Pediatric Tibial Shaft Fractures

Abstract

Tibial shaft fractures are one of the most common pediatric fractures. They require appropriate diagnosis and treatment to minimize complications and optimize outcomes. Diagnosis is clinical and radiological, which can be difficult in a young child or with minimal clinical findings. In addition to acute fracture, Toddler's and stress fractures are important entities. Child abuse must always be considered in a nonambulatory child presenting with an inconsistent history or suspicious concomitant injuries. Treatment is predominantly nonoperative with closed reduction and casting, requiring close clinical and radiological followup until union. Although there is potential for remodeling, this may not be adequate with more significant deformities, thus requiring remanipulation or rarely, operative intervention. This includes flexible intramedullary nailing, Kirschner wire fixation, external fixation, locked intramedullary nailing, and plating. Complications are uncommon but include deformity, growth arrest, nonunion, and compartment syndrome.

Keywords: *Flexible intramedullary nail, fracture, k-wire, pediatric, tibia*
MeSH terms: *Pediatrics, intramedullary nailing, tibial fractures*

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Introduction

Pediatric tibial fractures are the third most common pediatric long bone fracture after the femur and forearm, representing 15% of all pediatric fractures.[1] Of these, approximately 39% occur in the middle third, and 30% are associated with fibula fracture.[2,3] The average age of occurrence is 8 years, with males affected twice as often as females.[4] In younger children, aged 1–4 years, most tibial shaft fractures occur from falls or torsional forces as the body rotates on a planted foot, causing spiral, and oblique fractures. The fibula is usually intact in these fractures, preventing shortening but risking varus malalignment. Older children, aged 4–14 years, usually suffer from indirect sporting injuries or direct injury from motor vehicle trauma – either a crash or pedestrian struck. Direct traumas such as pedestrian versus vehicle account for 50% of the ipsilateral tibia and fibula fractures,[2] which can result in valgus malalignment. The tibia is the third most common fracture after the femur and humerus in polytrauma pediatric patients. Rarely, isolated fibula fractures occur, usually following direct trauma. Child abuse is an important consideration as the tibia is the second most common fractured bone and 26% of abused children have a tibial fracture,[5] although more so apophyseal ring or metaphyseal corner fractures.

Management of pediatric tibial shaft fractures is individualized based on age, co-existing injuries, and associated soft tissue and neurovascular injury. It is predominantly nonoperative with closed reduction and casting, requiring close followup. In the acute high-velocity trauma setting, the child must be managed according to full pediatric trauma protocol, with initial splinting. Operative options are used uncommonly and will be discussed in this paper. Overall, outcomes are good because of the healing and remodeling potential of pediatric patients. Nevertheless, the rare occurrence of malunion, nonunion, growth arrest, and compartment syndrome are important complications.

Anatomy

The anteromedial aspect of the tibial is subcutaneous with no overlying musculature for protection and the middle/distal tibia has no muscular origins, which can delay union in these areas.[6] The posterior tibial artery gives rise to the nutrient artery, which enters the posterolateral cortex, giving off ascending and descending branches. These form the endosteal vascular tree, which anastomoses with the periosteal vessels arising from the anterior tibial artery. This

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is susceptible to injury and possible compartment syndrome as it passes through a hiatus in the interosseous membrane. The common peroneal nerve is susceptible to injury as it wraps around the fibular neck subcutaneously. Of note, the fibula accounts for 6%–17% of the weight bearing load of the leg.[2] Isolated tibial shaft fractures can shorten and fall into varus malalignment because of posterior compartment muscle forces on the distal fragment. Conversely, ipsilateral tibia and fibula fractures can fall into shortening and valgus alignment because of the anterior and lateral compartment muscles pulling the distal fragment.[4]

Diagnosis

These patients present with an inability to bear weight on the injured leg, with varying degrees of pain, deformity, swelling/bruising, usually followed an acute trauma. There may be reduced range of motion of the knee and ankle. In younger children, there may be a limp, reluctance to move the affected limb, and no obvious history of trauma, such as with Toddler's fractures. A detailed history must be obtained from the child and parents, with emphasis on the mechanism of injury, detecting any other injuries, and current illnesses. The rest of the history must include past medical, surgical, medication allergy, and social history, including the birth and developmental milestones. Importantly, any features of child abuse (e.g., delay in presentation, inconsistent history, nonambulatory patient, proximal half of tibia fracture, and other injuries) must be excluded, and if present, all family and caregiver contacts should be explored. In the setting of high-velocity trauma, a brief history is obtained while full pediatric trauma protocol is undertaken.

