Pediatric tibia fractures account for 13% of pediatric fractures and 12% of surgical interventions in an urban pediatric orthopaedic setting. Nationally, 21.5% of orthopaedic trauma consists of tibia and fibula fractures in combination and individually. Although tibial fractures are common injuries, most can be treated without surgical intervention. When surgery is indicated, a variety of fixation options is available based on the age of the child, the location and pattern of the fracture, and the status of the soft tissues. Complications associated with the treatment may ensue in fractures that require surgery. This chapter discusses complications from the treatment of tibial eminence and tibial shaft fractures.

**Abstract**

Fractures of the tibial eminence and the diaphyseal tibia are common pediatric orthopaedic injuries. Although most tibial fractures can be treated nonsurgically, those that require surgical intervention may encounter specific complications. Surgical treatment of fractures of the tibial eminence may be complicated by failed fixation, knee joint stiffness, and arthrofibrosis of the knee, a complication rarely seen in children but occurring most frequently after tibial eminence injuries. Complications of healing after tibial fractures in pediatric patients are uncommon, although some tibial shaft fractures exhibit delayed union or nonunion, infection, and soft-tissue complications.

**Tibial Eminence Fractures**

Tibial eminence fractures, also known as tibial spine fractures, are relatively uncommon fractures of the tibia compared with distal physeal fractures and diaphyseal fractures. These injuries typically occur in older children and adolescents, aged 8 to 14 years, although they have been seen in the younger age group. The mechanism of injury is often twisting from noncontact sports, during which the knee is hyperextended or forcefully rotated while the knee is flexed. Other mechanisms include falls from bicycles and, uncommonly, high-energy injuries such as when pedestrians are struck by motor vehicles. This injury is often referred to as the child’s equivalent of an anterior cruciate ligament (ACL) tear because the mechanism of injury is similar to that which causes ACL tears—injuries that are less common in children compared with adolescents and adults. The tibial eminence is a nonarticular portion of the proximal tibial surface and serves as the insertion site for the ACL. As
force is applied to the knee, the ACL experiences tension forces that stretch the ligament. As the force application continues, the ligament-bone interface fails, creating an avulsion fracture of the tibial eminence, leaving the ligament elongated but attached to the fracture fragment.\textsuperscript{3,4}

Patient Evaluation
Patients with tibial eminence fractures present with the chief complaint of knee pain and swelling after an acute injury. Most of these fractures occur as isolated injuries. For patients who report high-energy mechanisms, however, an assessment of the patient’s airway status and cardiovascular status, as well as a thorough evaluation for associated injuries, must be performed before the orthopaedic examination. The physical examination typically reveals a large hemarthrosis, and the knee is held in a position of slight flexion. Passive knee range of motion is limited and painful.\textsuperscript{3,4} Ligament stress testing is often not useful because of involuntary muscle guarding and is painful to the patient, making it less likely that he or she will cooperate with the examination. The neurovascular status of the extremity is typically normal.

Imaging
High-quality AP and lateral views of the knee are essential for diagnosis. If the mechanism of injury or results of the examination are suggestive of other sites of injury, orthogonal views of both the entire femur and tibia are obtained as well. Hip pain is often not well localized in children. Special consideration should be made to obtain radiographs of the “joint above and joint below,” in this case, the hip. This is particularly important when an evaluation of the knee is benign or if the patient is insensate or unable to verbalize a complaint because of an underlying diagnosis. At the institution of this chapter’s authors, if the radiographs are not diagnostic, CT is used to fully assess the fracture pattern. MRI is another advanced imaging modality that is useful for assessing these injuries. MRI not only serves to delineate the fracture fragment but also allows the surgeon to identify associated meniscal entrapment or tears, other ligament injuries, and osteochondral fractures.

Classification
The Meyers and McKeever\textsuperscript{3} classification is most commonly used to describe tibial eminence fractures. A type 1 injury is a minimally displaced fracture of the tibial eminence. A type 2 lesion is one that is displaced anteriorly but has an intact posterior hinge. A type 3 fracture is one in which the fracture fragment is completely displaced from its fracture bed. Zaricznyj\textsuperscript{4} added a type 4 lesion to the Meyers and McKeever classification to describe a fracture that has complete displacement and has rotated out of the fracture bed. The fracture fragment may be a single piece or comminuted.

