REVIEW ARTICLE

Pediatric Femoral Shaft Fracture: An Age-Based Treatment Algorithm

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Received: 9 August 2020 / Accepted: 29 September 2020 / Published online: 10 October 2020
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Abstract

Purpose Fractures of the femoral shaft in children are common. The rates of bone growth and remodeling in children vary according to their ages, which affect their respective management.

Methods This paper evaluates the incidence and patterns of pediatric femoral shaft fracture and the current concepts of treatments available.

Results The type of fracture—closed or open; stable or unstable—needs to be taken into account. Child abuse should be suspected in fractures sustained by infants. For younger children, non-surgical management is preferred, which include Pavlik harness (< 6 months old) and early spica casting (6 months to 6 years old). Older children (> 6 years old) usually benefit from surgical treatments as outcomes of non-surgical alternatives are worse and are associated with prolonged recovery times. These operative measures for older children that are 6–12 years old include elastic stable intramedullary nailing and submuscular plating. Factors to be considered when devising an appropriate intervention include body mass, location of injury, and nature of fracture. For adolescent and skeletally mature teenagers (> 12 years old), rigid antegrade entry intramedullary fixation is indicated. In the event of open fractures or polytrauma, external fixation should be considered as a temporary treatment method for initial fracture stabilization.

Conclusion An age-based and evidence-based algorithm has been proposed to guide surgeons in the process of evaluating an appropriate treatment.

Keywords Pediatric · Femur · Fracture · Management · Review · Evidence · Children · Shaft · Algorithm · Adolescents

Introduction

Fractures of the femoral shaft are among the most common lower extremity fractures in children [1, 2], with an annual incidence of 20 per 100,000 in the United States and Europe [3–5]. The mechanisms of injury include high-energy trauma—road traffic accidents, falls, high-impact sports injury, and low-energy trauma such as pathological fractures [6, 7]. In younger children, particularly those in pre-walking age, non-accidental injuries should be considered [8–10].

Management of diaphyseal femoral fractures in children includes non-operative treatments such as Pavlik harness, traction, and spica casting [11], and operative treatments such as submuscular plating, elastic nails, rigid nails, as well as internal and external fixation [12–14]. Patient age is the main determinant of management strategy, but other parameters such as weight, fracture pattern, and presence of polytrauma should also be considered [2, 9]. Older children are managed by operative fixation due to shorter hospitalization durations, lower complication rates, and earlier mobilization compared to non-operative treatments [2, 4]. In contrast, non-operative measures are preferred in patients < 6 years old due to unique bone remodeling and rapid reparative ability with minimal complication rates [15].

In this study, we provide a review of the most up-to-date evidence relating to the treatment of femoral diaphyseal fractures in each age group. A pros-and-cons analysis is also done for these techniques. Finally, we present an algorithm

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Fig. 1 Algorithm of treatment for femoral shaft fractures in children

Table 1 Percentage of causes of femoral fractures among children in the US (in year 2000) and UK (between 1991 and 2001)

Cause of femoral fracture	US children age ≤ 18 (%)	UK children age ≤ 15 (%)
Falls	35	49.4
Traffic accidents	33	28.0
Child abuse	2	1.2
Others	30	21.4

to guide decision-making based on our institution's clinical practice (Fig. 1).

Epidemiology

Epidemiological studies (Table 1) in US [16] and UK [1] show that pediatric femoral fractures are commonly associated with falls (US: 35%, UK: 49.4%), traffic accidents (US: 33%, UK: 28%), and child abuse (US: 2%, UK: 1.2%). Males (US: 71%, UK: 68.5%) and young children between ages 2 and 12 are at high risk of femoral fractures (US: 53.8%, UK: 67.8%).

Diaphyseal fractures are the most common pediatric femoral fracture in US and UK, accounting for 68.0% of the closed fractures for children age < 18 in US (Table 2) and 57.5% of the cases for children age < 15 in UK (Table 3).

