Pediatr Pol 2026; 101 (2): 175-187
DOI: https://doi.org/10.5114/polp.2026.162941
Submitted: 30.11.2025, Accepted: 27.12.2025, Published: 30.06.2026

PEDIATRIA Polska
PISMO POLSKIEGO TOWARZYSTWA PEDIATRYCZNEGO
Polish Journal of PAEDIATRICS
OFFICIAL JOURNAL OF POLISH SOCIETY OF PAEDIATRICS

REVIEW PAPER

Femoral fractures in children – diagnostic approaches, classifications, treatment strategies, and outcomes: a comprehensive review

Katarina Čavka[1], Marko Bašković[2,3,4,5]

[1]School of Medicine, University of Split, Split, Croatia
[2]Children's Hospital Zagreb, Zagreb, Croatia
[3]School of Medicine, University of Zagreb, Zagreb, Croatia
[4]Croatian Academy of Medical Sciences, Zagreb, Croatia
[5]School of Medicine, Catholic University of Croatia, Zagreb, Croatia

ABSTRACT

Femoral fractures in children represent a significant injury, accounting for approximately 1–2% of all pediatric fractures. Due to the unique biomechanical and biological characteristics of the growing skeleton, diagnosis, classification, and management differ markedly from adult fractures. This comprehensive review consolidates current evidence on diagnostic approaches, emphasizing the importance of clinical examination complemented by advanced imaging modalities. Various classification systems are discussed to facilitate standardized assessment and guide treatment planning. Treatment strategies are tailored to age, fracture type, displacement, and associated injuries, ranging from conservative methods like casting and traction to surgical interventions such as flexible intramedullary nailing and plate fixation. Outcomes are generally favorable, with high union rates and excellent functional recovery. The article underscores the importance of individualized treatment plans and multidisciplinary management to optimize functional outcomes in pediatric patients. Advances in diagnostic technology and surgical techniques continue to improve prognosis, emphasizing the need for ongoing research to refine management protocols and minimize long-term sequelae in this vulnerable population.

KEY WORDS:
femoral fractures, proximal femoral fractures, femoral shaft fractures, distal femoral fractures, pediatric surgery, pediatric orthopedics.

INTRODUCTION

Femoral fractures in children, accounting for only 1–2% of all pediatric fractures, are relatively rare compared to other pediatric injuries [1]. They represent a significant clinical concern due to their potential impact on growth, development, and long-term function [2]. These injuries often result from falls, sports activities, or motor vehicle accidents and exhibit considerable variation across different age groups, reflecting the evolving anatomy and physiology of the pediatric skeleton [2, 3]. Particularly in very young children, non-accidental injury (battered child syndrome) must be considered, especially when the history is inconsistent with the injury pattern or when fractures are multiple or atypical for the reported mechanism. Accurate diagnosis relies on a combination of thorough clinical assessment and appropriate imaging modalities, with particular attention to subtle fractures and associated injuries [4, 5]. To facilitate effective management, various classification systems have been developed based on fracture location, pattern, and severity, guiding treatment decisions and prognostic evaluations. Management strategies range from conservative approaches, such as

ADDRESS FOR CORRESPONDENCE:
Asst. Prof. Marko Bašković, MD, PhD, MPH, Children's Hospital Zagreb, 16 Vjekoslava Klaića St., 10000 Zagreb, Croatia, e-mail: baskovic.marko@gmail.com

spica casting, to surgical interventions including intramedullary nailing and external fixation, tailored to the child's age, fracture characteristics, and overall health [6–8]. In addition, when evaluating pediatric fractures, clinicians should remain vigilant for signs suggestive of underlying oncological causes, such as osteosarcoma or Ewing sarcoma, which may present initially as pathological fractures. Understanding the healing process and potential complications is essential for optimizing functional recovery and minimizing long-term sequelae. While recent advances in minimally invasive techniques and biomaterials have improved treatment outcomes, challenges remain in standardizing care and ensuring that interventions are compatible with ongoing growth – meaning they do not interfere with the natural developmental processes, prevent deformities, or compromise long-term functional outcomes in pediatric populations [9, 10].

This review aims to synthesize current evidence, highlight emerging trends, and discuss best practices in the diagnosis, classification, treatment, and follow-up of pediatric femoral fractures.

ANATOMY AND DEVELOPMENT OF THE FEMORAL

The femoral, the longest bone in the body, consists of a proximal end with a spherical head, neck, and two trochanters, and a shaft. The femoral head articulates with the pelvis and features a fovea capitis connected to the acetabulum *via* the round ligament [11]. Growth occurs at the physes: the proximal physis, influencing the head and neck, and the distal physis, affecting the condyles and shaft. Injury to these growth plates can impair development, causing discrepancies or deformities [1, 2, 11]. At birth, a single proximal physis forms two ossification centers: the capital epiphysis ossifies between 4–6 months of age and closes around 18 years, while the trochanteric apophysis ossifies at the age of 4 and closes by 16–18 years [12]. The neck, 4–5 cm long, connects the head to the shaft and varies in angle from 135° at birth to about 130° in adulthood [2, 13]. The greater and lesser trochanters serve as muscle attachment sites, with the medial surface of the greater trochanter grooved for the trochanteric fossa [11]. The blood supply is primarily from the medial and lateral circumflex arteries, which are branches of the profunda femoris (deep femoral) artery. Additionally, the artery of the ligamentum teres (a branch of the obturator artery) contributes to the vascularization of the femoral head, particularly in children, and plays a crucial role in maintaining blood flow during growth [2, 14, 15]. Regarding innervation, the femoral nerve is the main motor and sensory nerve supplying the anterior thigh and the anterior hip joint capsule. The common peroneal (fibular) nerve supplies the short head of the biceps femoris in the posterior thigh and, through its distal branches, muscles of the anterior leg such as the tibialis anterior, it represents only one component of the complex neural network supplying the lower limb. The peroneal nerve specifically innervates muscles such as the tibialis anterior and the short head of the biceps femoris, but it is only one component of the complex nerve network servicing the thigh and hip regions. A comprehensive understanding of the femoral neurovascular anatomy thus involves these multiple arteries and nerves, which are essential considerations during surgical procedures and in the assessment of vascular or nerve injuries [2, 16, 17].

EPIDEMIOLOGY

Proximal femoral fractures are rare in children, comprising less than 1% of pediatric fractures [18, 19]. Boys tend to have a higher incidence, potentially due to greater involvement in physical activities, though this varies by population. In very young children, especially those under 2 years, fractures may result from non-accidental trauma, and suspicious injury patterns should prompt thorough investigation for potential abuse. Most cases (85–90%) result from high-energy trauma, such as falls from height, motor vehicle accidents, or sports-related injuries, with younger children often affected by falls or non-accidental trauma, and older children by accidents [15, 20]. Low-energy fractures are uncommon and typically indicate underlying bone or metabolic disorders [18]. Pathological fractures, occurring with minimal trauma or even spontaneously, should raise suspicion of underlying neoplastic processes such as osteosarcoma or Ewing sarcoma, which are more prevalent in adolescents and can mimic traumatic fractures. In children without a history of high-energy trauma or known conditions, non-accidental injury should be considered. Femoral shaft fractures are the most frequent femoral fractures, with an incidence of 10–20 per 100,000 children, more common in boys, and exhibiting a bimodal age distribution – peaks during toddlerhood and adolescence – primarily due to falls and vehicle accidents [3, 20–22]. Mortality rates are low, usually related to associated injuries rather than the fracture itself. Distal femoral fractures are less common, accounting for 12–27% of femoral fractures, more prevalent in boys and older children and adolescents [20, 21, 23].