The examination should involve assessing the general appearance and demeanor of the child, whether they are well, adequately nourished and playing, and interaction with the parents and others. Focused limb evaluation involves inspection for skin breaks, swelling, bruising, and deformity. The open fracture should be identified early and managed according to protocol. Palpation involves assessing for tenderness and crepitus, in addition to assessment for compartment syndrome by the firmness of the anterior, lateral, and deep compartments and pain on passive stretch of the ankle and toes. Where possible, the range of motion of the knee and ankle should be evaluated, and knee motion is usually very painful with an inability to ambulate. Stress fractures may allow some weight bearing, but this is painful and relieved by rest. Importantly, the neurovascular examination must be assessed by palpating dorsalis pedis and posterior tibial pulses, in addition to sensation in the cutaneous peripheral nerves. Re-evaluation must be performed frequently in the unconscious or uncooperative patient, with emphasis on excluding features of compartment syndrome. In the setting of high velocity and polytrauma, traction to realign gross tibial deformity and splint application will facilitate trauma resuscitation.[7,8]

Once the patient is stabilized, a complete head-to-toe musculoskeletal examination should be performed.

Imaging should involve anteroposterior (AP) and lateral radiographs of the tibia and fibula. Knee and ankle injuries should also be excluded with AP and lateral views of each, with the addition of a mortise view of the ankle. Pathological fractures must be excluded in low-energy fractures, with the scrutiny of imaging for bone loss. Computed tomography (CT) may be used judiciously for occult extension into or complex fracture patterns involving the ankle, taking note of the radiation risk. Technetium bone scans can be used to detect occult fractures or stress reactions when radiographs are normal. Magnetic resonance imaging (MRI) helps diagnose neoplastic processes, with an associated fracture and soft-tissue involvement. It may also rarely be used to exclude an occult fracture, although practically treatment is initiated with empirical casting (e.g., Toddler's fractures) and repeated weekly, radiographs at followup usually confirm or exclude such injuries effectively.

Classification of tibial shaft fractures is purely descriptive, based on the fibula is intact or not, the degree of angulation and displacement and whether it is an open fracture. As previously noted, 30% have an associated fibula fracture[1,3] which is usually complete and displaced but may involve plastic deformation because of a strong periosteum and lead to valgus displacement and shortening.[9] The fracture pattern can be described as simple transverse, oblique, spiral fractures, and more complex comminuted or intraarticular fractures. Most pediatric tibial shaft fractures are transverse or short oblique fractures in the middle or distal third of the shaft.[10] Over 37% are comminuted.[1] Finally, pediatric tibial shaft fracture can be occult, greenstick, with plastic deformation, or torus in nature.

Treatment

Nonoperative treatment

The majority of pediatric tibial shaft fractures are treated nonoperatively with simple manipulation and casting. This is particularly the case for undisplaced or minimally displaced tibial shaft fractures. If there is no significant soft-tissue swelling or injury, a long-leg cast is applied for 4–6 weeks, followed by progressive weight bearing in a short-leg cast (with a Sarmiento or patellar-tendon bearing modification, especially for more proximal fractures) for 4–6 more weeks. Toddler's fractures require approximately six weeks of casting. The fracture must be monitored for displacement closely in clinic on a weekly basis, particularly for the first 3 weeks while the fracture consolidates. Followup radiographs at 2 weeks are essential to look for periosteal new bone formation in suspected occult fractures, such as the Toddlers fracture. Reduction of swelling and atrophy can lead to loss of reduction, and thus repeated manipulation and casting may be required around

this time. Open or close wedging in cast can be used to correct malalignment <15°, beyond which manipulation and a new cast is applied, within 3 weeks of injury and thus avoid sedation or general anesthesia.[11,12] Close wedging of cast requires removal of 1–2 cm wedge of the cast at the fracture apex side, with cast closure. This must be monitored for fracture shortening or skin impingement. Open wedging requires a cut perpendicular to the tibia on the opposite side of the fracture angulation, with the insertion of varying block/cork sizes. The angulation is corrected, cast reinforced, and radiographs obtained to assess the fracture.