Table 2 Age group of children with femoral fracture in the US and UK

Age group (years)	Percentage US (%)	Percentage UK (%)
Age < 2	10.8	18.9
2 ≤ Age ≤ 5	21.3	32.8
5 < Age ≤ 12	32.5	35.0
Age ^a > 12	35.4	13.3

^aUpper limit for this age group (US: 18 years old; UK: 15 years old)

Table 3 Percentage of diaphyseal closed femoral fractures among children in the US (year 2000) and UK (between 1991 and 2001)

Location of femoral fracture	US children age ≤ 18 (%)	UK children age ≤ 15 (%)
Shaft	68.0	57.5
Others	32.0	42.5

Anatomy

Proximal and distal physes separate the epiphysis and metaphysis of the pediatric femur. They are critical for proper femoral development, and hence, intramedullary devices must be inserted carefully to avoid growth disturbances [17].

The deep branch of medial femoral circumflex artery (MFCA) [5] is the main blood supply of the femoral head prior to the fusion of physes. The arterial branches and anastomoses are often in close proximity to the greater trochanteric and piriformis fossa, and coincide with possible entry points of intramedullary nails [5, 18]. Hence, damage to these branches can result in avascular necrosis of the femoral head.

Bone remodeling occurs during childhood, as the primarily weak woven bone develops into a stronger lamellar bone [19, 20]. This property confers the pediatric femur the ability to tolerate a wide range of angular deformity and shortening than in older pediatric patients [17]. However, torsional deformities are generally less well tolerated as remodeling occurs to a smaller extent [21].

The strength of bone is enhanced with age due to a change in geometry, increase in cortical diameter, and area moment of inertia [22]. Thus, higher proportion of adolescent fractures are due to higher energy trauma.

Etiology/Pathophysiology

The etiology of pediatric femoral fractures varies with the patient's age. For younger children, a simple fall is a common cause of femoral fractures [3]. Injuries sustained by older children and adolescents are more likely due to high-energy trauma, with a large proportion of cases attributed to vehicle accidents [3]. Nonetheless, simple falls remain a plausible cause of femoral fractures in older children [8].

Pathological femoral fractures are comparatively rare in children, responsible for only 12.5% of pediatric femoral fractures under the age of 4 [17]. Common causes include cerebral palsy, osteogenesis imperfecta [16], osteosarcoma, and fibrous dysplasia [23]. Stress fractures of the femoral shaft are uncommon and give rise to only 4% of all femoral fractures in children [17].

Non-accidental Injury (NAI)

Young age is a strong predictor of non-accidental pediatric femoral fractures [24], with up to 60% of femoral fractures in infants < 1 year old due to suspected or confirmed child abuse [8, 10]. NAI should be suspected in children younger than walking age, and a detailed history, physical examination, fracture characterization, and injury scene investigation should be conducted for a thorough assessment of the cause of injury [25].

Associated Conditions

Femoral fractures may often be accompanied by soft-tissue damage which can involve neurovascular structures [18, 26]. The occurrence of femoral diaphyseal fracture in polytrauma

may be associated with injuries to the head, chest, and abdomen. Reports have shown the associations of Waddell's triad, comprising (1) ipsilateral femoral shaft fractures, (2) ipsilateral intra-abdominal injury injuries, and (3) contralateral head injury, with high-energy automobile trauma [27]. Hypotension serves as an important sign in pediatric trauma, and it is less commonly due to femoral shaft fractures [28]. Hence, children with both femoral shaft fracture and hypotension should be evaluated for alternative causes of blood loss.

Classification

The Pediatric AO Classification is a validated integrated classification system based on anatomy and morphology of the bone (Figs. 2, 3). It is highly recommended due to high inter-observer reliability among trained orthopedic surgeons (kappa, $k > 0.90$) [29, 30].

A broader classification system suggested by the American Academy of Orthopedic Surgeons (AAOS) and some studies [31] defines aligned and minimally displaced broken ends of the bone as stable fractures, and comminuted, spiral, and oblique fractures as unstable fractures [32]. The stability of the fracture has important surgical significance which is further elaborated under the "Algorithm" section.

