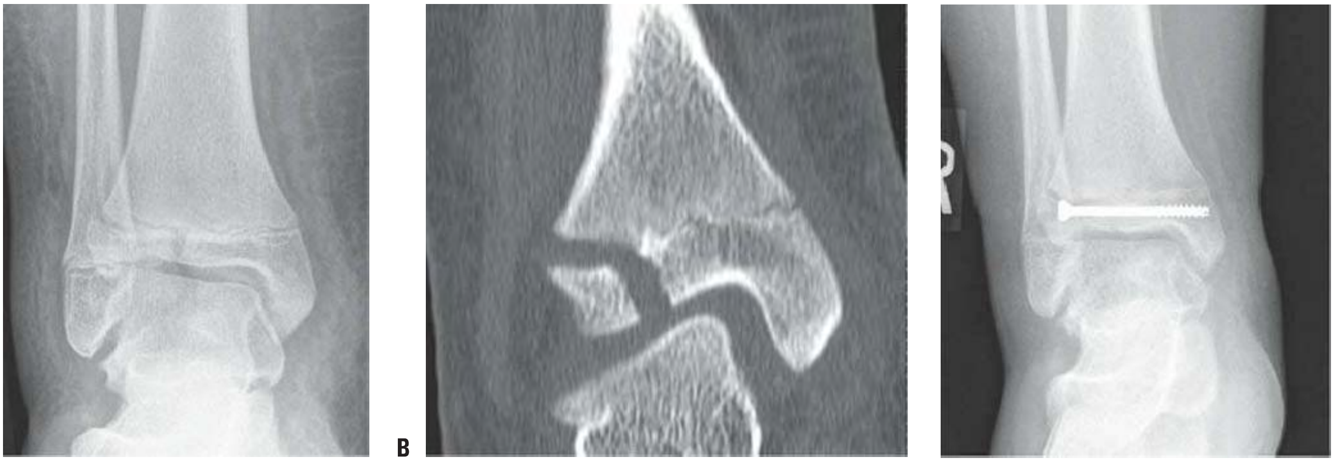
Transitional Fractures These fractures are also high risk and include the Tillaux and triplane injuries. These fractures occur as the growth plate is in the process of closing, so growth disturbance is not a concern. Restoration of articular congruity is the objective of treatment.

A B

FIGURE 34-39. **A, B:** This Salter-Harris II distal tibia fracture, with associated fibula fracture, occurred when the patient was struck by a car, creating a high-energy valgus force to the ankle. There was interposed periosteum medially, which was removed with a small incision. The fracture was fixed with a single pin, then a cast was placed.

A B C

FIGURE 34-40. Supination-inversion ankle fracture. **A:** The anteroposterior radiograph demonstrates a bimalleolar ankle fracture with ankle dislocation. There is a Salter-Harris type I fracture of the distal fibula and a Salter-Harris type III fracture of the medial tibial epiphysis. **B:** Lateral projection. **C:** Anteroposterior radiograph after open reduction and internal fixation. Transepiphyseal screws are used to avoid fixation crossing the growth plate. The joint surface is restored to anatomical alignment. No fixation was required for the fibula fracture. A smooth Kirschner wire can be placed across this physis, if needed, for ankle stability.



A B C

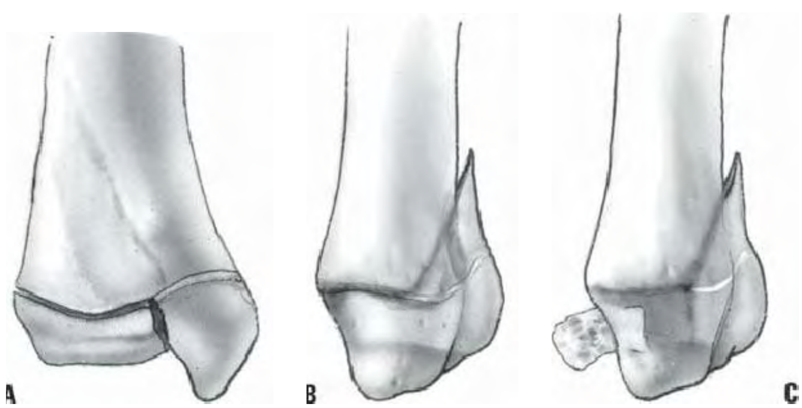
FIGURE 34-41. **A:** Anteroposterior radiograph of the ankle showing a displaced Tillaux fracture. **B:** CT defines displacement of 4 mm. **C:** Anteroposterior radiograph of the ankle after internal fixation with a 4.5-mm cannulated screw.