IMAGING

Imaging is essential for femoral fractures to confirm diagnosis, guide treatment, and predict outcomes by considering factors like age, fracture pattern, displacement, mechanism, vascular involvement, *etc*. [2, 24]. Plain radiography is the initial preferred modality, with anteroposterior and lateral views being typically sufficient. Special views, such as frog-leg or cross-table, can aid diagnosis but should be used cautiously, especially in acute trauma to avoid displacing fractures. Hip fractures are evaluated similarly, with radiographs revealing fracture type, displacement, location, and angulation. Magnetic resonance imaging (MRI) is particularly useful for non-displaced or stress fractures and early detection of avascular necrosis (AVN), which appears as osteopenia, sclerosis, or collapse on radiographs and is best confirmed by MRI. Bone scans can show AVN through decreased uptake, though they are less sensitive than MRI. For femoral shaft fractures, anteroposterior (AP) and lateral radiographs assess comminution, angulation, displacement, and shortening; computed tomography (CT) or MRI may be needed for non-displaced or stress fractures. Angiography is indicated if pulses are diminished. Evaluation of distal femoral fractures includes radiographs of the femoral, knee, and hip, with MRI or CT used to assess displacement and physeal injury. Throughout, minimizing radiation exposure is vital, and dose-reduction strategies should be employed to ensure safety in pediatric imaging [24].

HIP FRACTURES IN CHILDREN

MECHANISMS OF INJURY

Most pediatric hip fractures are caused by a high-energy trauma, e.g., a car accident or a fall from a height (from three meters or three times the child's height) [19, 25]. Hip fractures resulting from low-energy trauma often imply underlying conditions, such as malignant processes, unicameral bone cyst (UBC), aneurysmal bone cyst (ABC), fibrous dysplasia, osteogenesis imperfecta, osteopenia, rickets, and skeletal immaturity [26]. Stress fractures may occur in adolescents (10–19 years of age) who engage in athletics and long-distance running. Rarely, stress fractures develop in children younger than 10 years of age who are not overly physically active. Child abuse is also a possibility, especially if the child presents without a history of high-energy trauma or pre-existing pathology [26, 27].

CLINICAL PRESENTATION, PHYSICAL EXAMINATION, AND DIAGNOSIS

The clinical presentation of femoral neck fractures in the pediatric population is similar to presentation in adults. Most children present with a history of high-energy trauma, together with severe pain, and are unable to move the limb. Additionally, the hip is usually swollen and tender to palpation. In case of a displaced fracture, the limb will be externally rotated, slightly adducted, and shortened. In case of a displaced fracture of the femoral head, the limb will be internally rotated, with adduction and in flexion [2]. Children with an underlying bone condition might present with a displaced hip fracture coupled with a history of low-energy trauma [28]. Skeletally immature individuals may come with a limp, referred pain in the hip, thigh, or knee, and a history of low-energy trauma [2]. Children with stress fractures can have a limp, antalgic gait, and tenderness or pain in the hip, thigh, or knee. Non-displaced fractures might not be so obvious, often with only mild discomfort during passive motion of the limb. Stress fractures and non-displaced fractures are easily overlooked at first evaluation [18]. Prolonged hip pain without major trauma suggests a pathological or stress fracture [29]. Associated injuries such as head and neck injuries, thoracoabdominal and musculoskeletal injuries are most common and clinicians should look for them particularly in patients with a history of high-energy trauma [2]. Diagnosis is made based on history (mechanism of injury, symptom onset, pain characteristics), physical examination (limb alignment, swelling, tenderness, range of motion, and neurovascular integrity), and imaging. Anteroposterior radiograph of the pelvis, AP radiograph of the internally rotated hip, and lateral radiograph of the hip will confirm most hip fractures [9, 26]. They will provide information such as the type of fracture, location, and direction of the fracture line, displacement amount, degree of angulation, and the location of femoral epiphyses [2]. Anteroposterior radiograph with the hip internally rotated is important in displaced fractures, as externally rotated diaphysis can overlap and prevent correct fracture recognition. Frog-leg radiographs should be avoided, as they could cause great pain. Plain radiography might not show stress fractures or non-displaced fractures, and MRI or non-contrast CT will be needed [18].

CLASSIFICATION

Proximal femoral fractures are classified using the Delbet classification into four types (excluding stress and insufficiency fractures), which helps predict long-term outcomes, complications, and guide treatment decisions [19, 26]. For fractures involving the growth plate (physeal injuries), the Salter-Harris classification provides additional detail regarding the fracture pattern and potential growth disturbance. Delbet type IA is a transphyseal fracture without proximal fragment dislocation, while type IB is a transphyseal fracture with proximal fragment dislocation [2]. Both subtypes are at the highest risk of developing osteonecrosis, while type IB, according to some reports, progresses to osteonecrosis in most cases regardless of treatment option [30]. Delbet type II are transcervical fractures. They are the most common pediatric proximal femoral fracture type and account for 40–50% of fractures [2, 31]. The most common complication is osteonecrosis, and the best predictor of AVN is initial fracture displacement [18]. Delbet type III are cervicotrochanteric fractures, which occur through the base of the neck. Delbet type IV are intertrochanteric (fractures occur between the greater and lesser trochanter). They are the least common type of fracture and have the best prognosis. They progress into osteonecrosis in less than 10% cases, and complications such as coxa vara and non-union develop rarely. Stress fractures and proximal metaphysis fractures in newborns do not fit into the Delbet classification [2]. Stress fractures in children are described by anatomic location, type (tension or compression), and imaging characteristics and are not categorized under any formal classification. Other classification systems have been developed to address specific fracture characteristics, growth plate involvement, and to guide treatment strategies. These include the Ratliff classification, the AO Pediatric Comprehensive Classification of Fractures, and the Salter-Harris and Peterson classifications for physeal injuries [32–34]. The Ratliff system primarily focuses on the anatomical pattern and stability of proximal femoral fractures, categorizing them into intracapsular, extracapsular, and mixed types. It emphasizes the fracture's relation to the capsule and vascular supply, which is pertinent when considering the risk of AVN and planning surgical intervention. While less detailed in the anatomical subdivision than the Delbet classification, it provides a framework for understanding fracture stability and vascular compromise [32]. The AO Pediatric Comprehensive Classification of Fractures is a universally recognized system that details pediatric fractures based on anatomical location, fracture morphology, and growth plate involvement. It categorizes proximal femoral fractures into specific groups, including those involving the femoral neck, head, and trochanteric region, with subgroups delineating fracture pattern (e.g., displaced vs. non-displaced) and physeal involvement. This classification is particularly useful in research for standardizing reporting and facilitating comparative studies across different treatment modalities [33]. For fractures involving the proximal femoral growth plate (physeal fractures), the Salter-Harris classification remains the gold standard, describing fractures based on the involvement of the growth plate and metaphysis. Types I through V provide insight into the potential for growth disturbance and guide management decisions. The Peterson classification is a modification that considers the fracture's location relative to the physis and the presence of displacement, offering additional detail pertinent to surgical planning [34]. While the Delbet classification remains predominant in clinical practice for pediatric proximal femoral fractures, especially in predicting osteonecrosis risk, integrating other systems enhances comprehensive assessment.