Presentation and Physical Examination

Pediatric femoral fractures are not isolated injuries as they are commonly associated with falls and traffic accidents. According to the AAOS, initial physical examination of

Fig. 2 Classification of bone segments (left) and bone types (right) of the femur

Classification of femoral shaft fractures

*E.g. Classification of **32-D/5.1** corresponds to a simple and oblique femoral diaphyseal fracture

Fig. 3 Classification of long bone fractures in children

patients presenting fracture of the femoral shaft shows swelling and tenderness around the mid-thigh with complaints of severe pain. Waddell's triad often presents in patients involved in traffic accidents [27], and additional examinations of the thorax, abdomen, and head are required in such cases. These patients must be closely observed for signs of shock and hypotension due to severe hemorrhage from multiple injuries [33].

Radiographic imaging is also important to augment the conformational diagnosis of fractures. Common high-impact fractures associated with transverse, spiral, and comminuted pediatric femoral shaft fractures are displayed in Fig. 4.

Principles of Management

The management of pediatric femoral shaft fractures can be classified broadly into two groups: first, treatment of closed isolated fractures and second, treatment of open fractures and fractures associated with polytrauma. Age is the main determinant of management for fractures in the first group. Though uncommon in young children, fractures in the second group are very severe [1, 16] and require immediate mitigatory treatments to stabilize the fragments and to allow for treatment of other associated injuries. The fractured fragments can then be definitively fixed at a later date. Table 4 shows the acceptable ranges of acceptable alignment and shortening values [34]. Table 5 summarizes the pros and cons of each of the treatment methods.

Treatment of Closed Isolated Femoral Diaphysis Fracture Based on Age Group

Neonate and Infants Aged 6 months

Femoral fractures resulting from birth injuries are extremely rare, occurring in < 1% of live births [35], but can occur in vaginal breech presentations and difficult deliveries during birth [36].

Up to 60% of femoral fractures in infants < 1 year old are due to suspected or confirmed child abuse [8, 10]. Hence, primary management of femoral fractures in infants < 1 year old and those unable to walk should involve the evaluation of child abuse [37]. If child abuse is suspected, the management of the child's condition should be conducted in a multidisciplinary collaboration with social workers and child protective services while taking into account the relevant social, economic, and behavioral factors of the victim [38].

Infant femoral diaphyseal fractures are usually immediately treated with simple splint to provide stability and reduce pain [39], followed by application of Pavlik harness to immobilize the injured femur while maintaining an optimal position for reduction of the femur [40]. Immobilization with Pavlik harness serves as an excellent standard for management of femoral shaft fractures in neonates [40, 41], as it allows rapid callus formation with minimal complications [42]. At the same time, the Pavlik harness provides benefits of ease of application and adjustability, reduced hospitalization, minimal cost, and ease of nursing care and diapering [35, 41]. Children in this age group also present

Fig. 4 **a** X-ray of a right proximal 1/3 closed spiral femoral diaphyseal fracture in a boy aged 6 years, sustained from a road traffic accident. **b** X-ray of a right middle 1/3 closed transverse femoral

diaphyseal fracture, supported by external fixators. **c** X-ray of a right proximal 1/3 closed comminuted femoral diaphyseal fracture in a boy aged 15 years, sustained from a road traffic accident

Table 4 Acceptable alignment and shortening values post-treatment for pediatric femoral fractures

Age (years)	Varus–valgus angulation (°)	Anterior–posterior angulation (°)	Shortening (mm)
0–2	<30	<30	<15
2–5	<15	<20	<20
6–10	<20	<15	<15
11	<5	<10	<10

with excellent remodeling potential towards angulation and limb-length inequality (tolerating up to 15 mm of shortening and 30° of angulation) [34], further improving the efficacy of Pavlik harness. Findings report high tolerance to malunion, malalignment, and shortening when Pavlik harness is used in infants [41]. In the event of rare unstable fractures where Pavlik harness may not offer sufficient support, hip spica casting is a possible alternative, though potential complications include malalignment and skin ulcerations [35, 41]. Traction is rarely necessary for femoral fractures in this age group.

Older Infants to Young Children Aged 6 Months to 5 Years

In children 6 months to 5 years of age, the Pavlik harness is often insufficient to offer reasonable stabilization.