Tillaux fracture results from an external rotational force and consists of avulsion of the anterolateral portion of the distal tibial epiphysis by the anterior tibiofibular ligament. This is a biplane Salter-Harris type III injury; some are difficult to detect on plain radiographs. Closed reduction is often successful and is performed by internal rotation and immobilization in an above-knee cast. The quality of reduction should be accurately documented. CT scans are helpful if plain radiographs are inconclusive. Open reduction with internal fixation is indicated when joint surface step-off after closed reduction is >2 mm (249, 259) (Fig. 34-41). An anterolateral approach is used, and the fracture is fixed with partially threaded cancellous screws crossing the physis.

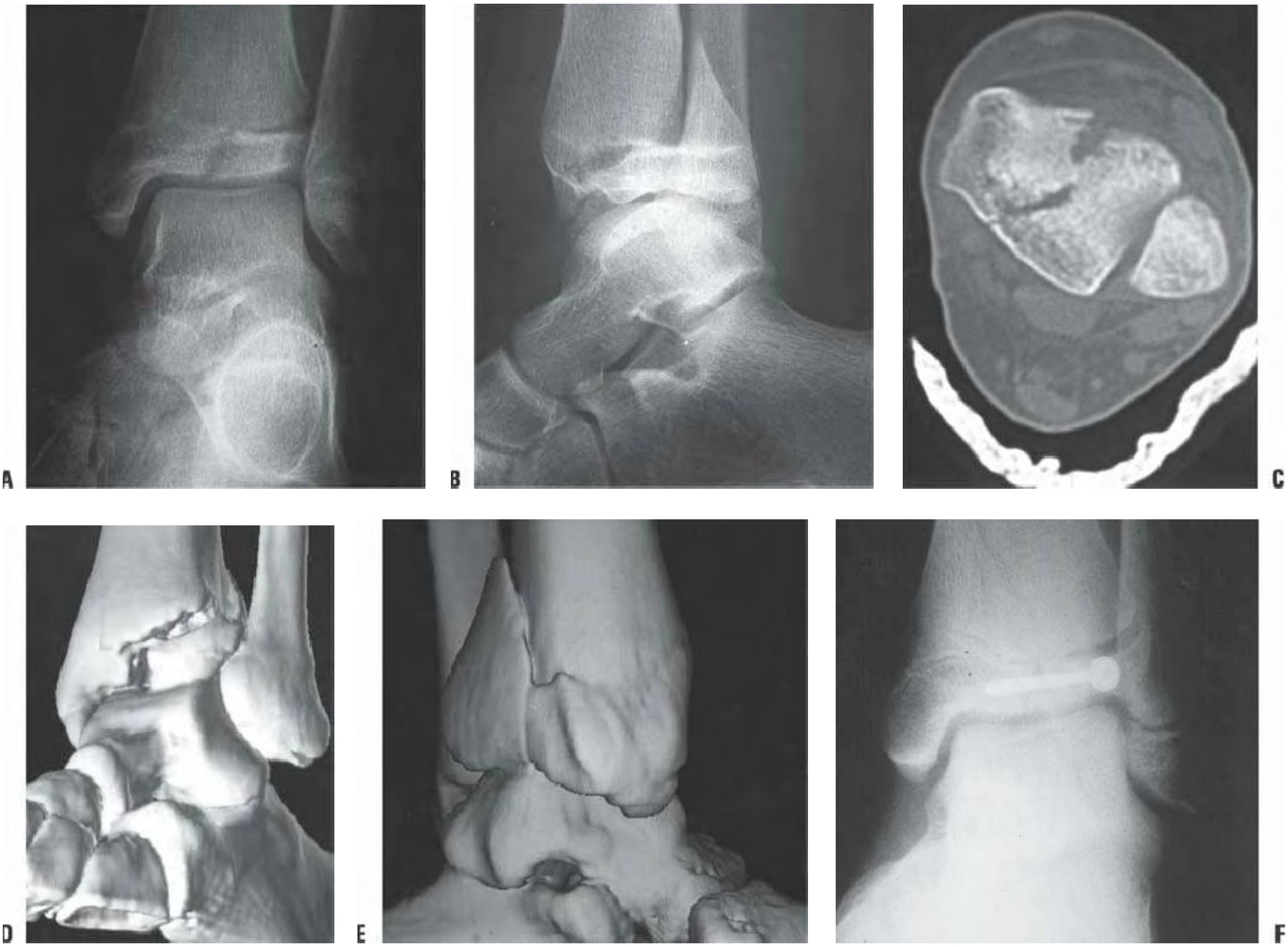
Triplane fracture is also caused by external rotation of the foot (260). On anteroposterior radiographs, it appears as a Salter-Harris type III fracture, but on the lateral projection it appears to be a type II fracture (Fig. 34-42). The triplane fracture may be a two-part or a three-part fracture, but greater degrees of comminution can occur. The CT scans of two-part fractures reveal a single fracture line on the horizontal section through the epiphysis. Three-part fractures demonstrate three radiating fracture lines ("Mercedes sign") on the transverse section through the epiphysis. An extra-articular type of triplane fracture can also occur when the fracture line exits through the medial malleolus beyond the articular surface (249). When seen early, initial management consists of attempted closed reduction with internal rotation and application of a long-leg cast. CT scan is recommended to confirm reduction (Fig. 34-43). Open reduction with internal fixation (Fig. 34-44) is indicated when joint surface incongruity exceeds 2 mm, when the patient presents late (anatomic reduction is difficult), or after failed closed reduction (249, 259, 261). The anterolateral approach is satisfactory for reduction and fixation of two-part fractures. Three- and four-part fractures generally require anterolateral, with or without posteromedial exposures. In rare circumstances in which articular congruity cannot be assured by direct visual inspection or radiographic evaluation, arthroscope-assisted reduction can be helpful.