Treatment

Nonsurgical
All type 1 fractures are treated with long leg cast immobilization. Although the ideal knee position has been debated, casting in slight flexion theoretically places the ACL under the least tension and is the preferred position to minimize the risk of displacement. An attempt should be made to reduce all type 2 fractures before considering surgery. After aspiration of the hemarthrosis and injection of intra-articular lidocaine, the knee is brought into full extension, or just slightly less than full extension, and a cast applied. Superior displacement measuring less than 3 mm on the lateral view of the knee is acceptable.\textsuperscript{3} Following cast application, patients are placed on crutches for non–weight-bearing ambulation for 4 to 6 weeks. After casting, a hinged knee brace is often prescribed, and rehabilitation is initiated. Historically, long leg casting was the primary form of treatment; however, there is a trend toward aggressively treating type 2 fractures initially with surgical reduction and fixation.

Surgical
Type 2 fractures that fail an attempt at closed treatment and all type 3 and 4 fractures are best treated with surgical reduction and fixation. Fracture reduction and fixation may be accomplished either through a parapatellar knee arthrotomy or with arthroscopic techniques. Regardless of the choice of procedure, the surgeon must be able to remove hematomata and fracture debris and directly inspect the fracture bed for impediments to reduction. An interposed meniscus has been identified in as many as 26% of type 2 fractures and in up to 65% of type 3 fractures; it is typically the medial meniscus. Other blocks to reduction include rotated fracture fragments and the intermeniscal ligament.\textsuperscript{6} Fixation options include suture fixation, cannulated screws, and a combination of screws with sutures (Figure 1). Sutures are typically placed through two parallel drill holes made in the anterior metaphysis and into the fracture bed, weaved through the fragment, and then tied over the front of the tibia after fracture reduction. The advantages of suture fixation...
are absence of prominent hardware, minimal risk of damage to the growing physis because of the small bone tunnels required, and the ability to gain superior fixation in comminuted fractures. A further advantage of suture fixation is that it also allows the surgeon to incorporate the ACL into the fixation. However, a substantial learning curve exists with the suture fixation technique when performed arthroscopically. Currently, evidence does not exist that the arthroscopic approach is superior to an open arthrotomy. Antegrade cannulated screw fixation, placed just short of the physis in the epiphysis, is a less demanding and more familiar technique of fracture fixation. When placed arthroscopically, screw fixation may require the creation of an auxiliary portal away from the standard medial and lateral sites; this is because of the angle needed for guidewire placement to enable the screws to be perpendicular to the fracture. In a cadaver model, pullout strength is stronger for suture fixation compared with screw fixation. Yet ACL strength testing showed that tibial translation was less when screws were used to fix tibial eminence fractures compared with sutures. It is the opinion of this chapter’s authors that the surgical approach and choice of fixation yield similar results as long as the impediments to reduction are removed and an anatomic stable reduction is achieved.

Outcomes
After fixation, patients are immobilized for 2 to 4 weeks, after which range of motion is initiated, typically in a hinged knee brace. There is a growing trend toward obtaining early stable fixation to allow for the immediate start of range of motion and decrease the morbidity associated with arthrofibrosis. Patel et al described criteria for return to play that included radiographic evidence of healing, no laxity or mechanical symptoms, no evidence of grade 2 or higher laxity on Lachmann testing, full range of motion, and motor strength equal to that of the uninjured leg. Most patients have an uncomplicated return to activity within 3 to 4 months after treatment of a tibial eminence fracture.