TREATMENT

Hip fractures in children can be managed operatively or nonoperatively. Nonoperative treatment is rarely indicated but may be appropriate in children younger than 2 years (or 4 years in some cases) old with Delbet fracture types IA, II, III, or IV that are non-displaced or minimally displaced, i.e., fractures that are inherently stable and unlikely to displace further with conservative management [18]. The recommended technique is closed reduction and immobilization using a spica cast, splinting, traction, or a Pavlik harness [35]. Immobilization typically lasts 6–12 weeks, depending on the fracture type and fixation stability. The acceptable alignment criteria for type II include an angulation of less than 5°, cortical translation of less than 2 mm, and no signs of malrotation; for types III and IV, an angulation of less than 10° is permissible. Operative treatment includes emergency open reduction and internal fixation (ORIF) with capsulotomy, closed reduction percutaneous pinning, or ORIF with pin/screw fixation or with a sliding hip screw. The goal is to achieve anatomical reduction, stable fixation, and preserve the proximal femoral physis to reduce growth disorders. Early surgical intervention (within 24 hours) is generally preferable to reduce the risk of complications. Emergency ORIF is indicated in open hip fractures, vessel injury, fractures with significant displacement, and concomitant hip or epiphyseal dislocation [2]. It is not clear from the literature whether capsulotomy or joint aspiration in those cases decreases the risk of osteonecrosis, but it is recommended by some authors as it does not add significant harm [36]. Smooth or threaded pins/K-wires are used in younger children, while cannulated screws are preferred in older children for better fixation [37, 38]. Open reduction and internal fixation with pins and screws is recommended for type I, II, and III fractures if closed reduction is unsuccessful. Open reduction and internal fixation with a sliding hip screw may be considered for displaced type IV fractures in older children (typically over 8–10 years), where the bone size is sufficient to accommodate the implant (Table 1, 2) [38].

COMPLICATIONS

Complications after hip fractures are common and include AVN, coxa vara, non-union, infection, and premature physeal closure. Avascular necrosis of the femoral head is the most common and devastating complication, with different reported rates for types I–IV [2]. Overall AVN rate is 29–43% by various authors, with type I having the highest incidence rate and type IV the lowest. Most authors agree that age (older than 11 years), fracture type (more often with Delbet type I), and definitive treatment after 36 h are significant predictors of AVN, though some include displacement as a factor as well [39]. Older children with Delbet type I and II fractures have the highest risk [40]. Avascular necrosis may become visible on plain radiographs 6–8 weeks after the fracture, but radiographic signs could take up to two years to fully develop. Magnetic resonance imaging, however, can detect AVN as early as 2–3 weeks after the fracture, making it the gold standard for early detection [41]. Most cases become radiographically evident within the first year. Ratliff's classification of AVN can be used to describe severity: type I is total necrosis

TABLE 1. Surgical or non-surgical treatment based on age and body weight

Parameters	Indication for surgery	Type of surgical treatment
Age		
Infants (< 1 year)	Conservative management is preferred if fracture is minimally displaced; surgery is indicated for displaced fractures	CRPP is preferred if surgical intervention is necessary
Toddlers (1–3 years)	Displaced fractures generally require surgical fixation; non-displaced may be managed conservatively	CRPP for displaced fractures; ORIF if closed reduction fails or is not feasible
Children (4–12 years)	Displaced or unstable fractures require surgical fixation	ORIF with cannulated screws or pins; plate fixation in complex or comminuted cases
Adolescents (> 13 years)	Similar to adults, displaced fractures require surgical treatment	ORIF with cannulated screws or plates; plate fixation for complex or comminuted fractures
Body weight		
< 20 kg	Displaced fractures typically require surgical fixation; conservative if fracture is minimally displaced	CRPP preferred for appropriate cases; ORIF if reduction is difficult
20–40 kg	Surgical fixation indicated for displaced or unstable fractures	ORIF with cannulated screws; plate fixation for complex cases
> 40 kg	Surgical treatment similar to adults; indicates need for more robust fixation	ORIF with cannulated screws or plates; plate fixation in comminuted or unstable fractures

CRPP – closed reduction and percutaneous pinning, ORIF – open reduction and internal fixation

TABLE 2. Surgical treatment based on Delbet fracture classification

Type	Indication for surgery	Type of surgical treatment
I (transphyseal)	Usually requires prompt surgical intervention due to high risk of avascular necrosis	CRPP (if suitable) or ORIF
II (transcervical)	Usually displaced; surgical fixation recommended to prevent complications	CRPP or ORIF with cannulated screws
III (cervicotrochanteric)	Displaced fractures generally require surgical fixation	CRPP or ORIF; in complex cases, plate fixation
IV (intertrochanteric)	Usually more stable; management depends on displacement	CRPP for minimally displaced; ORIF or plate fixation for displaced or comminuted fractures

CRPP – closed reduction and percutaneous pinning, ORIF – open reduction and internal fixation

of the neck and head, type II is necrosis of the epiphysis, and type III is necrosis of the neck, sparing the epiphysis [38]. Management of AVN and other complications often involves limiting weight-bearing until revascularization occurs, with some cases requiring surgical procedures such as osteotomy or arthrodesis if deformities develop. Coxa vara develops from malreduction, loss of reduction, delayed union, or premature physeal closure, occurring in 13–30% of cases, and leads to pain, gait abnormalities, and poor hip mechanics [15, 36]. It is prevented by anatomical reduction and rigid internal fixation that avoids crossing the growth plate, with valgus osteotomy as a corrective measure if needed. Infections are rare (around 1%) but can present as prolonged pain, redness, and fever; they are managed with surgical debridement and antibiotics [2]. Lack of union, limb length discrepancies, growth disturbances, and abnormal bone healing are important late complications that can significantly impact function. Non-union or delayed union may occur, particularly in cases with significant soft tissue injury or infection, necessitating surgical intervention such as bone grafting or osteotomy. Limb growth disorders, including limb length discrepancy and deformities, can result from physeal injury or premature closure; these are managed with growth modulation procedures or lengthening techniques. It is essential to monitor patients longitudinally with clinical and radiographic assessments to detect these issues early and implement appropriate corrective measures. Regarding the management of AVN and other complications, weight-bearing protocols are tailored to the individual case, and decompression with grafting may be performed in selected situations to promote revascularization and healing.

FEMORAL SHAFT FRACTURES

MECHANISMS OF INJURY

The usual mechanism of femoral shaft fracture differs with the age of the child. If the child has not started to walk or is < 3 years, most femoral fractures will be a result of non-accidental trauma, which has been shown in multiple studies [1, 3]. Younger children (< 10 years) usually fall from a height, while older children (> 10 years) are mostly injured in collisions involving motor vehicles, bicycles, scooters, *etc*. [42]. Other possible mechanisms include underlying conditions (such as osteogenesis imperfecta, osteopenia, and benign or malignant bone tumors), as well as injuries in high-energy or high-velocity sports, and rarely, obstetrical trauma (difficult delivery or breech presentation).

CLINICAL PRESENTATION, PHYSICAL EXAMINATION, AND DIAGNOSIS

A femoral fracture can be diagnosed on clinical presentation and examination. History of instability of the limb and inability to walk or high-energy trauma, e.g., fall from a height, motor vehicle or bicycle crash, should raise suspicion. Localized pain and swelling, along with visible deformity, crepitus, or shortening of the limb, are usual tell-tale signs. Skin should be inspected for possible open fracture. Proximal femoral fracture signs, such as external rotation and hip pain, can point to a shaft fracture as they sometimes break together. Compartment syndrome is rare but will present with increasing pain and swelling of the limb or, less often, with pallor, paresthesia, pulselessness, and paralysis. One should bear in mind to search for associated injuries in children with femoral shaft fracture, especially if the child is hemodynamically unstable. Head, neck, thoracoabdominal, and extremity associated injuries are all plausible, with head and thoracoabdominal injuries being the most dangerous. Anteroposterior and lateral plain radiographs of the femoral from hip to knee joint are needed to evaluate and confirm the fracture and to exclude associated injuries. Additional body parts radiographs or CT scans will be done based on suspected associated injuries, especially in high-energy trauma [2]. If child abuse is suspected (dubious history report, multiple fractures), additional skeletal radiographs and evaluation of possible associated injuries should be undertaken. A transverse bone fracture should alert the physician to probable non-accidental trauma [43].

