

# Tibial Shaft Fractures in Children and Adolescents

Rakesh P. Mashru, MD,  
Martin J. Herman, MD, and  
Peter D. Pizzutillo, MD

Dr. Mashru is Trauma Fellow, Campbell Clinic, University of Tennessee College of Medicine, Memphis, TN. Dr. Herman is Assistant Professor, Orthopedics and Pediatrics, Orthopedic Center for Children, St. Christopher's Hospital for Children, Philadelphia, PA. Dr. Pizzutillo is Chief, Orthopedic Surgery Section, Director, Orthopedic Center for Children, and Professor, Pediatrics and Orthopedic Surgery, St. Christopher's Hospital for Children, Philadelphia.

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Reprint requests: Dr. Herman, Orthopedic Center for Children, St. Christopher's Hospital for Children, Erie Avenue at Front Street, Philadelphia, PA 19134.

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## Abstract

Tibial shaft fractures are among the most common pediatric injuries managed by orthopaedic surgeons. Treatment is individualized based on patient age, concomitant injuries, fracture pattern, associated soft-tissue and neurovascular injury, and surgeon experience. Closed reduction and casting is the mainstay of treatment for diaphyseal tibial fractures. Careful clinical and radiographic follow-up with remanipulation as necessary is effective for most patients. Surgical management options include external fixation, locked intramedullary nail fixation in the older adolescent with closed physis, Kirschner wire fixation, and flexible intramedullary nailing. Union of pediatric diaphyseal tibial fractures occurs in approximately 10 weeks; nonunion occurs in <2% of cases. Some clinicians consider sagittal deformity angulation >10° to be malunion and indicate that 10° of valgus and 5° of varus may not reliably remodel. Compartment syndromes associated with tibial shaft fractures occur less frequently in children and adolescents than in adults. Diagnosis may be difficult in a young child or one with altered mental status. Although the toddler fracture of the tibia is one of the most common in children younger than age 2 years, child abuse must be considered in the young child with an inconsistent history or with suspicious concomitant injuries.

Fractures of the tibial shaft are among the most common injuries in children and adolescents and account for approximately 15% of long-bone fractures in that population. Only femur and forearm fractures are more common.<sup>1</sup> The mechanism of injury varies from minor falls or twisting injuries in young children to sports-related trauma and motor vehicle accidents in older children and adolescents. Injury to the tibia is the second most common fracture resulting from intentional trauma.<sup>2</sup> Tibial shaft fractures are less commonly caused by nonac-

cidental trauma than are apophyseal ring or metaphyseal corner fractures. In the multiply traumatized child, fracture of the tibia is the third most common long-bone fracture, after fractures of the femur and humerus.<sup>3</sup> The average age at injury is 8 years, and this injury occurs more frequently in boys than in girls.<sup>1</sup>

Most tibial fractures in children are short oblique or transverse fractures of the middle or distal third of the shaft. Thirty-seven percent of tibial fractures are comminuted.<sup>1</sup> Fractures of the tibial shaft occur in association with fibular fractures in

**Table 1****Symptoms and Signs of Compartment Syndrome****Symptoms**

- Pain out of proportion to injuries
- Persistent pain following removal of constrictive dressings/splints
- Paresthesias in the injured extremity

**Signs**

- Swollen and tense compartment
- Pain on palpation of compartment
- Pain on passive stretch of muscles in the involved compartment
- Prolonged capillary refill and loss of palpable pulse (late finding)
- Increased pressure measurements (>30 mm Hg)

30% of affected children.<sup>1,4</sup> Both tibial and fibular fractures are commonly complete, displaced fractures caused by high-energy trauma. Valgus angulation of the distal fragment and shortening are caused by overpull of anterior and lateral compartment muscle groups. Tibial fractures with an intact fibula occur in 70% of affected children and usually are the result of torsional forces.<sup>4,5</sup> Although isolated tibial fractures are often minimally displaced at presentation, varus angulation without shortening often occurs in the first few weeks after injury as a result of posterior compartment muscular forces on the distal fragment. Concomitant plastic deformation of the fibula may cause valgus displacement and malrotation in some children.<sup>5</sup>