Studies have shown a high tolerance to angulation and shortening (tolerating up to 20 mm of shortening and 15–20° of angulation) [34] but relatively lower tolerance to rotational deformity in this age group [21], which justifies the popular usage of other non-operative treatment methods. Traditionally, children in this age group were treated with early traction for 1–2 weeks followed by delayed spica casting (applied after 48 h of injury) immobilization [43]. However, more recent studies have found that such management methods are frequently associated with longer hospitalization duration, increasing cost, and high rates of infections associated with traction [43, 44]. Nevertheless, this method remains plausible for unstable, comminuted fractures or significant fractures with > 2 cm of initial shortening that cannot be effectively reduced by early spica casting (applied within 48 h of injury) [2, 9]. As callous formation occurs rapidly in young children, femoral diaphyseal fractures can be sufficiently stabilized for hip spica casting after a week of traction application [9].

In the event that a traction is applied, the type of traction used generally depends on the size of the child. Recommended skin tractions in smaller children (< 12 kg) are typically in the form of gallows traction, whereas Hamilton–Russell skin tractions are often used for larger children (≥ 12 kg) to provide better comfort and stabilization of injury [18].

Table 5 Summary of pediatric femoral shaft fracture treatments

Age	Bone profile	Treatment	Advantages	Disadvantages
$0 \leq \text{Age} < 6$ months	Excellent bone remodeling potential	Pavlik harness	Allows rapid callus formation Easily applied and adjusted Reduce hospitalization time and cost	Unable to provide sufficient support for unstable fractures
$6 \text{ months} \leq \text{Age} < 6$ years	High tolerance to angulation and shortening, but low tolerance to rotational deformity	Hip spica casting	Offers good support for unstable fractures	Prolonged casting leads to Excessive limb shortening Loss of reduction Peroneal nerve palsy Compartment syndrome Unacceptable angulation of fracture
$6 \text{ years} \leq \text{Age} < 12$ years	Strength of bone increases	Elastic stable Intramedullary Nailing (ESIN)	Good for stable transverse or short-oblique fractures Minimal surgical exposure Low infection risk Rapid rehabilitation	Backout of nails Malunion Unacceptable shortening in length-unstable or comminuted fractures
		Submuscular plate fixation	Minimal surgical exposure Less soft-tissue damage and smaller surgical scars Good for length-unstable, very proximal or distal or comminuted fractures	May cause leg-length discrepancy Additional surgical exposure during removal of plate
		External fixation	Good for fractures with extensive neurovascular tissue damage, open and/or polytraumatic fractures Relatively quick procedure; good as immediate life-preserving treatment for severe fractures with multiple injuries Safer option for metadiaphyseal fractures Low complication rates	Slow union Pin-site infection Overgrowth Malalignment Refracture
$\text{Age} \geq 12$ years	Approaches skeletal maturity, unable to stabilize fracture fragments sufficiently	Rigid intramedullary nail	Most stable Good for very proximal, very distal, length-unstable or long oblique fractures	Entry of nail at the femoral head may cause avascular necrosis

Many studies have compared early hip spica casting and early traction with delayed spica casting, and reported that while both methods achieve similar time to union, fracture shortening, angulation, and rotational deformity [45], early hip spica casting is associated with significantly reduced infection rates [4, 45], shortened hospitalization duration and lowered treatment costs [46, 47]. Thus, early hip spica casting is increasing in popularity [43]. However, prolonged casting may be complicated by excessive limb shortening, loss of reduction, peroneal nerve palsy, skin macerations, compartment syndrome, and an unacceptable angulation of fracture [48, 49]. Hence, proper casting techniques are necessary and patients should be monitored closely while in casts [18]. Cast wedging or cast change is also necessary to reduce the risk of excessive shortening and angulation.

Overall, early hip spica casting is a good management method for femoral shaft fractures in this age group. Early traction with delayed spica casting may be considered where indicated.

Older Children Aged 6–12 Years

Within this age group, non-operative measures such as traction, splinting, and early spica casting may still be relevant for younger children, and can produce satisfactory healing rates with low rates of infection or complications [9, 50]. However, non-operative measures appear effective only for minimally displaced fractures, which are relatively rare [50]. As the duration for immobilization using non-operative treatment methods increases with the age of the child,

operative alternatives are increasingly favored, because they allow earlier mobilization and weight-bearing. Moreover, operative techniques are associated with lower hospitalization costs and reduced social impact on families [9].

