



Review Article

Pediatric Tibial Shaft Fractures: A Comprehensive Review

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Abstract

Tibial shaft fractures are among the most common pediatric long bone fractures. These fractures have significant implications for growth, function and alignment, often requiring precise management to prevent complications such as limb length discrepancies and angular deformities. This review focuses on the classification, etiology and management of pediatric tibial shaft fractures, emphasizing recent advancements and remaining challenges. A comprehensive literature review was conducted in November 2024 using PubMed, Medline and Scopus. Articles were selected based on relevance to etiology, classification and management strategies. Both recent and foundational studies were included to provide a comprehensive perspective. The review explores the major types of tibial shaft fractures in children, including Toddler's fractures (and spiral fractures), transverse fractures, greenstick fractures, stress fractures, segmental fractures and comminuted fractures, focusing on their etiology, age-specific prevalence, clinical presentation, imaging findings, management strategies and potential complications. Younger children typically experience fractures due to low-energy mechanisms, such as twisting injuries, resulting in spiral or greenstick fractures. Older children and adolescents are more prone to high-energy trauma, causing transverse, comminuted or segmental fractures, often associated with fibular involvement. Most fractures are treated non-operatively using casting techniques tailored to fracture stability, angulation and age. Surgical interventions, including flexible intramedullary nailing, external fixation and plating, are reserved for complex or unstable fractures, open injuries or cases involving neurovascular compromise. Advances in classification systems, imaging modalities and surgical techniques have improved outcomes, yet opportunities exist to develop growth-preserving methods and improve long-term functional recovery. Future research should prioritize optimizing

individualized management strategies and exploring innovative technologies to enhance diagnostic accuracy and treatment efficacy.

Keywords: Tibial Shaft Fractures; Pediatric Fractures; Non-Operative Management; Operative Techniques

Introduction

Tibial shaft fractures are among the most prevalent injuries in the pediatric population, accounting for approximately 15% of long bone fractures [1]. Notably, they are the second leading cause of hospitalization among pediatric fractures, surpassed only by femoral fractures [2]. Approximately 39% of tibial fractures occur in the diaphysis, 50% occur in the distal third and 11% in the proximal third [3]. Tibial shaft fractures in the pediatric population have significant implications for growth, including the risk of limb length discrepancies and angular deformities, as well as temporary or prolonged functional impairments [4]. In the younger pediatric population, tibial shaft fractures are typically caused by low-energy rotational mechanisms, such as twisting injuries, resulting in spiral fractures. These may occur with or without fibular involvement at different levels. Fractures with an intact fibula are less prone to shortening but may develop varus deformities during healing [5]. In older children and adolescents, fractures are more commonly due to high-energy trauma, such as motor vehicle accidents or sports injuries. These injuries often lead to tibial and fibular fractures at the same level, with risks of shortening, valgus deformities, comminution and complications like compartment syndrome. Direct trauma in this group can result in stable transverse fractures when the fibula remains intact [3]. Additionally, tibial shaft fractures may sometimes be indicative of non-accidental trauma, particularly in very young

children. Child abuse should always be considered in cases where the injury mechanism is unclear or inconsistent with developmental milestones, as delayed diagnosis can have serious consequences [6]. The treatment of pediatric tibial fractures primarily focuses on restoring limb structure and function. Most closed, extra-articular fractures in pre-pubertal children are effectively managed with casting, with above- or below-knee options determined by fracture stability, location and age [7]. Surgical intervention is reserved for specific cases, such as open fractures, neurovascular injuries, compartment syndrome or when alignment cannot be maintained non-operatively [8]. The aim of this review is to explore the classification of tibial fractures in children and their management, emphasizing both non-operative and operative approaches.

Methods

This literature review was conducted in November 2024, focusing on the classification, etiology and management of pediatric tibial shaft fractures. The databases searched included PubMed, Medline and Scopus, utilizing keywords such as “Pediatric tibial fractures,” “Tibial shaft fracture classification,” “non-operative management,” and “Operative techniques.” Articles were selected based on their relevance to the etiology, management and organization of pediatric tibial fractures. The literature pool included articles from various regions and countries, all of which were written in English or translated into English. This review incorporated primary articles, narratives and systematic reviews to ensure comprehensive coverage of the topic. This manuscript primarily examines literature published recently but also includes some earlier studies that provide foundational concepts. References within the selected articles were further explored to provide a broader perspective. Each article was carefully assessed for relevance and validity to ensure the accuracy of the information reported.