**Clinical Presentation**

Children and adolescents commonly present with pain, tenderness, or deformity of the lower leg after an acute injury. The young child may present with a limp, diminished movement of the affected limb, or refusal to bear weight (often without a distinct history of injury, in the case of a toddler fracture of the tibia). A complete clinical history is required, including a detailed descrip-

tion of an observed traumatic event to exclude the existence of other serious injury involving the remainder of the musculoskeletal system, head, thorax, abdomen, or pelvis. Chronic and recent illnesses as well as the use of regular medications should be noted. When no traumatic event is witnessed or an inconsistent history is provided, the physician must obtain a detailed social history, including a diary of the child's most recent caregivers and family contacts.

Primary assessment and cardiorespiratory stabilization is the first priority in the child or adolescent presenting with potential multisystem injury.<sup>6</sup> The surgeon may facilitate effective trauma resuscitation and diagnostic evaluation by realigning gross tibial deformity using gentle longitudinal traction and temporary splint immobilization.<sup>6</sup> A complete musculoskeletal survey may be completed once the child is stabilized. Thorough examination of the injured extremity includes assessment of the hip, knee, and ankle joints; concomitant soft-tissue injury; compartment tension; and neurovascular status. Frequent reevaluation of the injured limb is necessary in the unconscious or uncooperative patient; signs and symptoms of compartment syndrome should be documented after each evaluation (Table 1).

**Radiographic Assessment**

Anteroposterior (AP) and lateral radiographs of the tibia and fibula, including the knee and ankle, are required to assess lower leg injuries. Especially in patients with low-energy injuries, careful assessment of the fracture configuration is necessary to make certain that there are no missing areas of bone suggesting a pathologic origin. Technetium bone scanning is helpful in the diagnosis of occult fractures or stress reactions when radiographs of the lower leg are

normal. A large percentage of toddler fractures are radiographically normal, and it is often prudent for the clinician to empirically immobilize these children and follow up with weekly serial radiographic examinations. When neoplasm is suspected, magnetic resonance imaging provides more comprehensive assessment of pathologic fractures of the tibia and surrounding soft tissues.

**Treatment**

Closed reduction with cast immobilization is the mainstay of orthopaedic management of diaphyseal tibial shaft fractures in children and adolescents. Nondisplaced fractures of the tibia without significant soft-tissue injury or swelling should be immobilized in a long leg cast for 4 to 6 weeks, followed by progressive weight bearing in a short leg cast (with a patellar tendon-bearing modification for fractures of the proximal shaft) for an additional 4 to 6 weeks. The toddler fracture of the tibia requires only 4 weeks of immobilization. Patient activity is allowed when the fracture site is not tender to palpation and follow-up radiographs document healing.

Closed manipulation and casting under conscious sedation or general anesthesia is indicated for displaced tibial fractures. A short leg cast is applied first to control the fracture reduction. The ankle is positioned in gentle plantar flexion to prevent apex posterior angulation of the fracture. This technique is most helpful in fractures involving the most distal third of the tibial shaft. After the short leg portion is set, the cast is extended to the groin with the knee flexed 30° to 60°. During cast application, the surgeon should carefully mold about the tibial fracture site, avoiding pressure over the fibular head and soft-tissue compartments. Molding to the supracondylar anatomy of the distal femur helps control rotation within the cast and enhances control of fracture align-

ment. Immediate bivalving of the cast is indicated in the uncooperative or obtunded child, or in one with soft-tissue swelling. Once the cast is bivalved, the child must be monitored for continued swelling or changes in neurovascular status. After reduction and casting, the patient is observed for compartment syndrome.

AP and lateral radiographs of the lower leg, including the knee and ankle joints, should be obtained immediately after reduction to verify alignment (Fig. 1). Acceptable parameters of reduction are up to 5° of varus or valgus angulation, <5° of sagittal angulation, and 1 cm of shortening. Translation of the entire shaft may be tolerated in a child younger than 8 years; 50% translation is acceptable in older children and adolescents. Up to 10° of varus and 10° of sagittal deformity are acceptable in children younger than age 8 years. Maintenance of reduction is monitored for 3 weeks with weekly radiographs of the lower leg. Wedging of the cast or repeat manipulation of the fracture with recasting can improve angulation within 3 weeks of injury, often without the need for sedation or anesthesia.