Complications Complications of pediatric ankle fractures are related to joint incongruity and growth disturbance. Both of these are influenced by the adequacy of reduction. Kling

FIGURE 34-42. Triplane fracture. **A:** On the anteroposterior radiograph, the fracture appears as a Salter-Harris type III fracture of the distal tibial epiphysis. **B:** On the lateral view, the fracture appears as a Salter-Harris type II fracture of the distal tibia. **C:** In the three-part triplane fracture, the anterolateral epiphyseal fragment is displaced as a separate fragment.



A B C



A B C D E F

FIGURE 34-43. Triplane fracture of the distal tibia in a 12-year-old girl with CT evaluation. **A:** The anteroposterior radiograph shows a Salter-Harris type III fracture. **B:** The lateral radiograph shows an apparent Salter-Harris type II fracture. This indicates a triplane injury. **C:** CT through the epiphysis confirms a two-part fracture. **D, E:** Three-dimensional reconstruction demonstrates the fracture from the anterolateral and the posteromedial views. **F:** Closed reduction was unsuccessful. Arthroscopically assisted open reduction was performed. The fracture was stabilized with a single anterolateral cannulated screw inserted percutaneously.

et al. (256) reported that 19 of 20 Salter-Harris type III and IV fractures that were treated with accurate open reduction and internal fixation healed without growth disturbance. In contrast, five of nine similar fractures that were treated by closed means developed bone bridges. The distal tibia and fibula grow 5 to 7 mm per year. Therefore, leg-length discrepancy is rarely a major problem, except in younger children. The more common problem is angular deformity due to asymmetric growth arrest. Complete epiphysiodesis, with or without contralateral epiphysiodesis, should be considered as soon as growth disturbance is recognized. Other alternatives for management of growth arrest are discussed in the injury to the physis section of this chapter. When ankle deformity has occurred, transphyseal osteotomy is a successful method of correction (262).

Restoration of joint congruity is essential to prevent long-term disability (259, 261). It is generally agreed that attempts should be made to reduce the step-off at the articular surface to 2 mm or less (263). The amount of gap that can be accepted without step-off is not clearly defined, but it may be slightly >2 mm. Although every attempt should be made to restore articular surfaces without placing fixation across the physis, it is the authors' opinion that maintenance of articular integrity is a higher priority than preservation of growth around the ankle.