Elastic Stable Intramedullary Nailing (ESIN)

ESIN (Fig. 5) using stainless-steel or titanium nails is increasingly popular for management of femoral fractures for children 5 years and older [51]. ESIN is widely applicable for many types of fractures, but is especially suitable for length-stable transverse or short-oblique fractures [50]. ESIN is advantageous compared to other surgical methods, primarily because it requires minimal surgical exposure, has low risk of infections, and offers shorter hospitalization with rapid rehabilitation [12, 13]. It also provides a shorter healing period with fewer major complications as compared to traction, early spica casting [14, 52], external fixation [53], and plating [54]. A flexible intramedullary nailing is able to provide relative stability—sufficient room for micromotion at the fracture site, promoting natural healing with abundant callus formation without disturbing growth plate development [12].

There are mainly two types of flexible elastic nails—titanium elastic nails (TEN) and stainless-steel nails with minor differences in method of application [9]. TEN nails are more elastic, and are able to limit stress-shielding of the fracture site from forces necessary for rapid callus formation [55]. However, biomechanical evidence has shown that patients weighing more than 49 kg or with age greater than 11 years have greater tendency for sagittal and coronal angulation, which leads to deformation of nails in femoral fractures treated with the more flexible TEN. This results in loss of reduction in the sagittal and coronal planes [56] causing poor radiographic and clinical outcomes [5, 18, 50]. Stainless-steel nails are more rigid and are often stacked to enhance canal filling [55]. Hence, many recommend the use of the more rigid stainless-steel nails for the treatment of fractures in heavier patients [57]. Proper surgical technique is also required to for optimal rotational, axial, and translational stability in these patients [5].

Elastic nails can be inserted using anterograde or retrograde methods. Two flexible nails are inserted via proximal lateral entry points slightly inferior to greater trochanter during anterograde insertion [58], whereas they are inserted via a medial lateral entry point 2–3 cm superior to distal femoral physis during retrograde insertion [58]. Retrograde insertion is indicated for most fractures proximal to the appropriate insertion points of the distal femoral approach, even for distal third femoral fractures, as it offers greater fracture stability [59]. On the other hand, anterograde insertion is reserved for fractures distal to the distal metaphyseal–diaphyseal junction [59], but the invasion of distal femoral physis with

nail tips [60] may be necessary to achieve sufficient stability. At the same time, maximization of nail spread at the fracture site, which is critical to confer fracture stability [59], is more difficult to achieve with anterograde insertion. Hence, plate fixation may be more preferable in fractures involving the more proximal and distal parts of femur, as the ability to bridge across the metaphyseal–diaphyseal junctions stabilizes the fracture while avoiding the growth plates [61].

Elastic nailing has some disadvantages such as backout of nails [32], malunion, and unacceptable shortening in length-unstable or comminuted fractures [62, 63]. End caps may be implemented (Fig. 6) in fractures involving unstable axis as they provide better axial stability to prevent nail backout, reduce soft-tissue irritation, and facilitate implant removal [32].

Submuscular Plate Fixation

In submuscular bridge plate fixation, the patient is positioned in a supine position and the procedure is performed under fluoroscopy [64]. The plate is pre-contoured to the bone for good post-operative alignment [65]. A lateral, longitudinal incision about 2–3 cm is made at the thigh either proximally or distally. The plate is then placed on the bone through the incision and screwed proximal and distal to the fracture location for stable reduction. Though submuscular bridge plates may be implemented in various fracture patterns, studies show that it is more effective in providing rigid stabilization for length-unstable [66] fractures, very proximal or distal [67] fractures, and comminuted [17] fractures. It is also indicated for obese children (> 49 kg) who cannot be sufficiently treated by ESIN [68]. Interest in submuscular bridge plate fixation methods (Fig. 7) has increased, because traditional method of compression plates causes prolonged surgical exposure and substantial soft-tissue damage [17], and is associated with high rates of infection. The main advantages of submuscular bridge plate fixation include minimal surgical exposure and preservation of periosteal blood supply [69], which significantly reduce soft-tissue damage, complication rates, and surgical scars. However, since submuscular plating is typically used for more complicated fractures, the rates of non-union, malunion, and leg-length discrepancy are still expected to be relatively high [70]. Furthermore, in the event that plate removal is deemed necessary, additional dissection may increase surgical exposure and soft-tissue damage [17, 70].