Wedging of the cast can be performed by either an opening or closing wedge technique. In a closing wedge technique, a 1- to 2-cm wedge of cast material is removed from the same side of the leg as the apex of the fracture. The wedge is then closed, correcting fracture angulation. Because this technique may cause the fracture to shorten or the skin to impinge in the wedge, close clinical and radiographic observation is required. In an opening wedge technique, small blocks of varying sizes may be inserted into the cast. The cast is cut perpendicular to the axis of the tibia on the side opposite the apex of the fracture. Once the appropriate size blocks are chosen, fracture reduction should be examined radiographically.

Closed tibial osteoclasis or open

**Figure 1**



**A**, Anteroposterior initial injury radiograph demonstrating marked displacement with valgus angulation and shortening in a 16-year-old boy with a tibial and fibular shaft fracture. **B**, Anteroposterior radiograph demonstrating acceptable alignment after application of a long leg cast.

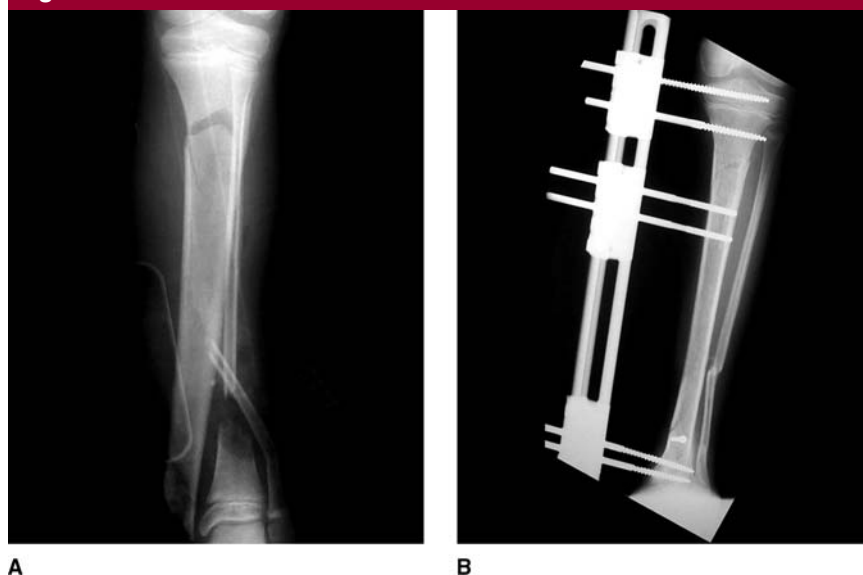
reduction of the tibia, with or without fibular osteotomy, may be performed in the operating room under anesthesia to realign more rigid malreduced fractures. Excessive shortening requires alternative techniques, such as external fixation or intramedullary rodding, to reestablish and maintain tibial length. Cast management for displaced fractures of the tibia is similar to that for nondisplaced fractures. Tibial fractures requiring repeated manipulation or open reduction, or fractures that are severely comminuted, should be immobilized for longer periods to achieve clinical and radiographic healing.

External fixation is most commonly used to stabilize severely comminuted and unstable tibial fractures and those associated with severe soft-tissue injury<sup>7-11</sup> (Fig. 2). Because of its ease of application and adjustability, external fixation is an excellent option for stabilizing tibial fractures in children with head or multisystem injuries. It also offers improved access to and nursing care