Time for fracture union varies according to patient age: 2–3 weeks for neonates, 4–6 weeks for children, and 8–12 weeks for adolescents.[2] The absence of fracture site tenderness and radiographic signs of healing guide this, after which progressive patient activity is allowed without immobilization as pain allows. A 4–6-week period may be recommended after cast removal before full active sporting activity can be initiated, to minimize the risk of refracture.

Displaced tibial shaft fractures may require initial closed reduction and casting, usually under sedation or general anesthesia. Acceptable reduction parameters[2,11,12] are shown in Table 1.

Patients <8 years of age can tolerate 100% translation of the shaft and up to 10° of sagittal and coronal angulation.[4,10] A short-leg cast is applied initially to control fracture reduction. The foot should be plantarflexed for 2–3 weeks by 10° and 20° for proximal and middle/distal-third fracture, respectively, to prevent apex posterior angulation of the fracture.[2] Once set, the cast is extended up into the groin with 30° to 60° of knee flexion to provide rotational control and prevent weight bearing.[10,11] The fracture site can be molded as required to achieve and maintain reduction and around the supracondylar femoral region for rotation control. Care is taken not to do so over bony prominences (e.g., fibula head) and the compartments, with appropriate amounts of padding. Bivalving is performed in the presence of swelling, a noncompliant or altered mental status to minimize the risk of compartment syndrome and often patients are admitted to hospital for a day for monitoring. Neurovascular status should be documented after every intervention. Radiographs are required to ensure that fracture reduction and alignment are within acceptable parameters.

Operative treatment

Pediatric tibial shaft fractures are managed operatively in <5% of cases,[2] the indications[2,9,10] of which are shown in Table 2.

Depending on the age and weight of the patient, operative techniques include flexible intramedullary nailing (weight), percutaneous Kirschner wires (age and soft tissue injury), rigid intramedullary nails (after proximal tibial physeal closure), and plating.

Table 1: Acceptable tibial shaft reduction parameters

Alignment	Accepted parameter
Angulation in sagittal plane (°)	<5-10
Angulation in coronal plane (°)	<5-10
Rotation (°)	<5
Cortical apposition (%)	>50

Table 2: Absolute and relative indications for operative treatment of tibial shaft fractures

Absolute	Relative
Unacceptable reduction	Multiple long bone fractures
Fracture instability	Ipsilateral femoral fracture (floating knee)
Significant soft-tissue injury	Spasticity syndromes (e.g., cerebral palsy and head injury)
Compartment syndrome	Bleeding diathesis (e.g., hemophilia)
Open fractures	Associated neurovascular injury

Closed and open reduction

Tibial shaft fractures that have partially malunited may require closed or open reduction, with or without a fibular osteotomy under general anesthesia. Cast application can be attempted, bearing in mind those requiring open reduction, repeated manipulation or with comminution require longer periods of immobilization for the union.[12] For more significantly shortened fractures or those who cannot be held in a cast, external fixation or intramedullary nailing may be required to restore and maintain length.

External fixation

Severely comminuted and unstable fractures and those with significant soft tissue or vascular injury require external fixation.[13,14] It is a particularly useful option to provide access for wound care and compartment checks, as well in children with head or multiple injuries because of its simple application and adjustability.[8,13] The uniplanar external fixator is placed anteromedially with two-half pins proximally and distally and a minimum of two rods to provide adequate stability. The construct may be augmented by minimal internal fixation, such as k- wires or plates. The external fixator can be converted to a cast after 4–6 weeks in young children, or in those unable to care or tolerate the frame. Alternatively, the frame is removed on union as an outpatient or under sedation. Pin site infection during fixation and refracture after removal are common complications.[15]