Complications
Fixation Problems
Loss of fixation and prominence of hardware are problems associated with less-than-satisfactory outcomes. In general, higher reoperation rates have been reported after screw fixation compared with suture fixation (Figure 2). Reoperation is indicated for two important reasons related to hardware failure. First, loss of fixation may result in loss of reduction or fracture nonunion. Residual anterior displacement of the fragment can lead to loss of full extension and pain because of impaction of the fragment with the notch cartilage. Nonunion, in addition to potentially causing loss of reduction and pain, may also present with signs and symptoms of ACL deficiency (Figure 3). Second, prominent hardware or screw pullout may result in pain associated with loss of extension from metal contact in the notch and chondral injury because of contact with the cartilage joint surface of the distal femur. With fixation loss, the fragment can become more comminuted as well as pull away from its reduced location. With that in mind, screw fixation plus a washer has the added benefit of placing compressive forces on the fracture fragment across a greater surface area.

Fixation complications are potentially preventable. For most fractures, screw fixation is ideally limited to one...
or two screws that measure no more than 4.0 mm in diameter. Countersinking the screw heads into the ACL footprint is the easiest strategy to prevent hardware prominence. Another solution is the use of headless or bioabsorbable screws. Comminuted fractures are best treated with suture fixation or a combination of screw and suture fixation. Screw fixation is more likely to worsen comminution and lose purchase of the fragments as compression occurs. However, the suture technique allows the surgeon to not only fixate the fracture fragment but also weave the suture

Figure 2  AP (A) and lateral (B) radiographs of an 11-year-old boy with type 2 tibial eminence fracture after a fall from his bike. C, Lateral radiograph after reduction and placement in a long leg cast in extension. Note the remaining anterior displacement of the fracture. D, Lateral radiograph 5 days after injury. The patient underwent arthroscopically assisted cannulated screw fixation. E, Lateral postoperative radiograph demonstrating that, during the index procedure, the Kirschner wire broke in the cannulated screw and was retained. Six weeks following the procedure, the patient had pain and decreased range of motion. F, Lateral postoperative radiograph demonstrating that, at 4 months from his index procedure, the patient underwent revision of the fixation to a single cannulated screw, which resolved his pain and improved his range of motion.
Complications of Tibial Eminence and Diaphyseal Fractures in Children

Knee Stiffness

Diminished range of motion is identified in 60% of patients who are treated for tibial eminence fractures and is seen in both surgical and nonsurgical patients. The most common loss of motion is inability to achieve the last 5° to 10° of terminal extension. Loss of extension may occur for several reasons; the most common are residual superior displacement of the fragment from inadequate reduction or comminution and hardware prominence. The most important risk factors for significant knee stiffness include the presence of a type 3 fracture, reoperation for fixation problems or healing complications, and prolonged immobilization. Although most patients have no functional deficits from loss of motion following these fractures, function in some patients is severely limited and intervention is required.

Malunion with anterior displacement that limits extension is uncommon and may be salvaged with débridement, notchplasty, and revision or removal of fixation if hardware prominence is a contributing factor. Nonunion is rare, especially when this injury is treated surgically. Nonunion that is painful or that results in loss of motion from anterior displacement may be treated with bone grafting and fixation revision or fragment and ACL débridement with bone grafting and fixation if hardware prominence is a contributing factor.

Knee Stiffness

Knee stiffness is a subjective problem for patients; most report minimal or no signs or symptoms of ACL deficiency in their daily lives. Symptoms of ACL laxity, when present, are more prevalent in nonsurgically treated patients versus those surgically treated. If ACL laxity or insufficiency is clinically significant and cannot be managed with conservative means such as rehabilitation and functional bracing, then it is best treated with débridement of the attenuated ACL and ligament reconstruction.  

ACL Laxity

After healing of tibial eminence fractures, as many as 74% of patients show evidence on KT-1000 testing of ACL laxity of the injured side compared with the opposite, normal side. Although this ACL instability is present objectively, it is rarely a subjective problem for patients; most report minimal or no signs or symptoms of ACL deficiency in their daily lives. Symptoms of ACL laxity, when present, are more prevalent in nonsurgically treated patients versus those surgically treated. If ACL laxity or insufficiency is clinically significant and cannot be managed with conservative means such as rehabilitation and functional bracing, then it is best treated with débridement of the attenuated ACL and ligament reconstruction.  