CLASSIFICATION

Femoral shaft fracture can be classified with the AO Classification based on the radiographic evaluation and the soft tissue condition. Radiographs are examined for fracture location (proximal, middle, and distal third of diaphysis), configuration (transverse, spiral, or oblique), angulation, comminution, and the amount of shortening, translation, and displacement. Fracture can be further depicted as open (fracture exposed to the external environment) or closed based on the physical examination and stable (transverse and oblique) or unstable (spiral and comminuted) [2]. The amount of comminution can be classified with the Winquist classification system, which assesses the stability of the fracture and guides treatment decisions [44]. The Gustilo open fracture classification categorizes open fractures into five categories based on the wound size, the extent of soft tissue damage, and the extent of contamination. It helps with making treatment decisions [45].

TREATMENT

Definitive treatment varies greatly and depends on the age and weight of the child, type of fracture, hemodynamic stability, and the surgeon's preferences. There are operative and nonoperative treatment options. Usually, children younger than 6 years will be treated nonoperatively, although in some cases of high-energy trauma and multiple associated injuries, flexible intramedullary nails might be needed [46]. If the child is younger than 12 months, fractures can be treated with a splint or spica cast. For neonates, a padded tongue depressor wrapped with a cotton roll provides an effective immobilization. A Pavlik harness can be used instead, if the child is younger than 4 months or up to 6 months if smaller in proportion [35]. Spica cast can be used for children aged 0–6 years if there is a closed fracture, shortening < 2 cm, and not polytraumatized. Fractures with shortening > 2 cm will require skin or skeletal traction with delayed spica casting [47]. Fractures with angulation > 10° will need closed reduction under sedation. Older children (> 6 years) are usually treated operatively, and the modality differs by age, weight, skeletal maturity, and fracture type. For patients aged 6–12 years with a stable fracture, closed reduction with flexible intramedullary nailing is the treatment of choice [47, 48]. There is some variability in the literature regarding the type of intramedullary nails used, with titanium nails and Enders stainless steel nails both described in different studies. Unstable fractures (highly comminuted or spiral) or in children weighing more than 49 kilos should be treated with submuscular bridge plating [49]. Children older than 12 and weighing more than 49 kilos will be treated with antegrade rigid intramedullary nail fixation [22]. The piriformis fossa entry point is associated with a small risk of osteonecrosis of the femoral head in skeletally immature, younger children [50]. That is why the approach below the greater trochanteric physis, or more laterally, is used until skeletal maturity allows for entry into the piriformis fossa in adolescence [51]. In this age group, submuscular bridge plating is used in severely comminuted fractures. In older children approaching skeletal maturity, the femoral shaft may be better suited for plate fixation due to the size and density of the bone. External fixation is reserved for severe soft tissue injury, open fractures, and multiple trauma (Table 3, 4) [2, 6].

TABLE 3. Surgical or non-surgical treatment based on age and body weight

Parameters	Non-surgical treatment	Surgical treatment	Notes
Age			
< 2 years	Usually spica casting	Rarely indicated; if needed, flexible nails or external fixation	Due to high remodeling potential, conservative treatment is preferred
2–6 years	Spica casting or traction	Consider intramedullary nailing (elastic or titanium nails) if fracture is unstable or displaced	Favor conservative approach is favored unless specific circumstances warrant surgery
6–12 years	Spica casting or traction	Flexible nails, external fixation (if indicated)	Surgical fixation is increasingly indicated for displaced or unstable fractures. External fixation may be specifically indicated in this age group in selected cases
> 12 years	Often surgical, especially with unstable fractures	Intramedullary nails (rigid or flexible), plate fixation	Surgical treatment becomes the standard in older children
Body weight			
< 20 kg	Spica casting	Usually flexible or elastic nails	Conservative conservative approach is preferred due to ease and remodeling capacity
20–49 kg	Casting or traction	Flexible nails, external fixation	Surgical options are considered more often with displacement or instability
> 49 kg	Often surgical	Rigid intramedullary nailing, plate fixation	Surgery becomes more common due to reduced remodeling potential

TABLE 4. Surgical or non-surgical treatment based on fracture type

Fracture type	Non-surgical treatment	Surgical treatment	Notes
Displaced, unstable	Typically traction and casting initially, but may require surgery	Flexible intramedullary nailing, external fixation, or plate fixation	Surgical treatment is preferred for unstable or significantly displaced fractures
Transverse and non-displaced	Spica casting	Usually not indicated, unless other factors required so	Conservative management is usually sufficient
Oblique or spiral fractures	Casting if stable, or traction	Consider internal fixation if fracture is unstable or displaced	Stability guides treatment choice
Comminuted fractures	Often traction or casting	Usually external fixation or plate fixation	Surgical approach depends on fracture complexity

COMPLICATIONS

Overall, complications in femoral shaft fractures are not common. They present either shortly after the high-energy trauma or after a period of time, where treatment modality and altered anatomy and physiology impact the type of complications. Infection, compartment syndrome, and neurovascular damage are complications that present shortly after the trauma [2]. Nerve injuries are usually transient and rarely result in nerve palsy, while vascular damage, evaluated with angiography or Doppler, requires urgent surgical treatment [52]. Infection presents a week after the operation or sometimes several weeks or months later as non-union. Patients should be closely monitored through regular clinical examinations and radiographic assessments during the healing process to detect early signs of complications. Vigilant observation allows for timely intervention, minimizing long-term sequelae. Complications ensuing from altered physiology and anatomy (prolonged immobilization) are deep vein thrombosis, fat embolism, and cast syndrome (duodenum obstructive compression). Delayed complications include leg length discrepancy, rotational and angular deformity, delayed union and non-union, and other complications arising from specific treatment modalities. Pavlik harness has a minimal complication rate, but there is a risk of femoral nerve palsy [2]. Spica cast treatment is often followed by skin complications (ranging from redness and skin irritation to blisters and excoriations) [53]. Traction of the injured limb can lead to nerve palsies, especially in heavier children and prolonged surgery time [2]. Pin-tract infection is a common complication from external fixation; other possible complications are refracture (result of early frame removal) and prolonged time to union [54]. Infection can be prevented by good pin care, pre-drilling of the pin holes, and short antibiotic treatment. Avascular necrosis of the femoral head is a possible complication after inserting rigid nails in skeletally immature children through the piriformis fossa [2]. Leg length discrepancy is the most common complication of femoral shaft fracture and is a result of either overgrowth (accelerated growth) or shortening at the fracture location [44]. Overgrowth is more common in younger children, boys, and those with comminuted or long oblique fractures. Leg length discrepancy is treated based on the anticipated discrepancy at skeletal maturity. For a difference of 0–2 cm, observation or a shoe lift is recommended. If the discrepancy is 2–5 cm, shoe lift, temporary or permanent contralateral epiphysiodesis is the treatment of choice. A difference of more than 5 cm is treated with a lengthening procedure like distraction osteogenesis. A discrepancy of more than 15–20 cm is treated with prosthetic fitting [2]. Non-union is rare and associated with infection or severe soft tissue damage [46]. Treatment includes either dynamization of the solid intramedullary nail by removing the distal locking screws or curettage of the fibrous non-union and bone grafting with autograft or demineralized bone matrix. Rigid fixation with plate or flexible intramedullary rods usually follows. Delayed union is mostly a result of using the external fixator and is treated by dynamization of the fixator or by removing the fixator and doing internal fixation with intramedullary rods, plates, and screws [2].