General Tibial Anatomy in Children

The pediatric tibia is uniquely adapted for growth and repair, with approximately 55% of longitudinal growth occurring at the proximal physis and 45% at the distal physis [9]. Its thick, highly vascular periosteum promotes rapid healing and remodeling, particularly in children under eight years old, who can tolerate greater angular and rotational deformities before requiring intervention. However, this remodeling capacity diminishes with age, making precise fracture alignment increasingly important in older children [9]. Anatomically, the tibia's subcutaneous anteromedial surface-especially in the middle and distal thirds-lacks muscular protection, making these regions more susceptible to trauma and delayed union due to limited soft tissue protection. The vascular supply originates from the posterior tibial artery via the nutrient artery, forming an endosteal network that anastomoses with periosteal vessels [10]. This delicate vascular structure, along with the interosseous membrane, is vulnerable to trauma and predisposes to complications such as compartment syndrome [5]. In children, the relatively weaker bones compared to ligaments mean that injuries causing ligamentous damage in adults are more likely to result in fractures in pediatric patients [11]. Isolated tibial fractures are prone to varus deformity due to posterior muscle forces. In contrast, combined tibial and fibular fractures often result in valgus deformity and shortening, driven by anterior and lateral muscle pull [5]. Fig. 1 illustrates the anatomical and physiological features of the tibia.

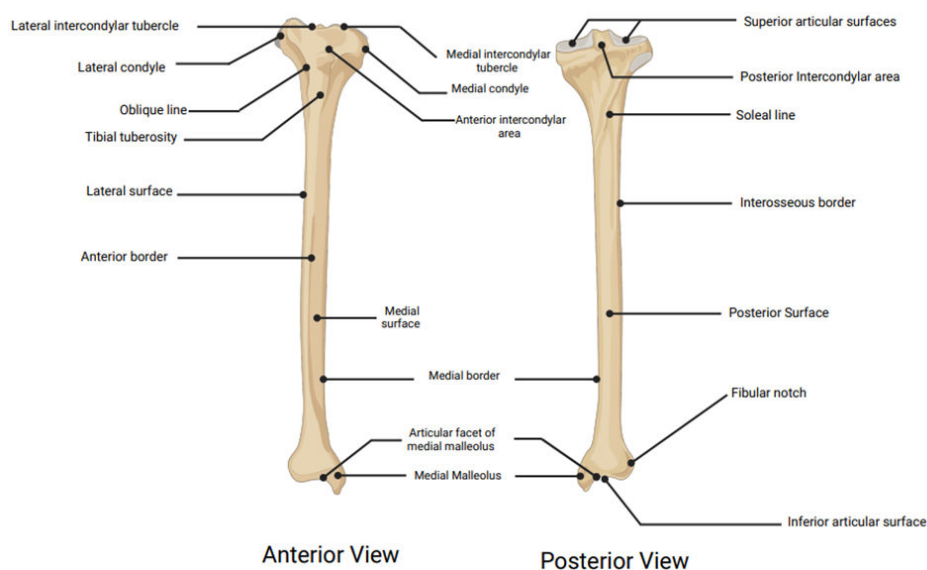


Figure 1: Anterior and posterior views of the anatomical features and landmarks of the tibia.

Pediatric Tibial Shaft Fracture Types

Tibial shaft fractures in children encompass a variety of patterns, each with distinct mechanisms of injury, clinical presentations and management approaches. Understanding these major types is essential for tailoring treatment strategies to optimize outcomes while accounting for growth and healing potential. The following sections will delve into each fracture type in detail.

• *Toddler's fracture*

Toddler's fracture is a type of spiral fracture that typically occurs in the distal tibia of children aged 9 months to 3 years. The term "Toddler's fracture" was coined in 1964 by Dunbar, et al., [12]. Toddler's fracture is also known as Childhood Accidental Spiral Tibial fracture (CAST), as this terminology encompasses a more comprehensive definition including children up to age 8 [13].

Toddler's fracture typically arises from mild trauma, such as tripping while walking or running or from falling from a low height [14]. Bones in young children are highly elastic due to their cartilaginous content, which plays a crucial role in the occurrence of toddler's fractures. When a child trips while running, the affected leg experiences sudden deceleration while the upper body and other legs continue moving. This, combined with the compressive force from the child's weight, creates a shearing force that can lead to a fracture [14]. The most apparent sign of this condition is a noticeable alteration in the child's gait, often presenting as limping or an outright refusal to walk [15]. Affected children may also exhibit localized warmth and tenderness along the tibia, which are key diagnostic indicators [16]. However, pinpointing tenderness can be challenging in young children since they might struggle to articulate their discomfort or accurately identify the exact location of pain. This necessitates careful observation and gentle examination to diagnose the fracture effectively.