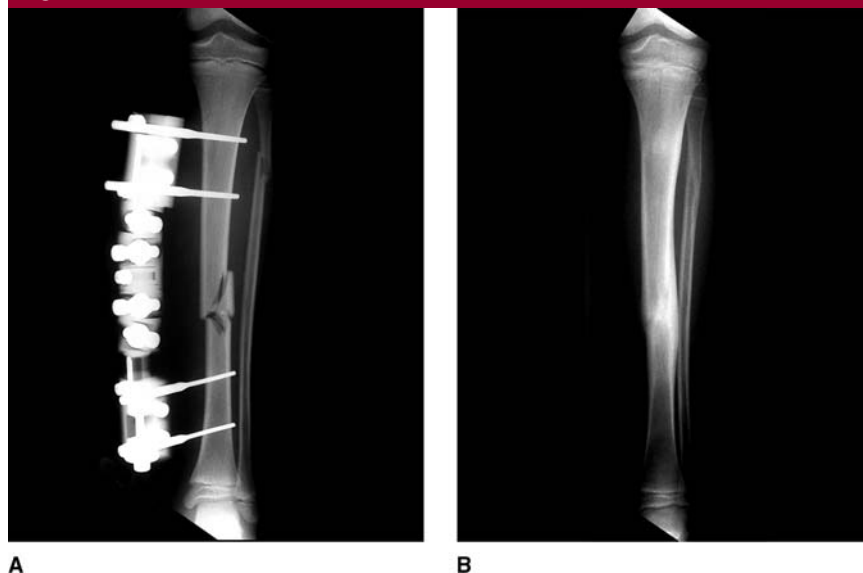
of the lower leg compartments.<sup>12</sup> Management of these injuries in a closed fashion with a long leg cast requires very close observation. Simple anteromedial frames using two half-pins above and below the tibial fracture site provide adequate stability (Fig. 3). Surgeons may wish to augment external fixation with minimal internal fixation, as per their preference case by case. Early weight bearing (within 4 weeks) and judicious dynamization of the external fixator may hasten healing.

Once clinical and radiographic healing is complete, the external fixation frame may be removed in the clinic or the operating room. Early removal of the frame and conversion to a cast within 4 to 6 weeks may be necessary in younger children or in patients unable to tolerate the frame or appropriately care for it. Pin tract infection and refracture of the tibia after frame removal are the most common complications in these patients.<sup>11</sup>

Although intramedullary fixation is the treatment of choice for adults

**Figure 2**

**A**, Anteroposterior radiograph of an open segmental grade IIIIC (Gustilo-Anderson classification) tibial fracture in a child who was hit by a car. **B**, Along with vascular repair, the patient was treated with an external fixator to allow minimal fixation and access to soft tissues.

**Figure 3**

**A**, Immediate postoperative anteroposterior radiograph of comminuted unstable tibial and fibular shaft fractures in acceptable alignment with external fixation in a 12-year-old child with a closed head injury. **B**, Anteroposterior radiograph taken 6 months after injury, demonstrating a healed fracture.

with fractures of the tibial shaft, its use in children and adolescents has been limited.<sup>13</sup> Rigid, interlocked

nails introduced through the proximal metaphysis of the tibia can cause inadvertent injury to the phy-

sis or the anterior tibial tubercle. The risk of growth disturbance of the proximal tibia, manifested as limb-length discrepancy and recurvatum of the proximal tibia, precludes the use of rigid, interlocked nails in children.

Flexible intramedullary rod fixation is gaining in popularity for management of stable tibial fractures in children and growing adolescents. Intramedullary Kirschner wires are effective for maintaining alignment and length in stable fractures of the tibia in the absence of severe comminution or fracture obliquity.<sup>14</sup> Unstable fractures with comminution may require supplemental use of a cast to hold the reduction. Elastic titanium nails, commonly used in the forearm and femur, also can provide stable fixation for unstable tibial shaft fractures.<sup>15</sup> The elastic nails are introduced through small drill holes in the proximal or distal tibial metaphyses (Fig. 4). The flexible, elastic nails are cut outside the bone beneath the skin, thereby eliminating the need for pin care. Access to the soft tissues of the leg for examination, débridement, or reconstruction thus is unimpeded.

For fractures that are rotationally unstable, a period of splint or cast immobilization is required when using constructs that do not impart rotational control. Such immobilization also functions as added protection for fractures in young or non-compliant children. Range of motion of the knee and ankle joints may be initiated immediately after fixation, and protected weight bearing on the involved limb is progressed within 2 to 3 weeks postoperatively. The flexible nails are removed in the operating room according to surgeon preference, usually within 4 to 6 months of injury.