DISTAL FEMORAL FRACTURES

MECHANISMS OF INJURY

The mechanism of injury mostly differs with the patient's age. Newborns can suffer from obstetrical trauma (causes being e.g. breech delivery, fast labor and delivery), which is not always recognized immediately and can be difficult to diagnose [55]. In infants and young children, falls from a significant height and abuse are common causes [3]. Children with a distal femoral fracture who are not walking yet, especially if a corner fracture, are highly suspicious of non-accidental trauma [56]. Falling from a height or being involved in a motor vehicle, bicycle, or scooter accident is a common cause of injury for school-age children. The usual mechanism in adolescence is engagement in high-energy sports (e.g., football, skiing) or motor vehicle accidents [57].

CLINICAL PRESENTATION, PHYSICAL EXAMINATION, AND DIAGNOSIS

The patient mostly has a history of high-energy trauma. Newborns present usually with swelling, redness, decreased and painful mobility of the affected limb after traumatic delivery. The child may be irritable when handled, and crepitus can be observed on motion. Local signs are often overlooked as they are not apparent, and diagnosis can be made days later [55]. Older patients will be in severe pain and unable to walk with a swollen distal femoral. The knee might be tense and swollen, along with visible deformity, and hamstring muscle spasm will often cause knee flexion. Skin should be searched for open skin lesions and open fractures. Careful neurovascular examination ought to be performed in all patients. Cold and pale limb, absent distal pulses, and swelling in the popliteal fossa call for urgent Doppler assessment or ankle brachial pressure index to evaluate potential vascular injury. Foot drop and foot sensory deficit point to peroneal or tibial nerve injury. Soft tissue should be palpated often during the first 48 hours to assess for possible compartment syndrome (signs being deep burning pain, diminished or loss of sensation, pallor, paresthesia, muscle weakness, paralysis) [2]. Associated injuries are common, especially in patients with a history of significant trauma, and should be thoroughly examined [3]. Anteroposterior and lateral plain radiograph of the femoral, knee, and hip should be done to confirm the diagnosis and rule out associated injuries. An oblique view can sometimes aid in the diagnosis of minimally displaced or non-displaced fractures when bone tenderness is present and standard radiographs do not show a fracture. A computed tomography scan helps with calculating the amount of displacement at the fracture site, while an MRI shows internal knee derangement and confirms physeal fracture. Computed tomography angiography should be done when physical examination or ultrasound suggests vascular injury. Newborn femoral fractures might be hard to diagnose with plain radiography, so MRI or ultrasound could be used instead [2, 58].

CLASSIFICATION

Distal femoral fractures are classified as physeal or metaphyseal fractures. Metaphyseal fractures are also called transverse distal metaphyseal fractures or supracondylar femoral fractures [23]. Physeal fractures are further classified into five types using the Salter-Harris classification. Type I has a fracture line extending through the physis, separating it from the metaphysis. A type II fracture runs partially through the physis and out of the metaphysis, creating a triangular metaphyseal fragment. Type III has a fracture plane going through a portion of the physis and across the epiphysis. In type IV, the fracture extends through the metaphysis, physis, and epiphysis, while type V represents crush injury to the physis, where the growth region is compressed or damaged without a clear fracture line [2]. The Salter-Harris classification describes physeal (growth plate) fractures of the distal femoral and, when combined with injury mechanism and displacement, assists in predicting outcomes and complications. While useful, it should be complemented by other assessment tools for comprehensive management (Table 5) [57].

TABLE 5. Surgical or non-surgical treatment based on Salter-Harris classification

SH type	Non-surgical treatment	Surgical treatment	Notes
I	Usually conservative if non-displaced; immobilization in cast	Surgery is generally not required unless displaced or unstable	High potential for remodeling, especially in younger children
II	Often managed conservatively if fracture is minimally displaced	Indicated if fracture is displaced or unstable; fixation with screws or pins	Most common SH fracture; good prognosis with proper treatment
III	Usually surgical to restore joint congruity if displaced	Typically requires ORIF	Displaced Type III fractures often need surgical stabilization
IV	Usually surgical due to intra-articular involvement	Surgical fixation is necessary to restore anatomy and joint surface	High risk of growth disturbance and deformity if untreated
V	Usually requires surgical intervention due to physeal damage	Surgery to minimize growth disturbance; may need physeal bar resection	Typically poor prognosis; early intervention is critical

SH – Salter-Harris, ORIF – open reduction and internal fixation

TABLE 6. Surgical or non-surgical treatment based on age and body weight

Parameters	Non-surgical treatment	Surgical treatment	Notes
Age			
< 5 years	Displaced or non-displaced fractures; generally non-surgical approach is favored due to remodeling potential	Usually reserved for complex, unstable, or open fractures	Conservative treatment is preferred in young children due to high remodeling capacity
5–10 years	Minimally displaced fractures	Indicated for displaced, unstable, or comminuted fractures	Surgical intervention is often preferred for displaced fractures
> 10 years	Generally surgical for displaced fractures due to limited remodeling	ORIF	Non-surgical approach is considered only in very specific, stable cases
Body weight			
< 20 kg	Often suitable for conservative management, especially if fracture is minimally displaced	Surgical fixation for displaced or unstable fractures	Weight influences fixation choice; less invasive methods are preferred in lighter children
20–40 kg	May be considered for non-displaced or minimally displaced fractures	Usually for displaced fractures; fixation methods vary	Increased weight necessitates surgical stabilization
> 40 kg	Conservative management is less common surgery is more likely needed if fracture is displaced	Surgical fixation with more robust hardware (e.g., plates, screws)	Higher body weight correlates with increased surgical indication due to stability concerns

ORIF – open reduction and internal fixation

TREATMENT

Treatment modality depends on the age of the patient, type of fracture, displacement, and associated injuries. Options include conservative treatment with splinting or casting and operative treatment with closed or open reduction and external or internal fixation with a stabilizing implant. Overall, non-displaced and stable fractures can be treated conservatively with long leg casting and should be closely overseen for displacement. If displacement occurs, closed reduction and fixation should be performed [2]. Infants up to 6 months with metaphyseal or diaphyseal fractures can be treated with splinting (tongue depressor with cotton padding). Metaphyseal or diaphyseal fractures in children from 6 months to 5 years can be treated with long leg casting, and for children older than 5 years, various types of fixation devices are available, such as pins, screws, flexible nails, plates, and external fixators. Fractures involving physis in younger children or fractures that are stable after reduction can be treated with long leg casting alone, though some authors argue that all physis fractures require fixation [59]. Reduction should always be attempted under sedation or anesthesia. Periosteum might be interposited, which will require open reduction [60]. Salter-Harris II, III, and IV with large metaphyseal/epiphyseal fragments should be fixated with screws that do not violate the physis. Kirschner wires can be placed across or near the physis in a cross-pin configuration when required. Children with distal femoral fractures need to be monitored for some time (frequency and duration depend on the surgeon, type of fracture, reduction, age, and operative technique), and injuries to the growth plate have to be monitored for at least one year (Table 6) [2].