Arthrofibrosis

In a small percentage of patients with tibial eminence fractures, severe knee stiffness develops in both flexion and extension, and a diagnosis of arthrofibrosis is made. Arthrofibrosis is intra-articular scar tissue formation and is rarely seen in children. The exact etiology is unknown, but proposed causes include a genetic predisposition to scar formation, an aberrant inflammatory response to an injury or surgery, or simply prolonged joint immobilization. Arthrofibrosis is seen most commonly in children after treatment of tibial eminence fractures. Patel et al retrospectively reviewed 40 patients with tibial eminence fractures and concluded that those who started range-of-motion exercises more than 4 weeks after injury required more time to return to full activity and were 12 times more likely to develop arthrofibrosis. In this study, arthrofibrosis was defined as a 10° flexion contracture or a flexion loss of 25° at least 3 months postinjury and after completing a formal physical therapy regimen. Although not used at the institution of this chapter’s authors, the use of a continuous passive motion device after the initial postoperative period may show added benefit in gaining additional degrees of motion.

Tibial Shaft Fractures

Tibial shaft fractures occur in children of any age and result from an array of injury mechanisms, such as a fall from standing height, sports activities, and high-energy mechanisms such as motor vehicle crashes. For younger children in particular, the surgeon also must be alert to the possibility of nonaccidental injury as the cause of a tibial fracture, that is, child abuse. One-third of all tibial shaft fractures are open, and 2% will lead to compartment syndrome. Similar to other pediatric fractures, most tibial shaft fractures can be treated in a closed fashion if the soft tissues allow and the cast treatment maintains acceptable alignment. Tibial fractures that are notably displaced, associated
with severe soft-tissue damage, or open represent a small group but present the greatest challenges to the surgeon because of the potential complications. This chapter focuses on the most common and important complications, including infections after open fractures, healing complications such as delayed union and nonunion, and compartment syndrome.

**Patient Evaluation**

Most patients with tibial fractures present with pain after an acute injury, swelling, inability to bear weight on the affected limb, and deformity when the fracture is displaced. For patients with injuries caused by high-energy mechanisms, evaluation by the trauma team, cardiovascular assessment, and stabilization are first performed. During the assessment, the limb ideally is grossly realigned, if necessary, and splinted. The orthopaedic examination includes assessment of the entire limb, including hip, knee, and ankle range of motion; a careful inspection of the soft tissues for compartment swelling, lacerations, and abrasions; and a complete neurovascular examination. When child abuse is suspected, a complete physical examination by the Child Protection Team and a social services evaluation are performed in the emergency department.

**Imaging**

High-quality AP and lateral radiographs of the tibia are essential for adequate fracture evaluation. Dedicated radiographs of the femur, knee, ankle, and foot are ordered based on the physical examination. Advanced imaging, such as CT or MRI, is uncommonly indicated. CT is sometimes considered to fully evaluate fractures that extend into the knee or ankle joint or fractures that occur through benign-appearing lesions such as bone cysts. MRI is useful for evaluating pathologic fractures that are suspicious for malignancy. A complete skeletal survey is ordered for patients who are potential victims of intentional trauma.

**Classification**

In children, no diaphyseal tibia fracture classification exists. Fractures are generally described based on their location within the bone, the fracture pattern, the direction, the amount of displacement, and whether the fracture was open. The Gustilo-Anderson classification is used to grade open fractures. The status of the fibula (intact, plastically deformed, fractured) is also included in the description of tibial shaft fractures.

**Treatment**

**Nonsurgical**

Nondisplaced fractures of the tibia are treated with long leg cast immobilization in the emergency department. For most displaced fractures without soft-tissue compromise, closed reduction under conscious sedation is the best initial treatment. After reduction, a well-molded, long leg cast is applied, ideally with the knee bent 20° to 40°, and the child is admitted to the hospital for observation. If the limb is severely swollen or if there is concern that the child will be unable to communicate that he or she is having worsening pain, the cast is bivalved before transfer to the hospital floor. Minimal pain medications are prescribed in the first 12 hours of admission, sufficient to comfort the patient but not to mask any possible impending compartment syndrome.