External Fixation

External fixation (Fig. 8) stabilizes fractures percutaneously. After reducing the fracture, pins are drilled perpendicularly into the proximal and distal axes of the femur, and subsequently stabilized by pin clamps, rings, or arches

Fig. 5 **a–c** Pre-operative X-ray of a 6-year-old boy (18 kg) with a left middle 1/3 closed spiral femoral diaphyseal fracture, sustained from a fall. **d, e** Post-operative X-ray taken at 9 months, showing good three-

point fixation by TEN with end caps for fracture stabilization and abundant callus formation

Fig. 6 **a** Immediate post-operative X-ray of an 11-year-old (35 kg) boy with a right middle 1/3 closed comminuted femoral diaphyseal fracture treated with TEN and stabilized with end cap. **b** Post-operative X-ray taken at 6-months, showing satisfactory recovery in terms of length, angulation, and rotation

Fig. 7 X-ray of a 10-year-old boy (50 kg) with a left middle 1/3 closed comminuted femoral diaphyseal fracture treated with submuscular bridging plate. Due to unstable nature of fracture and heavy weight of patient, plating is more beneficial as a treatment

Fig. 8 X-ray of a 9-year-old boy (40 kg) with a left proximal 1/3 closed comminuted femoral diaphyseal fracture along with long spiral fractures and intra-abdominal injury treated with external fixation (mainly for unstable patients and unstable fractures)

[71]. External fixation is generally indicated for severe fractures with extensive neurovascular tissue damage, open fractures, and fractures associated with polytrauma [72], and serves as an initial stabilization for these fractures. It is also indicated for specific metadiaphyseal fractures that are associated with pediatric pathologic fractures caused by bone cyst and non-ossifying fibromas [71]. External fixation is technically easier to perform with minimal complication rates [2] and low risk of damage to physes, making it more effective than intramedullary nails or plating in stabilizing these fractures. While it carries risks of slow union, pin-site infection, overgrowth, malalignment, and refracture [18, 73], some authors suggest that this could simply reflect the severity of the underlying injury [18].

Overall, when surgery is required, operative methods include submuscular plate fixation, insertion of intramedullary nails, and external fixation [17]. Among these options, intramedullary nails is the predominant treatment for closed, femoral diaphyseal fractures in children between 6 and 12 years of age [50, 52, 74]. Patient age, weight, sites of fracture, and stability patterns should be considered in formulation of the treatment plan [50].

Adolescents Aged 12 Years to Skeletal Maturity

As children approach skeletal maturity, non-operative procedures become increasingly impractical [18] due to their inability to stabilize fracture fragments sufficiently, resulting in prolonged union time. Rather, conventional or bridging plating techniques are preferred.

The efficacy of intramedullary nail in the treatment of femoral shaft fractures in adolescents is generally well accepted [75], with multiple studies reporting satisfactory length, alignment, and union of fracture [76]. However, the type of intramedullary nail fixation to be used for adolescents remains controversial. For smaller children, flexible intramedullary nails may be sufficient [5, 18]. For older and heavier (> 49 kg) children, especially those with length-unstable fractures, a more rigid antegrade intramedullary nail inserted into the lateral aspect of the greater trochanter of the femur (Fig. 9) would provide good stabilization and avoid avascular necrosis, as opposed to traditional rigid medullary nails with piriformis fossa entry [77]. The use of both types of nails is reported to be effective, with similar rates of malunion and leg-length discrepancy [77]. Alternative methods using careful implementation of flexible nails supplemented with adjunctive femoral bracing, casting, or prolonged bed rest have also shown positive healing outcomes with minimal complication rates [5, 18].