COMPLICATIONS

Complications can be acute or late. Acute complications are compartment syndrome, injury of the popliteal artery or peroneal nerve, and infection [2]. Peroneal nerve palsy generally shows spontaneous recovery over time, although the extent and timing of recovery can vary among patients [59]. Infection mostly presents early with fever, redness, and secretion, but can sometimes manifest months later as non-union. Late complications include physeal arrest with leg length discrepancy or angular deformity, loss of knee motion, and non-union [2]. Leg length discrepancy is common, and risk factors include high-energy trauma and severely comminuted or displaced fractures. Anderson-Green tables or Moseley straight-line graph can be used to calculate projected discrepancy at skeletal maturity. When the discrepancy is 2 cm or less, no treatment is needed; for 2–5 cm of discrepancy, options include contralateral epiphysiodesis in skeletally immature patients or femoral lengthening procedures in skeletally mature individuals. Discrepancies above that will require femoral lengthening procedures. Angular deformity is less common than leg length discrepancy and should be treated with osteotomy or epiphysiodesis when angulation is more than 5° [2, 61]. Loss of knee motion is common after a distal femoral fracture, especially with cast immobilization, but usually resolves with physical therapy. Non-union is an uncommon outcome that is usually associated with severe soft tissue injury, significant bone loss, or infection. Management of non-union often requires surgical intervention, including fibrous tissue removal and bone grafting to promote healing [2]. To mitigate the risk of complications, it is important to identify patients with high-energy trauma, severely comminuted or displaced fractures, and delayed presentations, as these factors are associated with an increased likelihood of non-union and deformity. Regular clinical and radiographic monitoring during the initial weeks post-injury allows for early detection of issues such as infection or non-union, facilitating timely intervention. Preventive strategies include meticulous surgical technique, proper fracture stabilization, early mobilization, and strict adherence to aseptic protocols, all of which contribute to reducing the incidence of complications.

PATHOLOGICAL FRACTURES OF THE FEMORAL

Pathological fractures in children often occur due to benign or malignant bone lesions that weaken the femoral's structural integrity. The most common cystic lesions involved are UBC, ABC, and, less frequently, fibrous dysplasia or ossifying fibromas [2, 62]. Unicameral bone cysts are especially prevalent in the pediatric population, typically affecting the proximal humerus and femoral [63]. These lesions appear as well-defined radiolucent zones with sclerotic borders on imaging, often occupying the metaphysis, and are characterized by cortical thinning that predisposes to fracture. Fractures usually traverse the cystic area, following the line of least resistance, due to the lack of normal lamellar bone. Radiologically, MRI can help assess cyst content and soft tissue involvement, aiding diagnosis and treatment planning [64]. The cysts' ongoing osteolytic activity, combined with mechanical stress, increases fracture risk, especially in larger cysts. Post-fracture, the cyst may serve as a focus for healing; however, recurrence remains common if residual tissue persists. Management varies from conservative immobilization for stable fractures to surgical procedures such as curettage, bone grafting, and internal fixation to restore stability and prevent recurrence [65, 66]. Minimally invasive options like percutaneous steroid injections or decompression are also being explored with varying success (Table 7) [67].

FEMORAL STRESS FRACTURES

Femoral stress fractures are overuse injuries caused by repetitive mechanical loading that exceeds the bone's capacity for repair and remodeling. While more common in adults, they are increasingly recognized in children and adolescents engaged in high-impact sports or activities involving lower limb stress [68]. The pathophysiology involves an imbalance in bone remodeling, with osteoclastic resorption surpassing osteoblastic formation, leading to microdamage accumulation that can progress to a clinically significant fracture [69]. Predisposing factors include sudden increases in training intensity, biomechanical abnormalities, nutritional deficiencies, and underlying conditions like osteoporosis or metabolic disorders [68]. They are reported more often in females, possibly related to the female athlete triad – disordered eating, amenorrhea, and osteoporosis – that impairs bone health [70]. Although rare in children, these fractures are often underdiagnosed due to diagnostic challenges. Affected individuals typically present with insidious groin, thigh, or anterior hip pain that worsens with activity and improves with rest; progression may include tenderness, swelling, and decreased range of motion [68]. Imaging is essential: radiographs may initially appear normal but later show cortical lucencies or sclerosis, while MRI is preferred for early detection of periosteal and marrow edema along fracture lines [71]. Differential diagnoses include osteoid osteoma, AVN, osteomyelitis, and soft tissue injuries. Most fractures occur in the subtrochanteric region, with femoral neck fractures posing higher risks of displacement and AVN if untreated. Management is primarily conservative – rest, activity modification, and gradual return – while surgical fixation is reserved for displaced or high-risk fractures [72, 73]. Early diagnosis and treatment are vital, as delayed management can lead to complete fractures and complications. Prevention involves gradual training, proper biomechanics, nutritional optimization, and screening for bone health issues in high-risk individuals [74].

TABLE 7. A comprehensive table outlining pathological femoral fractures in children associated with cysts, tumors, and systemic diseases

Parameters	Pathophysiology and features	Indications for treatment	Treatment options	Prognosis and notes
Unicameral (simple) bone cyst	Fluid-filled cystic lesion in the metaphysis, thinning cortex, often asymptomatic until fracture occurs	Symptomatic fractures, cysts > 2/3 of bone diameter, recurrent fractures	Immobilization (casting) for stable fractures Curettage + bone grafting for recurrent or large cysts Percutaneous steroid injection (less invasive) Internal fixation if unstable	Good healing with appropriate management; high recurrence risk if cyst persists
Aneurysmal bone cyst	Blood-filled, expansile, osteolytic lesion with multiloculated appearance; rapid growth may cause cortical expansion	Symptomatic fractures, significant deformity, or rapid growth	Curettage + bone grafting En bloc resection in aggressive cases Preoperative arterial embolization to reduce bleeding Internal fixation for stabilization	Favorable prognosis; recurrence possible, especially if incompletely excised
Fibrous dysplasia	Developmental fibro-osseous lesion replacing normal bone; may be monostotic or polyostotic	Fracture with persistent deformity or pain	Conservative: immobilization Surgical: osteotomy, curettage + grafting, internal fixation for deformity correction	Variable; some lesions stabilize over time, risk of deformity or deforming fractures
Osteofibrous dysplasia	Benign fibro-osseous lesion; can mimic ossifying fibroma	Fracture, deformity, or diagnostic uncertainty	Conservative management Surgical excision in selected cases	Generally good; rare malignant transformation to adamantinoma
Osteosarcoma	Malignant mesenchymal tumor producing osteoid; aggressive periosteal reaction	Pathological fracture, pain, soft tissue mass, systemic symptoms	Neoadjuvant chemotherapy Limb-sparing surgery or amputation Postoperative chemotherapy	Variable; prognosis depends on tumor response, stage at diagnosis
Ewing sarcoma	Malignant small round cell tumor; often affects diaphysis	Pathological fracture, systemic symptoms, soft tissue extension	Chemotherapy Local control with surgery and/or radiotherapy	Prognosis improves with early diagnosis; high risk if fracture occurs at presentation
Langerhans cell histiocytosis (eosinophilic granuloma)	Clonal proliferation of Langerhans cells causing localized osteolytic lesions	Fracture, pain, localized swelling	Observation for asymptomatic, stable lesions Curettage + bone grafting Corticosteroids Radiotherapy in selected cases	Generally excellent; high healing rate with appropriate treatment
Osteogenesis imperfecta	Congenital disorder characterized by defective collagen synthesis leading to brittle bones	Fractures with minimal trauma	Bisphosphonates to increase bone density Supportive care: immobilization, physical therapy Surgical fixation in high-risk fractures	Variable; ongoing management reduces fracture risk, improves quality of life
Metastatic lesions	Usually secondary to neuroblastoma, leukemia, or other malignancies	Pathological fracture, systemic symptoms	Chemotherapy/radiotherapy Surgical stabilization Palliative care	Poorer prognosis; treatment focuses on tumor control and fracture stabilization

The table covers conditions, clinical and radiological features, indications for treatment, treatment options, and prognosis considerations.