Toddler's fracture is primarily diagnosed clinically and initial radiographs may often appear negative [15]. When detectable, the fracture appears as a nondisplaced, faint hairline fracture on the anterior-posterior view and less commonly on lateral or oblique views [17]. If not visible initially, radiographs taken 1 to 2 weeks later may show signs of healing, such as subperiosteal new bone formation, which helps confirm the diagnosis [18].

The treatment for both confirmed and presumed Toddler's fractures is conservative, typically involving immobilization with a cast [15]. A controlled ankle motion boot or a short leg back slab is preferred due to their minimal complications and the convenience of removal by the family or family physician. Complications following a Toddler's fracture are uncommon due to the resilient nature of young bones, the typically low-energy mechanism of the injury and the rapid healing process in children, which usually spans about four weeks [5]. On rare occasions, slight malrotation of the tibia may occur after healing. Toddler's fractures typically do not necessitate routine assessment, intervention or follow-up by an orthopedic surgeon. If accurately diagnosed and managed at the initial presentation, patients with Toddler's fractures can be safely discharged without the need for additional clinical contact [19].

• *Greenstick Fractures*

Greenstick fractures are incomplete fractures of the long bones that are especially prevalent in children, owing to the pliability of their developing bones. Greenstick fractures can occur in both the diaphysis and metaphysis [20]. However, when the fracture extends to involve the physis, it is classified as a Salter-Harris fracture rather than a greenstick fracture [20]. They are more common in younger children, generally under the age of 10 years [21]. Etiology is often related to low-energy trauma, such as falls while playing, where the bone bends and cracks on one side without breaking completely through [22]. In their retrospective review of 135 cases of pediatric proximal tibia fractures, Mubarak, et al., demonstrated that the most commonly observed fracture pattern was the valgus greenstick (Cozen's) metaphyseal fracture [23]. Malnutrition, specifically vitamin D deficiency, increases the risk of greenstick fractures of the long bones after a trauma [20]. Interestingly, this fracture pattern resembles the way a green twig bends and splinters on one side while remaining intact on the other, which is the origin of the term.

Clinically, children with greenstick fractures present with localized pain, tenderness and swelling over the site of the injury [20]. There may also be visible deformity, depending on the extent of the bending. On imaging, plain radiographs are diagnostic and reveal a cortical break on one side of the bone, with the opposite cortex bent but intact [24]. Sometimes, oblique views are required to confirm the diagnosis and rule out other associated injuries [25]. All greenstick fractures necessitate immobilization and delaying casting by a few days after the initial injury can help reduce the likelihood of needing to recast due to swelling that

develops post-fracture [20]. Referral to an orthopedic specialist at the first visit is typically advised but may vary based on the child's age and the severity of the fracture's angulation [20]. The goal is to correct the angulation to prevent residual deformity while relying on the excellent remodeling potential of pediatric bones. Nondisplaced greenstick fractures can be treated with a volar short arm splint unless angulation exceeds 15° [24]. Angulated fractures require immediate closed reduction and immobilization in a long arm splint, with follow-up within 3 days [24]. Complications are rare but can include incomplete reduction, resulting in mild angular deformities or re-fracture in cases of premature return to activity [20]. Overall, the prognosis is excellent, with most children achieving full functional recovery without long-term sequelae.

• *Transverse Fractures*

Transverse fractures of the tibial shaft are among the most common types of fractures in children, particularly in school-aged individuals, due to their increased involvement in outdoor activities and sports [26]. These fractures typically result from high-energy impacts, such as direct blows to the leg during contact sports like football or basketball or falls from significant heights where the force is transmitted directly to the bone [27]. Clinically, children often present with acute pain and tenderness localized to the fracture site, visible swelling and a refusal or inability to bear weight on the affected limb [28].

On imaging, plain radiographs provide a clear depiction of a horizontal fracture line that spans the shaft of the tibia [28]. Due to the strong periosteum surrounding pediatric bones, these fractures are often minimally displaced, though exceptions can occur with severe trauma [29]. The thick periosteum not only helps limit displacement but also contributes to the excellent healing potential in this age group [30].

Management generally involves conservative treatment with immobilization using a long-leg cast for stable fractures. However, fractures with significant displacement or angulation may require closed reduction and casting, or, in rare instances, surgical intervention using flexible intramedullary nailing or external fixation [31]. Complications, although uncommon, can include angular deformities, limb-length discrepancies, delayed union or malunion [32]. Despite these risks, the high remodeling capacity of pediatric bones often ensures favorable outcomes [30].