An exception to the general treatment in a long leg non–weight-bearing cast is the toddler fracture, which is a nondisplaced fracture of the tibial shaft in patients aged 9 months to 6 years. The mechanism of injury is usually a twisting of the foot, and the incident may not be noticed by the caregiver or even the child. Initially the fracture may present as a limp or as the child’s refusing to bear weight on the extremity. The radiographs at presentation are usually normal; repeated radiographs in 7 to 10 days show subperiosteal new bone formation. Toddler fractures can be treated in a short leg walking cast.

Postreduction radiographs are ordered and carefully evaluated immediately after reduction. Although some controversy exists regarding reduction parameters, acceptable alignment for children younger than 8 years is generally considered 10° of varus/valgus displacement or less, 10° of sagittal deformity or less, and less than 1 cm of shortening. In children older than 8 years, 5° or less of varus/valgus deformity, 5° or less of sagittal deformity, and minimal shortening with at least 50% of cortical apposition are acceptable parameters of reduction. Most remodeling potential is achieved in the first 2 years after the injury. Rotational deformities will not remodel with growth. Insult to the tibia may bring about accelerated longitudinal growth but is less significant than that found in pediatric femur fractures. It has been reported that less than 5 mm of overgrowth may occur.

After discharge from the hospital, the patient is given instructions to remain non–weight bearing with crutches or a walker and is seen weekly, with radiographs for the initial 3 weeks after injury. Cast wedging and repeat
reduction are other nonsurgical options when the initial reduction is not acceptable. After 4 to 6 weeks, the long cast is changed to a short leg cast, and progressive weight bearing is begun. Most closed children's tibial fractures heal in 8 to 12 weeks. Return to full activities may be expected within 4 to 6 months after a short course of physical therapy.

**Surgical**
Indications for surgical treatment include fractures that lose reduction after an initial attempt at cast treatment, irreducible fractures or those with unstable fracture patterns, open fractures, and fractures in the setting of polytrauma. Surgical treatment is often preferred in children with underlying neuromuscular diagnoses, such as cerebral palsy, in which closed treatment often fails. Surgical treatment varies widely based on the age of the child, associated soft-tissue injury, and fracture specifics, such as location and fracture pattern. Treatment options include percutaneous pin fixation, external fixation, flexible intramedullary nails, locked tibial nails, and plate fixation (Figure 4). Overall, outcomes of surgical management of tibial shaft fractures are not as satisfactory as those for cast treatment of tibial fractures. The difference in outcomes is related primarily to the fact that more severe injuries are more likely to require surgical intervention; in addition, difference in outcomes is related to the complications of surgical treatment specifically, including implant complications, infections, and healing delay from fracture site exposure.

**Complications**
Although the list of potential complications related to fractures of the tibia and its treatment is extensive, some of the most challenging and common problems related to this injury are infections after open fractures, bone-healing complications such as delayed union and nonunion, and compartment syndrome of the lower leg.

**Infection After Open Fractures**
*Prevention*
Infection after open fractures is uncommon, occurring in 2% to 10% of patients, with the risk highest in grade III injuries. Many of these infections are easily treated with local wound care and oral antibiotic therapy; however, deep soft-tissue infections and osteomyelitis develop in a small percentage of patients. The best strategy for reducing the sequelae of these complications is prevention. Initial emergency department treatment should include infusion of intravenous antibiotics according to the Gustilo-Anderson open fracture classification grade, determining and updating the patient’s tetanus status, and covering...
the open wound with a sterile dressing while the extremity is splinted. All open fractures should be irrigated and débrided in the operating room within 24 hours of the injury or, ideally, within 6 to 8 hours, if possible.14,16 Repeat débridement in the operating room is then done every 24 to 48 hours until all visible contamination and devitalized tissue have been removed. Wound management options vary depending on the extent of the soft-tissue injury and include primary wound closure, vacuum-assisted closure, skin grafting, and flap coverage. Although the ideal length of antibiotic prophylaxis is not known, it is the practice of this chapter’s authors to administer intravenous antibiotics from the time of admission until 48 hours after the final débridement.