FRACTURES OF THE FOOT

Fractures of the metatarsals and phalanges of the toes are common, accounting for 7% to 9% of all pediatric fractures (1, 88, 184). However, fractures of the tarsal bones are uncommon in children and account for <1% of all fractures in childhood. Most are nondisplaced and may be an underreported cause of limping in toddlers (264, 265). The rarity of fractures of the midfoot and

FIGURE 34-44. Triplane fracture. **A, B:** Anteroposterior and lateral triplane fracture in a 14-year-old. **C, D:** Anteroposterior and lateral radiograph after closed reduction and internal fixation of the distal tibia. No fixation was chosen for the distal fibula.

hindfoot is attributed to the fact that the juvenile foot is very flexible, with a large component of cartilage until late adolescence. The ossification center of the medial cuneiform does not appear until 4 years of age. Some of the secondary ossification centers do not appear until 10 years of age or later. Therefore, there are numerous ossification centers in various stages of development. This can make radiographic interpretation difficult. Comparison radiographs of the opposite foot should be obtained when the diagnosis of a fracture is in question. A CT scan or an MRI is often helpful to evaluate complex injuries.

Talus Fractures and Dislocations

Talar Neck Fractures Fractures of the talar neck are thought to result from forced dorsiflexion. However, there is a 25% to 30% incidence of associated medial malleolar fractures, which suggests a supination component to the deforming force (266). Most talar neck fractures in children are nondisplaced. Most displaced fractures are from high-energy trauma. Displacement jeopardizes the tenuous blood supply of the talus because the neck region is the primary site of vascular penetration into the talus. Fortunately, there are numerous vascular anastomoses within the body of the talus. The principal blood supply penetrates the neck from within the tarsal canal that is formed by the sulcus of the calcaneus and the sulcus of the talus at the base of the neck. The other major blood supply is a deltoid branch from the posterior tibial artery that enters the medial body of the talus along the deltoid ligament (267).

Letts and Gibeault (268) proposed a classification for pediatric fractures of the talus, which is helpful to determine prognosis:

Type I. Minimally displaced fracture of the distal talar neck (the incidence of osteonecrosis is low)

Type II. Minimally displaced fracture of the proximal neck or body (the risk of osteonecrosis is low with this type also)

Type III. Displaced talar neck or body fracture (osteonecrosis is more likely)

Type IV. Talar neck fracture with dislocation of the body fragment (osteonecrosis is expected in these fracture dislocations)

Treatment Fractures that are minimally angulated (<5 degrees on the anteroposterior view) and displaced <2 mm can be managed closed (269). The foot is placed in slight plantar flexion to reverse the mechanism of injury. Immobilization in a non–weight-bearing below-knee cast is continued until union is evident, usually at about 6 weeks. Then a full–weight-bearing cast is used for an additional 4 to 6 weeks. Displaced fractures require open reduction with internal fixation. The anteromedial approach is preferred for fragment reduction. Kirschner wires or cannulated screws can be placed anterior to posterior or retrograde, depending on the fracture pattern (Fig. 34-45). Lag screws are recommended because they may eliminate displacement better than smooth wires (266). Cast immobilization with non–weight-bearing activities is maintained until union is achieved.

Osteonecrosis in children does not usually prevent healing of the fracture, and the long-term outcome may be satisfactory. Prolonged non–weight bearing in a cast yields the best results when osteonecrosis has developed (269). Subchondral lucency may become visible in the body of the talus 6 to 8 weeks after fracture (Hawkins sign). This sign results from disuse osteopenia and indicates that the body of the talus is vascularized.

Osteochondral Fractures of the Talar Dome Forced supination of the foot, as in a sprained ankle, may produce osteochondral fracture of the medial or lateral margin of the talar body. This lesion should be suspected when a "sprained ankle" does not improve as expected. Medial lesions tend to be posteromedial and result from inversion, plantar flexion, and external rotation. Lateral lesions tend to be anterolateral and result from inversion and dorsiflexion. Plain radiographs of the ankle mortise in plantar flexion and dorsiflexion may be necessary to visualize the fracture. A CT scan or an MRI is useful in problematic cases.