CONCLUSIONS

While recent advances in diagnostic imaging and minimally invasive treatment strategies have enhanced the management of pediatric femoral fractures, challenges remain in optimizing treatment protocols across different age groups and fracture types. Limitations related to long-term outcomes, potential growth disturbances, and the variability in individual responses underscore the need for further research. Future studies should focus on establishing standardized, age-specific guidelines and evaluating long-term functional and developmental outcomes to ensure comprehensive and effective care for affected children.

DISCLOSURES

1. Institutional review board statement: None.
2. Assistance with the article: None.
3. Financial support and sponsorship: None.
4. Conflicts of interest: None.

REFERENCES

1. Rewers A, Hedegaard H, Lezotte D, Meng K, Battan FK, Emery K, et al. Childhood femur fractures, associated injuries, and sociodemographic risk factors: a population-based study. Pediatrics 2005; 115: 543-552.
2. Herring JA. Tachdjian's pediatric orthopaedics. 6th ed. PA: Elsevier, Philadelphia,2022.
3. Loder RT, O'Donnell PW, Feinberg JR. Epidemiology and mechanisms of femur fractures in children. J Pediatr Orthop 2006; 26: 561-566.
4. Kraus R, Dresing K. Rational usage of fracture imaging in children and adolescents. Diagnostics (Basel) 2023; 13: 538.
5. Caldwell L, Chan CM, Sanders JO, Gorczyca JT. Detection of femoral neck fractures in pediatric patients with femoral shaft fractures. J Pediatr Orthop 2017; 37: e164-e167.
6. Liau GZQ, Lin HY, Wang Y, Nistala KR, Cheong CK, Hui JHP. Pediatric femoral shaft fracture: an age-based treatment algorithm. Indian J Orthop 2020; 55: 55-67.
7. Kulkarni SL, Mannual S, Daragad M, Patil N, Ernest D. Management of complex femur fractures in children: a report of three cases. J Orthop Case Rep 2021; 11: 33-37.
8. Sun J, Wang T, Zhao N, Chen H, Chen C. Pediatric femoral shaft fractures: the American Academy of Orthopaedic Surgeons clinical practice guidelines versus actual management in a teaching hospital. Transl Pediatr 2024; 13: 938-945.
9. Duffy S, Gelfer Y, Trompeter A, Clarke A, Monsell F. The clinical features, management options and complications of paediatric femoral fractures. Eur J Orthop Surg Traumatol 2021; 31: 883-892.
10. Han F, Liu Z, Wei Q, Ding L, Yu L, Wang J, et al. Minimally invasive implantable biomaterials for bone reconstruction. Eng 2025; 46: 23-46.
11. Standring S. Gray's anatomy: the anatomical basis of clinical practice. 42nd ed. Elsevier, Amsterdam 2020.
12. Ogden JA. Skeletal injury in the child. Springer, New York, NY 2000.
13. Van Geel P, Cools W, Laumen A. Evolution of head-shaft angle and neck-shaft angle in childhood. Acta Orthop Belg 2021; 87: 435-441.
14. Seeley MA, Georgiadis AG, Sankar WN. Hip vascularity: a review of the anatomy and clinical implications. J Am Acad Orthop Surg 2016; 24: 515-526.
15. Dial BL, Lark RK. Pediatric proximal femur fractures. J Orthop 2018; 15: 529-535.
16. Watson EC, Adams RH. Biology of bone: the vasculature of the skeletal system. Cold Spring Harb Perspect Med 2018; 8: a031559.
17. Dimeglio A. Growth in pediatric orthopaedics. J Pediatr Orthop 2001; 21: 549-555.
18. Beaty JH. Fractures of the hip in children. Orthop Clin North Am 2006; 37: 223-232.
19. Mirdad T. Fractures of the neck of femur in children: an experience at the Aseer Central Hospital, Abha, Saudi Arabia. Injury 2002; 33: 823-827.
20. Engström Z, Wolf O, Hailer YD. Epidemiology of pediatric femur fractures in children: the Swedish Fracture Register. BMC Musculoskelet Disord 2020; 21: 796.
21. Salonen A, Laitakari E, Berg HE, Felländer-Tsai L, Mattila VM, Huttunen TT. Incidence of femoral fractures in children and adolescents in Finland and Sweden between 1998 and 2016: a binational population-based study. Scand J Surg 2022; 111: 14574969221083133.
22. Galano GJ, Vitale MA, Kessler MW, Hyman JE, Vitale MG. The most frequent traumatic orthopaedic injuries from a national pediatric inpatient population. J Pediatr Orthop 2005; 25: 39-44.
23. Sepúlveda M, Téllez C, Villablanca V, Birrer E. Distal femoral fractures in children. EFORT Open Rev 2022; 7: 264-273.
24. Miao KH, Miao JH. Radiological diagnosis and imaging of femoral shaft fractures. Anatomia 2023; 2: 282-299.
25. Pape HC, Krettek C, Friedrich A, Pohlemann T, Simon R, Tscherne H. Long-term outcome in children with fractures of the proximal femur after high-energy trauma. J Trauma 1999; 46: 58-64.
26. Patterson JT, Tangtiphaiboontana J, Pandya NK. Management of pediatric femoral neck fracture. J Am Acad Orthop Surg 2018; 26: 411-419.
27. DeFranco MJ, Recht M, Schils J, Parker RD. Stress fractures of the femur in athletes. Clin Sports Med 2006; 25: 89-103.
28. Silva LCA, Asma A, Ulusaloglu AC, Rogers KJ, Bowen JR, Howard JJ, et al. Closed displaced femur fractures in children with nonambulatory cerebral palsy. J Pediatr Orthop B 2023; 32: 452-460.
29. Goolsby MA, Barrack MT, Nattiv A. A displaced femoral neck stress fracture in an amenorrheic adolescent female runner. Sports Health 2012; 4: 352-356.
30. Xin P, Li Z, Pei S, Shi Q, Xiao L. The incidence and risk factors for femoral head necrosis after femoral neck fracture in pediatric patients: a systematic review and meta-analysis. J Orthop Surg Res 2023; 18: 22.
31. Yadav SK, Agrawal AC, Kar BK, Sakale HS, Sahoo B, Chandan R. Pediatric fracture of the neck of femur. J Orthop Dis Traumatol 2018; 1: 11-14.
32. Feng W, Zhang H, Zhu D, Song B, Wang Q. Clinical features of pediatric femoral neck fractures and analysis of risk factors for avascular necrosis of the femoral head: a retrospective case-control study of 45 patients. Injury 2024; 55: 111829.
33. Joeris A, Lutz N, Blumenthal A, Slongo T, Audigé L. The AO Pediatric Comprehensive Classification of long bone fractures (PCCF). Acta Orthop 2017; 88: 129-132.
34. Cepela DJ, Tartaglione JP, Dooley TP, Patel PN. Classifications in brief: Salter-Harris classification of pediatric physeal fractures. Clin Orthop Relat Res 2016; 474: 2531-2537.
35. Stannard J, Christensen KP, Wilkins KE. Femur fractures in infants: a new therapeutic approach. J Pediatr Orthop 1995; 15: 461-466.
36. Pandey RA, John B. Current controversies in management of fracture neck femur in children: a review. J Clin Orthop Trauma 2020; 11: S799-S806.