• *Stress Fractures*

Pediatric tibial stress fractures commonly occur in the proximal third of the tibia in children aged 10 to 15 [33,34]. These fractures arise from repeated abnormal strain on normal bone, leading to gradual onset of activity-related pain without a history of trauma [5]. Sports activities or changes in exercise routines are typical causes of tibial stress fractures in children [35]. Symptoms can vary, with some cases showing tenderness and swelling and bilateral involvement is possible. Differential diagnoses, including infection, sprains, periostitis, compartment syndrome and neoplasia, should be carefully excluded [5,36].

Initial radiographs may appear normal but should be repeated within 1-2 weeks to detect signs such as periosteal bone formation, endosteal thickening or an "eggshell callus" [5, 37]. Fractures can range from acute to chronic and may be complete or incomplete. CT imaging can reveal marrow density changes and new bone formation, while technetium bone scans show localized uptake early on [28]. MRI provides detailed imaging, showing cortical low-signal intensity and associated soft tissue edema [5].

Stress fractures in the anterior cortex of the tibial diaphysis are a distinct form of pediatric stress fracture resulting from reduced vascular supply and persistent tension exerted by posterior leg muscles [38]. On imaging, these fractures are notable for their characteristic appearance as the "Dreaded Black Line" on MRI [38,39]. Histological examination reveals resorption cavities lined with active osteoblasts and areas of immature bone formation [40].

Treatment is typically non-operative, involving a short period of immobilization and non-weightbearing activity, followed by gradual activity resumption based on pain and healing progress, usually within 4-6 weeks [28]. However, iliac crest bone grafting and external bone fixation and may be of great utility for managing stress fracture non-unions [28]. Complications are rare but include nonunion, especially in the mid-tibia, which may require surgical excision and bone grafting and recurrent stress fractures, which necessitate strict activity modifications [41].

• *Segmental Fractures*

Segmental tibial fractures involve two or more distinct fracture lines within the tibial shaft, creating at least one intermediate bone segment [42]. These fractures are rare in children and typically result from high-energy trauma, such as motor vehicle accidents or falls from significant heights [42,43]. Their unique nature lies in the significant disruption of the cortical bone continuity, often leading to instability and complications in management and healing [44].

Clinically, segmental fractures present with severe pain, swelling and visible deformity of the lower limb. Neurovascular compromise may occur due to the high-energy mechanism of injury, necessitating a thorough examination of distal pulses and sensory function [43]. Associated injuries, including fibular fractures, soft tissue damage or compartment syndrome, are common and should be carefully assessed [45]. Radiographically, plain X-rays in anteroposterior and lateral views are sufficient to confirm the diagnosis, showing multiple fracture lines with separation of bone fragments [43].

Management of segmental tibial fractures is challenging due to the high risk of nonunion and malunion [45]. Treatment often requires surgical intervention, such as external fixation, intramedullary nailing or plate fixation, depending on the fracture pattern and the child's age [42]. Open fractures, which are common in high-energy injuries, demand urgent debridement, stabilization and antibiotic therapy to prevent infection. The healing process in segmental tibial fractures is prolonged compared to simpler fracture types due to compromised blood supply to the intermediate bone segment [44]. Close follow-up is essential to monitor for complications such as delayed union, nonunion or angular deformities [45]. Despite the complexities, the regenerative potential in pediatric patients often results in satisfactory outcomes when managed appropriately [7].

• *Comminuted Fractures*

Comminuted tibial fractures occur when the bone is broken into three or more fragments, usually resulting from high-energy trauma such as motor vehicle accidents, falls from great heights or direct blows [46]. These fractures are less common in children compared to adults, albeit they comprise more than 37% of pediatric tibial shaft fractures [47]. The extent of bone fragmentation often leads to instability and makes management particularly challenging.

Clinically, children with comminuted tibial fractures present with intense pain, marked swelling and visible deformity. Radiographic evaluation using standard anteroposterior and lateral X-rays provides a clear view of the fragmented bone. In complex cases, CT imaging may be necessary to better assess fracture morphology and guide surgical planning. Specifically, CT imaging is essential to visualize the fragment in size, degree of comminution and articular impaction, in addition to preoperative and postoperative planning [48].

Management of comminuted fractures often involves surgical intervention. External fixation or intramedullary nailing is typically employed to stabilize the fragments, especially in open fractures [5, 49]. Unstable fractures with comminution may necessitate the additional use of a cast to maintain the reduction. Elastic titanium nails, often employed in the forearm and femur, can also offer effective stabilization for unstable tibial shaft fractures [28, 50]. Healing times in comminuted fractures are prolonged due to the disrupted blood supply and extensive bone damage. Pediatric bones generally exhibit excellent healing potential, but complications such as delayed union, malunion or angular deformities can still occur. Long-term follow-up is essential to monitor for these complications and to ensure proper bone remodeling, particularly in younger children.