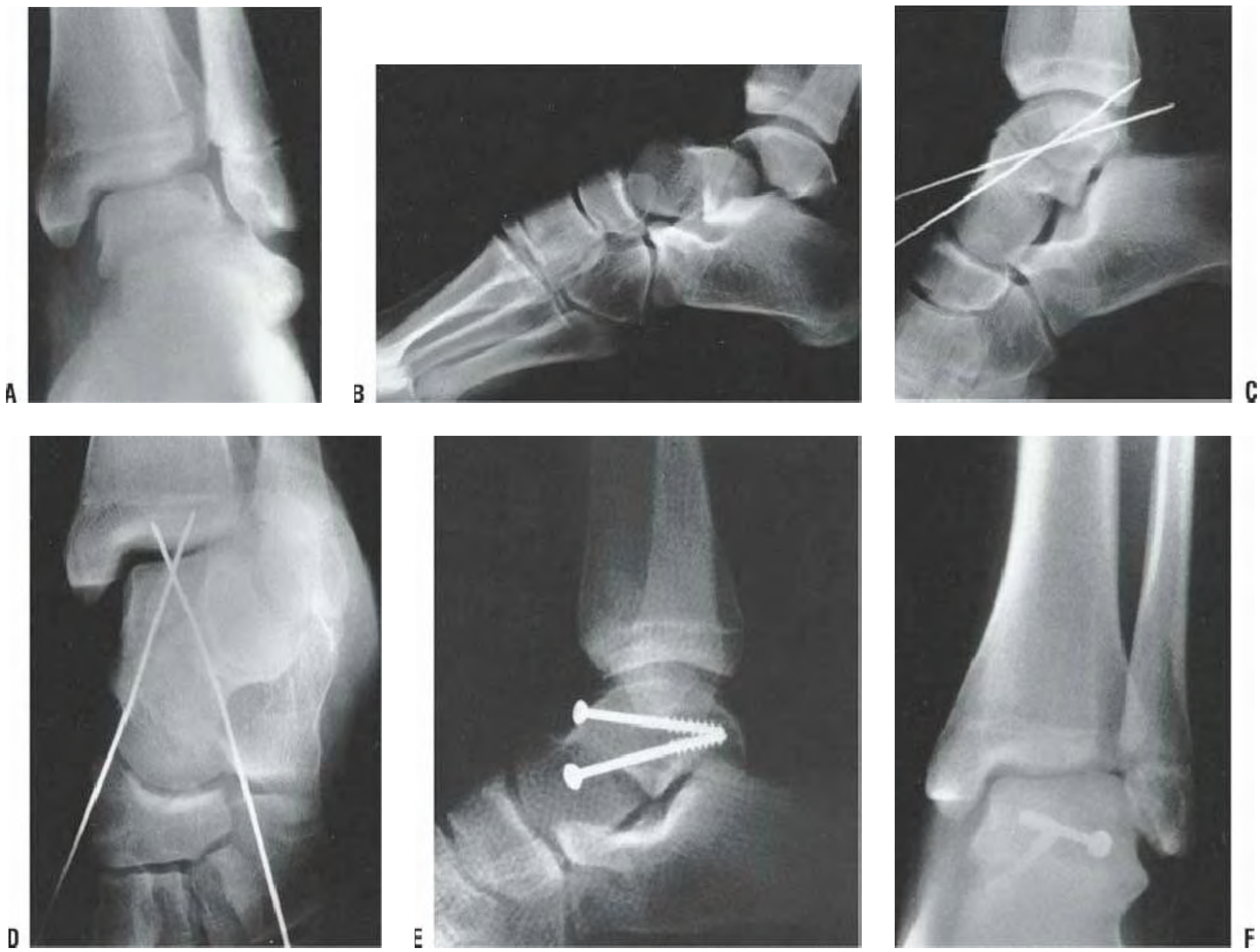


FIGURE 34-45. Talus fracture. **A:** Anteroposterior radiograph of the ankle of a 13-year-old gymnast who injured her foot during a dismount. It appears that the head and the neck of the talus are displaced laterally toward the fibula. **B:** The lateral projection shows a type III talus fracture with subluxation of the talonavicular joint. **C:** The intraoperative film shows provisional fixation with Kirschner wires. The fracture is reduced with plantar flexion of the foot. **D:** Another intraoperative anteroposterior view shows anatomical alignment of the talar neck with the body. The entry sites for the screws are in the nonarticular portion of the talar neck. **E:** The postoperative film shows cancellous screw placement. **F:** An anteroposterior radiograph shows restoration of the normal alignment of the ankle. Compared with the injury radiograph, there is no longer a prominence of the talar neck laterally.