Intramedullary nailing

Intramedullary nailing can be rigid or flexible. Rigid locked intramedullary nailing in pediatric patients can provide stable fixation to almost all tibial shaft fracture types. However, its use is very limited because of damage to the proximal tibial physis and or the tibial tuberosity, which can cause leg length discrepancy and recurvatum deformity. As

such it is not recommended if the physes are open. On the contrary, flexible intramedullary nailing is more commonly used to treat these fractures [Figure 1].[16,17] Intramedullary Kirschner wires have been described, especially in stable tibial shaft fractures [Figure 2]. A supplementary cast may be needed for unstable fractures with obliquity or comminution. Elastic titanium intramedullary nails are increasingly used in stable and unstable fractures of the tibia, in younger children (<10 years) below a weight of 110lbs (50 kg); although, they can be used in children above these thresholds.[18] These nails are prebent to a long curve, introduced into the bone through drill holes and impacted to be proud outside skin or buried into the skin. The latter has advantages of not requiring pin site care, and both give access to the overlying leg tissue unless a cast is placed for rotational control or lack of cooperation.[19] Progressive weight bearing is allowed after 2–3 weeks with hip, knee, and ankle range of motion exercises from the outset.[16,17] Hardware is removed at 6–9 months, noting the temporary risk of refracture to warrant a delay in returning to full sporting activities.

Alternative fixation methods

Closed reduction with percutaneous Kirschner wire fixation and protection in a cast is useful for unstable, oblique fractures without comminution,[20] especially in younger children. This has been used in managing lower grade open fractures, as an alternative to external fixation.[19] Pin site infection is a common complication although they can be removed in the outpatient setting. Formal open reduction internal fixation with plates and screws [Figure 3] should generally be avoided if possible in pediatric patients because of the large exposure, periosteal, and scarring involved. However, percutaneous plating may be safe when other fractures are difficult to treat with other techniques.[21]

Complications

Malunion

With angular malunion of the tibia, which is particularly apparent with external fixation there may be remodeling over a period of 2–3 years according to the age and sex of the patient. Significant remodeling of the tibial

Figure 1: Radiographs of leg bones anteroposterior and lateral views of a tibial shaft fracture of a 16-year-old male (weighing 52 kg) sustained injury while playing basketball. Attempted closed reduction had failed so he underwent flexible intramedullary nailing (a) Initial injury showing a displaced tibia and fibula shaft fractures, with valgus angulation (b) Anteroposterior and lateral radiographs following two 4 mm prebent flexible intramedullary nails and posterior splint immediately postoperatively

Figure 2: Radiographs of leg bones anteroposterior and lateral views of a Grade 2 open distal tibial shaft fracture in a 6-year-old girl following a sledging accident treated with irrigation, debridement, and percutaneous Kirschner wire fixation with casting. (a) Radiographs of the initial injury showing displaced fracture both bones leg distal 1/4th (b) Radiographs of the leg one month after two percutaneous Kirschner wires were inserted (c) Radiographs of the leg following hardware removal and fracture union 5-month postoperatively
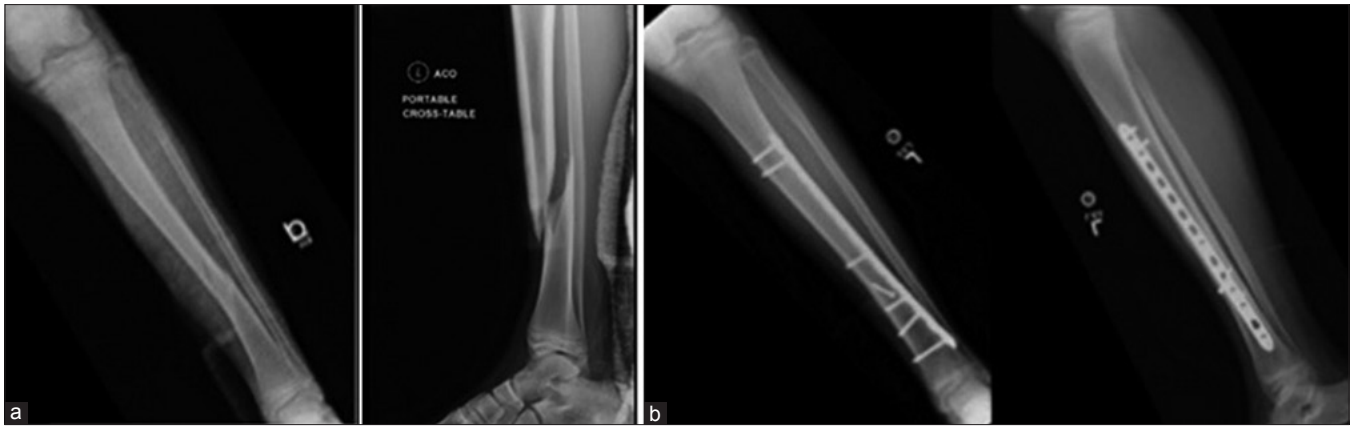
Figure 3: Radiographs of leg bones anteroposterior and lateral views of a 14-year-old boy with a Grade 2 open tibia and fibula fracture treated with irrigation, debridement, and open reduction internal fixation with plating. (a) Radiographs of the initial tibia and fibula injury showing cortical displacement and mild apex posterior angulation. (b) Radiographs of the tibia at 4-months postoperatively showing fracture union after an interfragmentary screw and locking plate