Gunshot wounds are another source of extremity fractures in children. Removal of retained bullet fragments is indicated when they are in the joint or are causing neurovascular compromise. Tibial gunshot wounds may be treated with same algorithm as that used for open tibial fractures, with retrieval of bullet fragments, if necessary. Wounds with minimal comminution may be treated with local wound irrigation and débridement and casting or fixation, as the fracture pattern indicates.17

An important part of open fracture care that potentially protects the soft tissues and reduces the risk of infection is fixation of the fracture. In children, most open fractures can be stabilized at the time of the first débridement. Possible exceptions are fractures with severe soil or fecal contamination or lawn mower-type injuries. This chapter’s authors prefer to use flexible nails whenever possible as the first choice for fixation because of the ease of insertion and aftercare compared with the next most commonly used means of fixation, the external fixator. In one series of tibial fractures treated with flexible nails, the infection risk was not higher when these implants were used acutely for stabilizing open fractures compared with closed fractures.18

Treatment of Infection
An infection should be suspected when wound healing is prolonged, erythema or chronic wound drainage is seen, fracture healing is delayed, or hardware failure such as breakage or loosening is identified. In some cases, laboratory studies are helpful to confirm the diagnosis. Elevated erythrocyte sedimentation rate and C-reactive protein level may be seen in the face of chronic deep infections, but normal blood work does not exclude an infection. The best way to establish the diagnosis of osteomyelitis after an open fracture is by intraoperative biopsy and culture of the site.

Treatment of an infection is individualized. Intraoperatively, devitalized soft tissue and bone sequestra are débrided, and loose or broken hardware is removed. Intraoperative cultures are obtained and, when suspicion for infection is high, empiric antibiotics are started. In some cases, it is helpful to place antibiotic-impregnated cement beads at the site. Whether to remove or revise the hardware is sometimes a difficult decision. An unstable infected nonunion is less likely to heal than a stable infected nonunion. Therefore, unless some substantial healing has occurred before hardware removal, intact and solidly fixed hardware is maintained. Revision fixation is indicated for frank loosening or breakage and is accomplished with replacement with new implants, external fixation, or delayed reimplantation of other implants after several weeks of antibiotic therapy. Soft-tissue infections and defects can be managed by local wound care, vacuum-assisted closure devices, and, eventually, skin grafts and flaps, as the individual case demands. Antibiotics should be changed from empiric to culture specific as soon as results are available and then continued long term via a PICC (peripherally inserted central catheter) line.

Bone Healing Complications
Prevention
Delayed union and nonunion are rare in children because, with adequate treatment, most tibial fractures in the pediatric group heal uneventfully. Achieving adequate fracture stability at the time of initial treatment is the best way to prevent bone-healing complications. Flexible nail fixation is the primary method of stabilization in most surgically treated fractures in children and adolescents with open tibial tubercle growth centers. Several reports have confirmed the efficacy of flexible nail fixation, with some caveats. Lengthy, unstable fracture patterns, fractures in the proximal or distal third of the shafts, and fractures that occur in older adolescents and heavier patients are at risk for healing complications with flexible nails.19,21 It is important that the surgeon check, after inserting the flexible nail, that the fracture is axially compressed by confirming compression across the fracture side; this will ensure that the nails do not contribute to a delayed healing or nonunion. External fixation and plating are the best methods for achieving fracture stability in children with fractures not amenable to flexible nail fixation. In older patients with closing or closed tibial tubercle growth centers, locked intramedullary
Complications of Tibial Eminence and Diaphyseal Fractures in Children

Table 1
Etiologies of Abnormal Bone Healing

<table>
<thead>
<tr>
<th>Abnormality</th>
<th>Cause</th>
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<tbody>
<tr>
<td>Mechanical</td>
<td>Non-weight-bearing</td>
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<tr>
<td></td>
<td>Inadequate fracture stability</td>
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<tr>
<td>Biologic</td>
<td>Bone/periosteum loss</td>
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<td>Inadequate vascularity</td>
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<td></td>
<td>Abnormal bone</td>
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<td>Infectious</td>
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<td>Implant infection</td>
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nail fixation is the best option. Bone grafting of large defects within 6 to 8 weeks of injury also is used to prevent healing complications in patients with more severe open injuries.