Initial treatment after diagnosis is non–weight-bearing immobilization for 6 to 8 weeks. Many patients become asymptomatic in spite of persistent defects (270). Drilling and pinning, or removal of the loose fragment, is indicated if symptoms persist after a period of immobilization. This frequently can be accomplished arthroscopically.

Lateral Process Fracture Lateral process fractures of the talus may occur in a dorsiflexion inversion or twisting injury to the foot. These fractures are easily missed because the initial symptoms are similar to those of an ankle sprain (271). A high index of suspicion and good quality anteroposterior radiographs of the talus are required for diagnosis. More commonly, the patient presents with persistent symptoms after an "ankle sprain" (272). The diagnosis can be made with stress radiographs or CT scanning. Displaced fractures are often associated with other fractures.

Treatment consists of cast immobilization for nondisplaced injuries. When the patient presents late or an acute fracture is displaced, small fragments can be excised, but large fragments should be treated with reduction and internal fixation.

Calcaneus Fracture Fractures of the calcaneus may be extra-articular, sparing the subtalar joint, or intra-articular. Extra-articular fractures are more frequent in younger children (75% of cases), whereas intra-articular fractures account for most calcaneus fractures in adolescents and adults. Fracture of the calcaneus may be minimally displaced and can be easily overlooked in children. Delay in diagnosis occurs in 30% to 50% of cases (273–275). Swelling, pain, or localized tenderness after a fall should alert the clinician to the possibility of calcaneus fracture. Multiple radiographic views are recommended for diagnosis. However, CT scan has evolved as the best method for imaging calcaneal fractures, both for the assessment of displaced fractures and occasionally for the diagnosis of occult fractures.

Schmidt and Weiner (275) classified calcaneal fractures in children as extra-articular, intra-articular, or those with loss of the insertion of the Achilles tendon and significant soft-tissue injury (e.g., lawn mower injury). Intra-articular fractures in adults have been further classified by Sanders et al. (276) to help plan surgical management and predict outcome.

Treatment Nondisplaced and extra-articular fractures have good prognoses. Closed injuries are usually treated with 4 to 6 weeks of cast immobilization and progressive ambulation as tolerated. Displaced avulsion fracture of the tuberosity of the calcaneus is an extra-articular fracture that requires reduction (277). This may be accomplished by closed reduction using direct pressure over the Achilles insertion while the knee is flexed and the ankle is plantar-flexed to relax the posterior calf muscles. Open reduction with internal fixation is recommended if closed reduction is unsuccessful.

Long-term satisfactory results have been reported in younger children after nonsurgical management of intra-articular calcaneal fractures (278, 279). However, open reduction and internal fixation is recommended for most displaced intra-articular fractures (280). A series of 14 pediatric calcaneal fractures (7 tongue type and 7 joint-depression type) treated with open reduction and fixation reported good results, with complications in 3/14 children. The preferred approach is through a lateral, L-shaped incision, lifting the peroneal tendons within their sheath and protecting the sural nerve. The lateral wall of the calcaneus is folded down to reveal the medial side, allowing elevation of depressed central fragments. Internal fixation of the posterior facet is achieved by placing subchondral cancellous screws into the medial sustentaculum. The lateral wall is buttressed with an H-shaped or Y-shaped plate. Excessive comminution of the articular surface precludes this type of surgery (276). Long-term results in children are usually good.

Midfoot Fractures and Tarsometatarsal Injuries

Injuries to the tarsometatarsal joints and fractures of the cuboid or cuneiform bones are rare in children but can have long-term sequelae (281, 282). Fracture of the base of the second metatarsal is usually an indication of associated tarsometatarsal joint injury. These injuries are often misdiagnosed and may occur more commonly than recognized (283) (Fig. 34-46). The mechanism of injury may be direct impact but, more commonly, forced plantar flexion of the forefoot combined with a rotational force produces midfoot injuries (284). Heel-to-toe compression of the foot can also produce these injuries. Dislocations or displaced fractures require closed reduction. Percutaneous pinning and cast immobilization may be necessary to maintain reduction.