Other fixation options include percutaneous pin fixation and plate-screw constructs.<sup>15</sup> In younger children with noncomminuted, unstable oblique fractures, closed manipulation of the fracture with percutane-

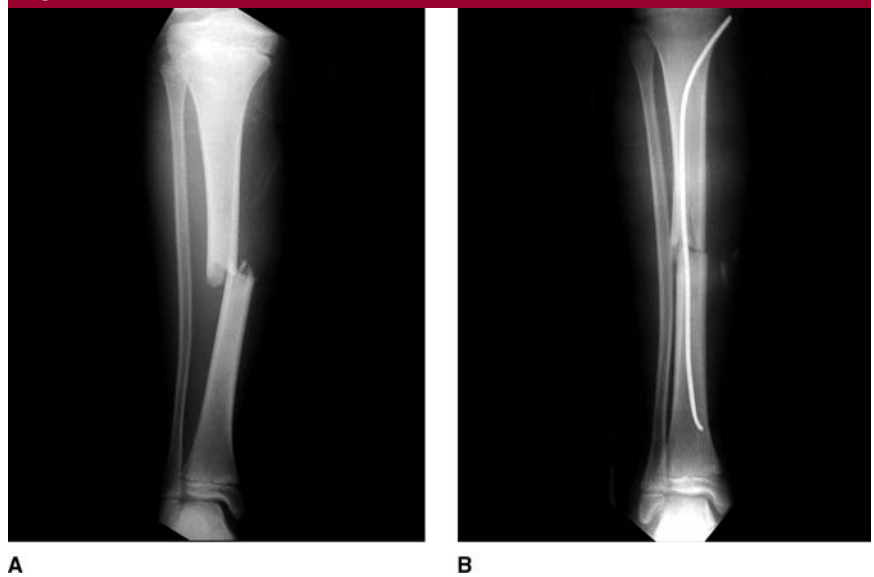
ous pin fixation under fluoroscopic guidance provides sufficient stability to maintain reduction in a cast. However, this option can introduce the possibility for infection in an otherwise closed injury. This technique also is useful in conjunction with débridement of open tibial shaft fractures.<sup>15</sup> Standard open reduction and plate fixation, which requires a large exposure with soft-tissue stripping, usually is not indicated in children.

### Open Fractures of the Tibia

To diminish the risk of infection and enhance healing, urgent stabilization and aggressive débridement of contaminated and devitalized soft tissue and bone should be done within 8 hours of injury. Repeated débridement is performed as necessary. Guidelines for antibiotic coverage and tetanus prophylaxis are the same as those for adults with open fractures.<sup>7-10,15-17</sup> Prolonged delay in wound closure or coverage decreases the chance for a successful outcome. Although small, clean wounds may be closed primarily over a drain, delayed primary closure and vacuum-assisted closure are preferred for managing larger or contaminated wounds.<sup>18</sup> Skin grafting, rotational flaps, or free tissue transfers are necessary for coverage of extensive soft-tissue defects.<sup>19-21</sup>

Vascular injuries are uncommon in open tibial shaft fractures in children and adolescents. Unlike those in adults, grade IIIC injuries in the pediatric population rarely require amputation. Fractures of the proximal tibial metaphysis are most commonly associated with vascular injuries, most notably disruption of the anterior tibial artery. Injuries involving the posterior tibial and popliteal arteries have a poorer prognosis than those involving the anterior tibial and peroneal arteries.<sup>22</sup> Stabilization of the fracture before revascularization prevents later dis-

**Figure 4**



**A**, Anteroposterior radiograph of a transverse tibial diaphyseal fracture in an 11-year-old child. **B**, Postoperative anteroposterior radiograph demonstrating acceptable reduction and alignment after stabilization with an elastic intramedullary nail.

ruption of the repair.<sup>23</sup> In limbs with prolonged ischemia, temporary arterial and venous shunting may be necessary before bone stabilization. To diminish the risk of compartment syndrome, four-compartment fasciotomy is recommended after restoration of blood flow.<sup>24</sup>

### Complications

#### Compartment Syndrome

Multiple studies have shown that the incidence of compartment syndrome in adults with open tibial fractures ranges from 6% to 9%.<sup>17,24,25</sup> By comparison, acute compartment syndromes occur less frequently in children and adolescents with tibial shaft fractures, with most of them developing in adolescents.<sup>26</sup> Prolonged periods of elevated intracompartmental pressure (>30 mm Hg) may cause irreversible damage to muscle and nerves. Serial physical examinations, measurement of compartment pressures, and a high index of suspicion are necessary for early diagnosis of compartment syndrome. Fasciotomy of the

involved compartments of the lower leg improves outcome. With timely diagnosis and decompression of intracompartmental pressures, most children and adolescents have no long-term sequelae.<sup>26</sup> Failure to recognize and aggressively treat compartment syndromes in children and adolescents may result in severe permanent disability and limb amputation.