Treatment of Delayed Bone Healing
As with adult patients, it is critical that the surgeon consider the possible etiologies for delayed bone healing (Table 1).

In the setting of an open fracture, ruling out deep infection or instability at the fracture site is the first step. After the infection is ruled out, delayed bone healing can be broken down into two broad categories: mechanical instability, typified by a hypertrophic nonunion, and biologic failure of healing, typified by an atrophic nonunion. Inadequate fracture stabilization and instability may result from premature removal of a cast; patient noncompliance with instructions to protect or limit weight bearing; hardware failure, such as plate breakage or screw pullout; an inadequate fixation construct, such as the use of flexible nails in a comminuted fracture; or a combination of these. The steps needed to achieve bone healing in most children with hypertrophic nonunion are débridement of hypertrophic callus; addition of fixation or revision of inadequate fixation; and protected, progressive weight bearing (Figure 5). The use of external bone stimulators, although commonly used for adults with delayed bone healing, has not been critically evaluated in children. Unlike the situation in the adult orthopaedic literature, there is no specific definition for delayed healing in pediatric patients. After infection and instability have been accounted for, it may simply require additional time for progression to a healing fracture.

Biologic failure of fracture healing is less common in children compared with adults. Severe loss of soft tissue, periosteum, and bone at the fracture site is the most common cause of atrophic nonunion in children. Poor soft tissue or bone perfusion, such as from a vascular injury or a burn, is another biologic reason for delayed bone healing. Abnormal bony architecture, caused by the presence of local pathology such as a tumor or a systemic disease such as renal rickets, is another consideration, but less commonly seen. If the delayed healing is related to one of these biologic processes, iliac crest bone grafting, occasionally even vascularized grafting, excision of abnormal bone, and management of systemic bone conditions are considerations for management of atrophic nonunions. Bone transport is an option when a large defect is present.

Compartment Syndrome
Compartment syndromes are rare in children. These develop as a result of increased soft-tissue pressures within the lower extremity compartments. Increases in tissue pressure may result from external forces such as a cast that is too tight, from vascular compromise such as diminished tissue perfusion from an arterial laceration, and from tissue trauma that results in severe swelling that compromises venous outflow and, ultimately, tissue perfusion. The most common etiologies in children are upper extremity fractures of the elbow and wrist and fractures of the tibia. Fractures caused by a high-energy mechanism of injury, crush injuries, and fractures associated with vascular injuries are typically associated with compartment syndromes of the lower leg. In practice, however, compartment syndromes of the tibia may occur in a wide variety of scenarios. Minimally displaced fractures of the proximal tibia, closed diaphyseal fractures treated with reduction casting, open fractures, and fractures treated surgically with flexible nails are some of the fracture types in which compartment syndromes can develop.

It is possible to induce a compartment syndrome with multiple errant attempts at passing flexible nails across the fracture site. At the institution of this chapter’s authors, the number of attempts at passing flexible nails is limited to three. When the surgeon is unable to successfully pass the nails, then a limited incision is made at the fracture site. This enables a direct reduction and increases the ease by which the nails can be passed.

Diagnosis and Prevention
Most tibia fractures are treated with closed reduction and long leg casting in the emergency department. Children with displaced fractures, those with moderate or severe swelling regardless of the fracture type, individuals who are unable to communicate pain because of intellectual disability, and those with diminished limb sensation are admitted to the hospital for observation. After admission, the cast is bivalved and overwrapped with an elastic bandage,
with the leg positioned on pillows level with or just above the chest. Analgesia is given that provides relief of pain but does not sedate the patient or otherwise makes regular evaluation of neurovascular status difficult. NSAIDs or low-dose narcotic pain medications are generally prescribed, and pain scores and analgesia needs are carefully tracked during the first 12 hours of admission. Pain and the neurovascular examination are documented at 2- to 4-hour intervals by the nursing staff, who are instructed to call the covering physician for significant changes in the pain level or the neurovascular examination.