Fractures of the Metatarsals Metatarsal fractures are common in children, accounting for 5% to 7% of all pediatric fractures (1, 88). In younger children, the first metatarsal is most commonly fractured; in older children, it is the fifth metatarsal injured at the highest rate (285). The mechanism of injury-producing metatarsal fracture is usually direct trauma or crush to the foot. Associated swelling can be significant and may cause compartment syndrome.

Fractures of the base of the fifth metatarsal are usually avulsion injuries. These injuries can cause diagnostic confusion. A transverse fracture at the junction of the metaphysis and diaphysis is called a *Jones fracture*. This fracture has a high incidence of nonunion. An oblique avulsion fracture through the tuberosity of the fifth metatarsal may be confused with the normal secondary ossification center of the apophysis or avulsion of the apophysis. The apophysis does not extend into the joint. Stress fractures may also occur at this location. Prolonged casting is frequently required for fractures at the base of the fifth metatarsal, and healing should be verified before resumption of activities.

Nondisplaced and minimally displaced metatarsal fractures can be immobilized in a below-knee cast for 4 to 6 weeks, with weight bearing as tolerated. Most fractures of the fifth metatarsal in the pediatric population do well clinically after a course of walking cast, unless the fracture is an intra-articular displaced


A B

FIGURE 34-46. Tarsometatarsal joint injury. A file cabinet landed on the dorsum of this 4-year-old girl's foot. **A:** There is widening between the first and the second metatarsals, and a small fragment of bone is seen in the space. This suggests a partial incongruity, with lateral subluxation of the metatarsals. **B:** The contralateral foot shows a normal relation of the tarsometatarsal joint.

fracture type or the fracture occurs in the proximal diaphyseal area. Fixation of Jones fractures in active adolescents should be considered to allow faster return to regular activities and prevent refracture (286). Surgical treatment is indicated for open fractures, severely displaced fractures of the metatarsal heads, and displaced intra-articular fractures (Fig. 34-47). Kirschner wire fixation is usually adequate, but the pinning technique requires securing the metatarsophalangeal joint in a reduced position. If this is not done, extension contracture of the metatarsophalangeal joint can result in development of a prominent and painful metatarsal head. The wires are left in place for 3 to 4 weeks with non–weight-bearing immobilization, followed by weight bearing in a cast until union is complete.

Compartment syndrome of the foot should be considered when severe pain and swelling develop after injury. The diagnosis, particularly in young children, can be extremely


A B

FIGURE 34-47. Tarsometatarsal displacement. **A:** Anteroposterior projection of the foot of a 14-year-old boy who sustained a plantar flexion injury in a motor vehicle crash. There is complete dislocation of the first metatarsal–cuneiform joint and medial displacement. There are fractures of the second, third, and fourth metatarsal shafts. The ipsilateral tibial fracture was treated with intramedullary fixation. The swelling in the foot was attributed to the tibial shaft injury, and diagnosis of the foot injury was delayed. **B:** The postoperative anteroposterior radiograph demonstrates reduction and pinning of the fracture dislocation.

difficult. Many children without compartment syndrome develop considerable swelling after having their foot run over by a car or crushed by a heavy object. In equivocal cases, very close observation is helpful: in children without compartment syndrome, the swelling and pain improves with elevation over a few hours; when compartment syndrome is present, the pain worsens in the early postinjury period, despite elevation. If the child has severe swelling and worsening pain, the compartments should be measure. Fasciotomy is indicated if compartment syndrome is confirmed. Compartment syndrome of the foot can involve any of the nine compartments: medial, lateral, four interosseous, and three central (287). Fasciotomy is best performed through dual dorsal incisions centered over the second and fourth metatarsals. Blunt and sharp dissection is performed through each interspace to release all compartments. The dorsal approach can also be combined with a medial incision to release the medial compartment.

Fractures of the Phalanges A direct blow usually causes these common injuries. Fractures of the phalanges can be treated with closed management, such as buddy taping and use of a hard-soled shoe. The exception to this is an open fracture, which most often occurs to the proximal phalanx of the great toe and may require open debridement and stabilization with Kirschner wires. The physis of the great toe's proximal phalanx underlies the nail bed and may be injured in the same fashion as a nail bed avulsion of the hand (Seymour's fracture) (288). Antibiotics should be prescribed if there is concern about a communicating skin breach. Obvious contamination requires debridement.

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