Fig. 9 **a** Immediate post-operative X-ray of a 15-year-old boy (50 kg) with a right proximal 1/3 closed comminuted femoral diaphyseal fracture treated with lateral trochanteric entry rigid intramedullary nailing. **b** Post-operative X-ray taken at 4 months, showing good union and recovery

Entry of standard rigid intramedullary nail involves greater trochanteric and piriformis fossae, which coincides with the main blood supply of MCFA [9, 18], which hence presents a risk of arterial impingement and avascular necrosis. Although some preliminary studies indicate that a lateral greater trochanteric tip entry is safer and more effective [78], there is no well-accepted treatment that completely avoids the trochanteric and piriformis fossae. Since avascular necrosis and proximal femoral growth disturbances due to trochanteric apophysis damage can cause long-lasting effects, great precautions must be taken when using rigid intramedullary fixation [79, 80].

There is no consensus on the minimum age at which intramedullary nailing can safely be conducted without damaging the trochanteric growth plates. Some advocate for the nailing to be conducted in children greater than 8 years of age [81], while others maintain that nailing is only safe in children greater than 13 years of age [79]. Nonetheless, evidence shows that the longitudinal growth of the bony greater trochanter and cartilage is largely complete around 8 years of age. Therefore, it may be acceptable to perform intramedullary nailing for children greater than 8 years of age [82].

Treatments of Open Femoral Diaphysis Fractures and Management in Polytraumatic Setting

Open femoral fractures are caused by high-impact trauma, resulting in open wounds near the fracture, and is associated with the Waddell's triad. Hemorrhage from the open wound is often associated with hypovolemia, stroke, and organ failure [83].

Some reports support the use of closed intramedullary nailing to manage less severe open femoral fractures (Type I, II, IIIa under Gustilo–Anderson Classification) [83]. Nailing promotes early mobilization and weight-bearing, while reducing risks for non-union and infection [84]. Regular wound cleansing with the prescription of antibiotics can also help prevent infection. However, this method requires a lot of time which makes it unsuitable to manage more severe open femoral fractures with extensive bleeding [83].

In emergency cases when patients suffer from severe open fractures and multiple injuries [85], external fixation (Fig. 8) is performed within 30 min to quickly stabilize the fracture, followed by treatment of associated injuries, allowing for immediate life preservation [83]. However, complications such as pin-tract infections and neurovascular damage [86] are common.

External fixation is a temporary treatment that needs to be removed and fixed definitively later on, which decreases complication rates and infection risks as opposed to leaving the patient on external fixation [87]. The conversion of external to internal fixation depends on the patient's physical state and the condition of the local soft tissue. It is usually

performed 2 weeks post-surgery [72], with the administration of intravenous antibiotics to reduce infection risks [83].

Hence, closed intramedullary nailing, alongside wound cleansing and antibiotics prescriptions, can be effective for less severe open fractures [83]. Nonetheless, its relatively longer operative time makes it unsuitable for severe open fractures, in which the stability of the general condition of the patient should be prioritized. In severe polytraumatic cases, special consideration outside of the algorithm [9] should be given based on the open wound, multiple injuries in other parts of the body, and the overall physiological stability of the patient. External fixation can be performed immediately for temporary reduction of the open fractures in pediatric patients of all age categories [88], while other critical conditions are maintained. Conversion to internal fixation, which is associated with higher union rates and fewer complications, can be performed once the patient's conditions stabilize [5].

Conclusion

Femoral shaft fractures in children are common. These fractures have various causes and many management methods are available. They can be treated with either non-operative or operative procedures. Non-operative methods include Pavlik harness, early spica casting, and traction. Operative methods may involve intramedullary nailing, plate fixation, and external fixation. The major determinants in choosing the specific method or combination of procedures should involve primarily the age of patient, fracture pattern, and weight. The time for recovery, mobilization, and possible complications should also be considered as secondary determinants. The existing evidence and the authors' experience have led to the proposition of a treatment algorithm for the management of pediatric femoral shaft fractures.

Compliance with ethical standards

Conflict of interest There is no conflict of interest.

Ethical standard statement This article does not contain any studies with human or animal subjects performed by the any of the authors.

Informed consent For this type of study, informed consent is not required.

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