shaft occurs in girls <8 years and boys <10 years of age, compared to 50% of correction for girls 9–12 years and boys 11–12 years.[2,5] Once >13 years, <25% of correction occurs from remodeling, with complex, apex posterior, and varus deformities the least forgiving.[15] Corrective osteotomies of the tibia and fibula to restore the mechanical axis of the limb may be considered if the residual deformity after skeletal maturity is significant. Otherwise, there is a risk of knee and ankle symptoms, in addition to premature joint degeneration. Rotational malunion of the tibia does not remodel with growth. A malpositioned foot is poorly tolerated and can lead to ankle problems, especially if greater than 10°.[4] As such, a corrective supramalleolar derotational osteotomy may be required in these patients, especially if there is abnormal limb appearance and gait disturbance.

Growth arrest

Mild tibial growth inhibition can occur after tibial shaft fractures, especially in those over 8 years. Physeal injury to the proximal tibia may occur from a concomitant occult tibial tubercle or physeal crush (e.g., Salter–Harris I or V) injury, or indeed pin placement from external fixation.[15] The anterior physis is usually affected, causing a recurvatum deformity although complete physeal growth arrest will lead to leg length discrepancy. If severe enough, these can be addressed with osteotomies and limb lengthening procedures. Overgrowth can occur in tibial shaft fractures, but it is not as common or as significant as that seen in the femur. The overgrowth is <5 mm after healing,[1] usually in patients with comminuted fractures and <10 years of age.[4,10]

Delayed and nonunion

Nonunion is rare in pediatric patients but may occur with suboptimal immobilization, an intact fibula, infection, or external fixation. The overall nonunion rate is <2% of cases[10] with a 10% incidence following intramedullary nailing.[15] Twenty-five percent of pediatric open tibial fractures involve delayed or nonunion,[22] increasing with worsening soft-tissue injury, wound infection, fracture

instability, or increasing age.[23] Infection at the fracture site can be diagnosed with a history and clinical examination and elevated C-reactive protein level and erythrocyte sedimentation rate. Fracture instability can lead to a hypertrophic nonunion with excessive fracture callus, radiographic lucency at pin fixator sites. CT scans can be used to look for trabecular bridging in addition to routine serial radiographs. Atrophic nonunions with no callus and atrophic bone ends on radiographs are seen in routine radiographs. Treatment options include protected weight bearing and bone stimulators, which have a limited evidence base.[23] Like adults, revision fixation treating the infection, fibula osteotomy, and conversion to a reamed intramedullary implant (adolescent) or plating with possible bone grafting are options. In addition, an Ilizarov frame can be used to manage these issues as well as segmental defects using distraction osteogenesis to restore leg length.[15]

Compartment syndrome is rare in pediatric patients, compared to their adult counterparts in whom tibial fractures are the most common cause.[8,24] The diagnosis must nevertheless be excluded in all tibial shaft fractures, using serial clinical examination and measurement of compartment pressures as needed. Treatment is emergent two incisions, four compartment fasciotomies before prolonged increased intracompartmental pressure can lead to irreversible muscle and nerve damage, and possible amputation. Long term patients can have severe functional disability, contractures, and pain, which can be avoided fully in pediatric patients with early diagnosis and decompression.[25]