#### Delayed Union or Nonunion

With appropriate treatment, union of closed tibial shaft fractures usually occurs within 8 to 12 weeks after injury. Delayed union or nonunion has been observed in nearly 25% of immature patients with open tibial shaft fractures.<sup>27</sup> The risk of delayed union rises with increasing age and increasing severity of the open wound.<sup>28,29</sup> Concurrent wound infection and instability at the fracture site may contribute to the development of delayed union. Elevated erythrocyte sedimentation rate and C-reactive protein level suggest infection of the fracture site.



Progressive angulation of the fracture, minimal callus formation, and radiographic lucency about fixator pin sites indicate fracture site instability. Radiographic evaluation, including computed tomography scans of the fracture site, is useful to assess progression of healing. As in the adult population, protected weight bearing on the involved limb may enhance healing of delayed union in children. Despite anecdotal reports, no published data indicate that bone stimulators have been successful in treating tibial nonunion in children and adolescents. Excision of atrophic callus as well as iliac crest bone grafting, fibular osteotomy, and cast immobilization or revision of fixation may be required in patients for whom non-surgical treatment is ineffective. The Ilizarov fixator also has been reported to be useful in the management of these complications,<sup>28</sup> especially for fractures with segmental defects. The Ilizarov frame may be used with distraction histogenesis techniques to manage complicated defects and restore leg length. In addition, appropriate antibiotic treatment is necessary for patients with concomitant fracture sepsis.

### Malunion

Remodeling of angular deformity of the tibial shaft is relatively reliable in children younger than age 8 years. Ten degrees of coronal or sagittal plane angulation will remodel predictably in children aged 8 years and younger.<sup>2</sup> After age 12 years, angular deformity of the tibial shaft usually improves <25%. Single plane deformities, apex anterior angulation, and varus alignment are more likely to remodel than complex deformity, apex posterior angulation, and valgus alignment.<sup>1</sup> Most remodeling occurs in the first 2 years after injury. Although correcting single-plane deformity is controversial, residual limb malalignment may be clinically significant and result in pain and premature symptomatology of the ankle and knee joints. In symptomatic chil-

dren or those at risk for premature joint degeneration, corrective osteotomy of the tibia and fibula is indicated to restore the normal mechanical axis of the limb.

Rotational malunion does not remodel with growth. Malrotation beyond 10° may result in functional impairment or unacceptable cosmesis. Distal derotational osteotomy of the tibia and fibula is indicated for children with rotational malunion who experience gait disturbance or abnormal limb appearance.

### Growth Disturbance

Accelerated longitudinal growth of the femur is expected in the young child who sustains a fracture of the femoral shaft, but it is not consistently observed after tibial shaft fracture. In children, overgrowth usually does not exceed 5 mm after healing of a tibial shaft fracture.<sup>1</sup> Fractures in children younger than age 10 years and those with comminution are at greatest risk of overgrowth. Mild growth inhibition may be seen after tibial shaft fractures in children age 8 years and older. Growth disturbance of the proximal tibial physis, resulting in recurvatum deformity of the proximal tibia, may occur after injury of the tibial shaft.<sup>30</sup> The most likely explanations for this phenomenon are unrecognized injuries of the proximal tibial physis or the anterior tibial tubercle at the time of the original trauma, or iatrogenic injury from traction pin or fixator screw placement.

## Related Clinical Entities

### Child Abuse

Tibial shaft fractures are rarely found in abused children. The diagnosis of child abuse must be considered when tibial fractures are discovered in the nonambulatory child, the clinical history is inconsistent with the injury, and other physical findings are suggestive of abuse. A complete investigation for suspected abuse includes a thorough physical examina-

tion, skeletal survey, and evaluation by social services personnel.