Management of Pediatric Tibial Shaft Fractures

Non-operative management remains the cornerstone for treating pediatric tibial shaft fractures, especially for undisplaced or minimally displaced fractures. Techniques such as casting, close and open wedging and bivalving are essential components of this approach, tailored to ensure proper alignment and reduce complications. Detailed descriptions of these techniques can be found in Table 1 [5,8,33,45,51].

In the rare instances where pediatric tibial shaft fractures require operative management, several techniques are employed based on the patient's age, weight, fracture pattern and associated injuries. These include flexible and rigid intramedullary nailing, percutaneous Kirschner wires, external fixation and plating. The decision-making process takes into account factors such as growth plate involvement, fracture stability and soft tissue conditions. Detailed descriptions of these techniques are provided in Table 2 [5,8,41,45,52].

Technique	Description
Initial Casting	Long-leg cast for 4-6 weeks, followed by short-leg cast with Sarmiento or patellar-tendon bearing modification for another 4-6 weeks
Close Wedging	Removal of a 1-2 cm wedge at the fracture apex, closure of cast and monitoring for shortening or skin issues
Open Wedging	Perpendicular cut opposite fracture angulation with cork insertion, angulation correction and reinforced casting
Short-Leg Casting	Applied initially with plantarflexion: 10° for proximal fractures, 20° for middle/distal fractures, followed by extension to a long-leg cast
Long-Leg Casting	Extended to the groin with 30°-60° knee flexion for rotational control, with molding at the fracture site
Bivalving the Cast	Done in cases of swelling, altered mental status or noncompliance to reduce compartment syndrome risk

Table 1: Techniques for non-operative management of pediatric tibial shaft fractures.

Technique	Description
Flexible Intramedullary Nailing	· Preferred for younger children (<10 years) and those under 50 kg
	· Nails are prebent and inserted through drill holes
	· May require a supplementary cast for unstable fractures
	· Progressive weight bearing is allowed after 2-3 weeks and hardware is removed at 6-9 months
Rigid Intramedullary Nailing	· Provides stable fixation for most fracture types but limited to patients with closed proximal tibial physes due to risks of growth plate damage, leg length discrepancy and recurvatum deformity
Percutaneous Kirschner Wires	· Useful for unstable oblique fractures without comminution in younger children
	· Often combined with casting. Pin site infections are a common complication, but removal is straightforward in outpatient settings
Plating	· Avoided where possible due to extensive exposure and scarring
	· Percutaneous plating is a safer alternative for difficult fractures
External Fixation	· Ideal for severely comminuted fractures, soft tissue/vascular injuries and cases needing wound care or compartment monitoring
	· A uniplanar fixator with two half-pins proximally and distally is commonly used
	· Can be converted to a cast after 4-6 weeks or removed upon union
	· Pin site infections and refractures post-removal are common complications
Closed or Open Reduction	· Indicated for malunited or shortened fractures
	· May involve fibular osteotomy
	· Cast application or surgical fixation (external or intramedullary) is required to maintain alignment
Alternative Fixation Methods	· Includes closed reduction with percutaneous Kirschner wire fixation or minimal internal fixation (K-wires or plates) for lower-grade open fractures
	· Casts are used for protection.

Table 2: Techniques for operative management of pediatric tibial shaft fractures.

Conclusion

Pediatric tibial shaft fractures present unique challenges due to their implications for growth and function, despite the significant advancements in their management. While current approaches-ranging from non-operative techniques like casting to advanced surgical interventions-offer effective solutions, gaps in understanding remain. Future research should focus on optimizing fracture classification systems to improve individualized treatment planning, particularly for complex cases. Additionally, there is a need to explore innovative growth-preserving surgical techniques and biomaterials that minimize complications such as growth disturbances and malunion. Advances in imaging modalities and the integration of artificial intelligence could further enhance early diagnosis and outcome prediction. Lastly, longitudinal studies assessing the long-term functional outcomes of these fractures will provide valuable insights, helping to refine current management protocols and ensure the best possible outcomes for pediatric patients.

Author Contributions

BS conceptualized the review. BS, JAK and AH performed the literature review and wrote the first draft. JAK and AH contributed equally towards the manuscript and share second authorship. All authors read and contributed to the editing of the final manuscript.

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Conflict of Interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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