37. Chandankere V, Shah H. Controversies in the management of pediatric neck femur fractures – a systematic review. J Orthop 2021; 27: 92-102.
38. Bali K, Sudesh P, Patel S, Kumar V, Saini U, Dhillon MS. Pediatric femoral neck fractures: our 10 years of experience. Clin Orthop Surg 2011; 3: 302-308.
39. Spence D, DiMauro JP, Miller PE, Glotzbecker MP, Hedequist D, Shore B. J. Osteonecrosis after femoral neck fractures in children and adolescents: analysis of risk factors. J Pediatr Orthop 2016; 36: 111-116.
40. Canale ST, Tolo VT. Fractures of the femur in children. Instr Course Lect 1995; 44: 255-273.
41. Beltran J, Burk JM, Herman LJ, Clark RN, Zuelzer W, Freedy MR, et al. Avascular necrosis of the femoral head: early MRI detection and radiological correlation. Magn Reson Imaging 1987; 5: 431-442.
42. Hedlund R, Lindgren U. The incidence of femoral shaft fractures in children and adolescents. J Pediatr Orthop 1986; 6: 47-50.
43. Di Laura Frattura G, Cochard B, De Marco G, Vazquez O, Dayer R, Ceroni D. Femoral fractures in non-accidental trauma and child abuse: biomechanical perspective and insights. Front Pediatr 2025; 13: 1484920.
44. Winquist RA, Hansen ST Jr, Clawson D. Closed intramedullary nailing of femoral fractures. A report of 520 cases. J Bone Joint Surg Am 1984; 66: 529-539.
45. Gustilo RB, Anderson JT. Prevention of infection in the treatment of one thousand and twenty-five open fractures of long bones: retrospective and prospective analyses. J Bone Joint Surg Am 1976; 58: 453-458.
46. Heffernan MJ, Gordon JE, Sabatini CS, Keeler KA, Lehmann CL, O'Donnell JC, et al. Treatment of femur fractures in young children: a multicenter comparison of flexible intramedullary nails to spica casting in young children aged 2 to 6 years. J Pediatr Orthop 2015; 35: 126-129.
47. Flynn J, Luedtke LM, Ganley TJ, Dawson J, Davidson RS, Dormans JP, et al. Comparison of titanium elastic nails with traction and a spica cast to treat femoral fractures in children. J Bone Joint Surg Am 2004; 86: 770-777.
48. Ho CA, Skaggs DL, Tang CW, Kay RM. Use of flexible intramedullary nails in pediatric femur fractures. J Pediatr Orthop 2006; 26: 497-504.
49. Chen LK, Sullivan BT, Sponseller PD. Submuscular plates versus flexible nails in preadolescent diaphyseal femur fractures. J Child Orthop 2018; 12: 488-492.
50. Del Balso C, Bartley D, Cashin M, Carey T, Lawendy AR. Rigid intramedullary nail fixation of traumatic femoral fractures in the skeletally immature. OTA Int 2021; 4: e128.
51. Orler R, Hersche O, Helfet DL, Mayo KA, Ward T, Ganz R. Avascular femur head necrosis as severe complication after femoral intramedullary nailing in children and adolescents. Unfallchirurg 1998; 101: 495-499.
52. Kluger Y, Gonze MD, Paul DB, DiChristina DG, Townsend RN, Raves JJ, et al. Blunt vascular injury associated with closed midshaft femur fracture: a plea for concern. J Trauma 1994; 36: 222-225.
53. DiFazio R, Vessey J, Zurakowski D, Hresko MT, Matheney T. Incidence of skin complications and associated charges in children treated with hip spica casts for femur fractures. J Pediatr Orthop 2011; 31: 17-22.
54. Carmichael KD, Bynum J, Goucher N. Rates of refracture associated with external fixation in pediatric femur fractures. Am J Orthop (Belle Mead NJ) 2005; 34: 439-444.
55. Krosin MT, Lincoln TL. Traumatic distal femoral physeal fracture in a neonate treated with open reduction and pinning. J Pediatr Orthop 2009; 29: 445-448.
56. Arkader A, Friedman JE, Warner WC Jr, Wells L. Complete distal femoral metaphyseal fractures: a harbinger of child abuse before walking age. J Pediatr Orthop 2007; 27: 751-753.
57. Riseborough EJ, Barrett IR, Shapiro F. Growth disturbances following distal femoral physeal fracture-separations. J Bone Joint Surg Am 1983; 65: 885-893.
58. Hsu CS, Hellinger JC, Rubin GD, Chang J. CT angiography in pediatric extremity trauma: preoperative evaluation prior to reconstructive surgery. Hand (N Y) 2008; 3: 139-145.
59. Eid AM, Hafez MA. Traumatic injuries of the distal femoral physis. Retrospective study on 151 cases. Injury 2002; 33: 251-255.
60. Segal LS, Shrader MW. Periosteal entrapment in distal femoral physeal fractures: harbinger for premature physeal arrest? Acta Orthop Belg 2011; 77: 684-690.
61. Vogt B, Gosheger G, Wirth T, Horn J, Rödl R. Leg length discrepancy – treatment indications and strategies. Dtsch Arztebl Int 2020; 117: 405-411.
62. Ortiz EJ, Isler MH, Navia J, Canosa R. Pathologic fractures in children. Clin Orthop Relat Res 2005; 432: 116-126.
63. Rajasekaran R, Krishnamoorthy V, Gulia A. Unicameral bone cysts: review of etiopathogenesis and current concepts in diagnosis and management. Indian J Orthop 2022; 56: 741-751.
64. Margau R, Babyn P, Cole W, Smith C, Lee F. MR imaging of simple bone cysts in children: not so simple. Pediatr Radiol 2000; 30: 551-557.
65. Van Geloven TP, van der Heijden L, Laitinen MK, Campanacci DA, Döring K, Dammerer D, et al. As simple as it sounds? The treatment of simple bone cysts in the proximal femur in children and adolescents: a retrospective multicenter EPOS study of 74 patients. J Child Orthop 2024; 18: 85-95.
66. Costa DD, Gabrielli E, Cerrone M, Di Gialleonardo E, Maccauro G, Vitiello R. Pathological fractures in aneurysmal bone cysts: a systematic review. J Clin Med 2024; 13: 2485.
67. Meirlaen S, Haoudou R, Thiteux Q, Bellanova L, Docquier PL. Treatment of bone cysts by percutaneous injection of demineralized bone matrix mixed with bone marrow. Acta Orthop Belg 2022; 88: 559-567.
68. Beck B, Drysdale L. Risk factors, diagnosis, and management of bone stress injuries in adolescent athletes: a narrative review. Sports (Basel) 2021; 9: 52.
69. Pepper M, Akuthota V, McCarty EC. The pathophysiology of stress fractures. Clin Sports Med 2006; 25: 1-16, viii.
70. Zhang Z, Jia H, Ren N, Cheng H, Luo D, Li Y, et al. High prevalence of borderline hip dysplasia in young patients with femoral head subchondral stress fractures. J Orthop Traumatol 2025; 26: 54.
71. Tins BJ, Garton M, Cassar-Pullicino VN, Tyrrell PN, Lalam R, Singh J. Stress fracture of the pelvis and lower limbs including atypical femoral fractures – a review. Insights Imaging 2015; 6: 97-110.
72. Robertson GA, Wood AM. Femoral neck stress fractures in sport: a current concepts review. Sports Med Int Open 2017; 1: E58-E68.
73. Bernstein EM, Kelsey TJ, Cochran GK, Deafenbaugh BK, Kuhn KM. Femoral neck stress fractures: an updated review. J Am Acad Orthop Surg 2022; 30: 302-311.
74. Knechtle B, Jastrzębski Z, Hill L, Nikolaidis PT. Vitamin D and stress fractures in sport: preventive and therapeutic measures – a narrative review. Medicina (Kaunas) 2021; 57: 223.