An evolving compartment syndrome most commonly presents in children, regardless of age, with increasing pain that requires increased dosing or frequency of analgesia to control, clinical signs of inconsolability or anxiety, and inability to find a position of comfort in bed manifesting as agitation. These findings—analgesia, anxiety, and agitation—are referred to as the three A’s. For older children, the examination is more reliable and reflects the classic signs and symptoms associated with compartment syndrome, including increasing pain, especially with passive stretch of the toes or ankle; paresthesias, paralysis, or muscle weakness in the limb; pressure in the compartments of the lower leg; and pulselessness, a late finding. These findings—pain, paresthesias, paralysis, pressure, and pulselessness—are referred to as the five P’s and are useful guides for the physician; however, they are not as consistently identified in children as in adults.22

Figure 5  AP radiographs of a 15-year-old boy who sustained a tibia and fibula fracture as a pedestrian struck by a car. A, Distal tibia and fibula fractures were medially displaced, with a grade II open injury on the medial side. B, The index surgical procedure included irrigation and débridement medially, open reduction and internal fixation of the distal fibula, and intramedullary flexible nails in the tibia. C, Follow-up AP radiograph at 6 months postoperative demonstrating a hypertrophic nonunion of the tibia. D, Radiograph made at 9 months, after revision of tibia fixation with a rigid tibial intramedullary nail.
At first suspicion of the development of a compartment syndrome, the soft padding is split to the skin and, in some cases, the anterior portion of the cast is removed. If relief of pain is not noted within 10 to 20 minutes, the diagnosis may be confirmed with measurement of compartment pressures, especially in the setting of an unconscious or noncommunicative patient. It is the practice of this chapter’s authors, however, to rely almost exclusively on the clinical findings to make the decision to perform a fasciotomy. The keys to prevention of complications related to compartment syndrome are early diagnosis and emergency surgery at the time of diagnosis.

**Treatment**

A lower leg fasciotomy is performed through medial and lateral calf incisions that extend from 2 to 3 cm below the knee to 2 to 3 cm above the ankle (Figure 6). On the lateral side, the intermuscular septum is identified, and fascial incisions are made along the length of both the anterior and lateral compartments. On the medial side, after release of the superficial posterior compartment of the tibia, the deep posterior compartment also must be identified and released. A reliable way to release the deep posterior compartment is to identify the medial fascia first in the mid-tibia, just along the posterior bone border, and extend the fascial incision proximally, releasing some of the traversing fibers of the overlying gastrocnemius muscle to identify the fascial edge. The distal extent of the fascia is then released. After release of the compartments, each lower leg muscle should be individually inspected to ensure that it is adequately released and is showing signs of perfusion, such as contractility to electrocautery stimulation and a pink color. This chapter’s authors apply a vacuum-assisted closure system after release, with plans made for a return to the operating room for delayed closure or skin grafting, as needed.

Fortunately, most children who receive a diagnosis in a timely fashion and who undergo adequate emergency fasciotomies make a full functional recovery. Some will experience pain or persistent weakness that frequently responds to a course of physical therapy. The manifestations of late diagnosis, missed diagnosis, or inadequate decompression are more problematic. Muscle necrosis results in weakness or complete paralysis of the affected muscles. Muscle and tendon scar formation may lead to ankle and foot contractures and deformities.
that interfere with ambulation. Use of orthoses, such as an ankle-foot orthosis, and physical therapy are useful in cases of mild deformity. Surgical options such as tendon releases about the ankle and foot, and osteotomies, with or without limited fusions, are sometimes indicated for severe deformities.

Summary
Tibial fractures in the pediatric population are common injuries. Tibial eminence fractures are unique to this population, and careful treatment is required to avoid healing complications. Tibial shaft fractures do not exclusively occur in the pediatric population, but there are specific considerations for determining treatment in the growing skeleton. Consideration by the treating surgeon of the possible complications and their prevention in regard to tibial eminence and tibial shaft fractures will allow an injured child to heal and return to full activity as soon as possible.

References