Toddler's fracture

Toddler's fractures are usually undisplaced spiral or oblique fractures of the distal half of the tibia, usually with an intact fibula. They occur in walking patients <3 years of age, most commonly at 27 months in boys[2,26] and are also known as childhood accidental spiral tibial fractures. The distal tibial physis appears at 2 years so physeal

injuries must be suspected even if not apparent. These tibial fractures occur from low energy twisting of the foot with the knee fixed or a fall. Clinical presentation is usually irritability with an antalgic gait or an inability to weight bear, often following a minor event or no history of trauma. The history must be explored carefully and clinical examination usually reveals tenderness on the tibial crest but often no swelling. Radiographs may initially be normal and thus should be repeated in 1–2 weeks where periosteal new bone formation may be seen. Technetium bone scans are rarely performed but unlike localized uptake with infection, they show diffuse tibial uptake in a Toddler's fracture. These fractures rarely displace and are managed nonoperatively using a long-leg cast for 2–3 weeks followed by a short-leg cast for 2–3 weeks.[10] Advice to protect the cast from soiling in these young patients should be given to the parents.[26] Complications are very rare due to young age, low-energy injury, and fast healing time (4 weeks),[4] although slight malrotation may be noticed, without clinical significance.

Stress fracture

Pediatric tibial stress fractures occur mostly in the proximal third between 10 and 15 years of age.[11] The less common fibula stress fractures occur in the distal third most commonly, between 2 and 8 years of age.[2] Stress fractures occur when normal bone is subject to repeated abnormal strain, and thus, there is an insidious onset of pain, which is activity related, but no history of trauma. For the tibia, the mechanism is sporting activities and possible change in exercise pattern, whereas, for the fibula, it may be the repeated motion from ice skating. Tenderness and swelling is variable, but the contralateral leg may be involved. Diagnoses such as infection, sprains, periostitis, exercise-induced compartment syndrome, and neoplasia must be excluded from the study. Radiographs may be initially normal, but it is important to exclude acute fracture, and thus, should be repeated in 1–2 weeks from symptom onset to show periosteal new bone formation, endosteal thickening, or "eggshell callus".[5,10] The fractures can be complete or incomplete, acute, or chronic. CT scans may show increased marrow density, new bone formation and soft tissue edema; technetium bone scan shows localized uptake within 1–2 days, and MRI scan shows cortical low-signal intensity. Treatment is predominantly nonoperative with a short period of casting and initial nonweight bearing, followed by progressively increasing activity according to pain and signs of fracture healing, which is usually by 4–6 weeks. Complications are rare and included nonunion (middle third), which can be excised, and bone grafted, and recurrent stress fractures, which require strict activity modification.[16,23]

Child Abuse

Although pediatric tibial shaft fractures are rarely seen from child abuse, this must be excluded in every child. Child abuse usually leads to metaphyseal corner or apophyseal ring injuries of the tibia.[5] Nevertheless, clinical features of a delay in presentation, inconsistent history, previously known to social, and concomitant injuries in a nonambulatory child should raise suspicion. A detailed history and physical examination, followed by radiographs and possibly a skeletal survey should be performed. Pediatric and social services should be consulted from an early stage.

Summary

Pediatric tibial shaft fractures are common injuries, which requires management, is individualized based on the age and size of the patient, as well as the nature of the fracture and any associated soft-tissue injury. Often there may be no history of trauma and only a reluctance or inability to weight bear. As part of the assessment, child abuse must be excluded, and high-velocity injuries should be managed according to pediatric trauma protocol. Most of these fractures are treated nonoperatively in a cast, although there are distinct operative interventions that work well in the few that require it. Importantly, the proximal tibial physis and tibial tubercle must be considered when planning treatment. Fortunately, complications are rare with the ability of young children to remodel and heal rapidly. Compartment syndrome is rare compared to their adult counterparts but must be examined for systematically with emergent fasciotomies to prevent long term loss of function or limb.

Conflicts of interest

There are no conflicts of interest.

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