### Toddler Fracture

Toddler fractures of the tibia, which are caused by low-energy twists and falls, are minimally displaced short spiral or oblique fractures without fracture of the fibula.<sup>31</sup> The onset of limping after a minor event, or without an obvious injury in a young ambulatory child, warrants a detailed search for local tenderness of the tibia with radiographic evaluation to rule out a toddler fracture. However, these injuries may be radiographically silent. As a result, prolonged immobilization in a long leg cast may not be necessary for such injuries. These fractures rarely displace, and healing is often complete after 4 weeks of cast immobilization. Radiographs taken at the fourth week after injury often reveal periosteal reaction indicative of fracture healing.

### Insufficiency Fracture

Insufficiency fractures of the tibia occur in the nonambulatory child with neuromuscular disease, such as spastic quadriplegia or spina bifida. These fractures are caused by unrecognized or minor trauma. Limb swelling and hyperemia may be confused with osteomyelitis or cellulitis. Children with osteogenesis imperfecta commonly sustain fractures of the tibial shaft as a result of diminished bone density and progressive bowing deformity. It is important to attempt to align these fractures anatomically, if possible, to avoid the possibility of deformity. Two to 4 weeks of cast immobilization followed by weight bearing in a long leg brace or ankle-foot orthosis will promote healing of the injured tibia and prevent worsening osteopenia from disuse. Children with osteogenesis imperfecta and multiple tibial fractures with deformity may benefit from realignment osteotomy of the tibia and intramedullary rod fixation.<sup>32-34</sup>

## Floating Knee

A tibial shaft fracture that occurs with an ipsilateral femur fracture (ie, floating knee) is uncommon in children. Multiple treatment combinations, including cast immobilization of both fractures, femoral traction and tibial casting, and fixation of one fracture with cast immobilization of the other fracture may be used successfully.<sup>35</sup> However, stable fixation of both long-bone fractures allows early range of motion of the knee and earlier weight bearing, and it improves outcomes in children aged 7 and 8 years.<sup>35</sup>

## Stress Fracture

Stress fractures of the tibia usually involve the proximal third of the tibia. They occur in active children older than age 10 years with a history of insidious onset of pain that worsens with activity, but with no history of trauma.<sup>36</sup> The patient may report a change in exercise pattern related to sports training. AP, lateral, and oblique radiographic views reveal localized periosteal reaction or endosteal thickening of the involved area. Technetium bone scanning is useful to confirm the diagnosis. Most children and adolescents with stress fractures of the tibia improve after a short period of immobilization or limited weight bearing followed by gradual reintroduction of impact activities. External bone fixation and iliac crest bone grafting may be used for managing stress fracture nonunions.

## Summary

Treating a child or adolescent with a tibial shaft fracture may be challenging for the orthopaedic surgeon. Although there are some similarities between adult and pediatric fractures, the treatment algorithm differs. Each patient must be given individualized care based on the clinical presentation. Age is one of the differentiating criteria used in the management of these injuries.

The great majority of children are best treated with closed reduction and a long leg cast. Close follow-up with repeat radiographs increases the likelihood of a successful outcome. External fixation is reserved for patients with unstable or comminuted fracture patterns and those with soft-tissue compromise. Modalities such as intramedullary fixation should be reserved for cases that specifically warrant them.

Although most tibial fractures ultimately end in uncomplicated outcomes, possible complications include compartment syndrome, nonunion or malunion, and growth disturbance. Urgent fasciotomies for compartment syndrome must be performed to relieve pressure inside the myofascial compartments to prevent muscle necrosis. As in the adult, secondary closure and soft-tissue reconstruction procedures are used to cover any defect in the lower limbs. Although not always pathognomonic for child abuse, the surgeon must be cognizant of the possibility of intentional trauma with a tibial shaft fracture. The appropriate social services should become involved when the clinical scenario warrants. Toddler fractures of the tibia should be included in the differential diagnosis of an ambulatory child who refuses to bear weight. With proper initial care and prevention of complications, a good outcome can be expected in most children and adolescents with tibial shaft fracture.

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