Subtrochanteric Femur Fractures in Children

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Introduction

Fractures in the subtrochanteric region are a particularly challenging subset of femur fractures to manage. These fractures are rare and account for 4–17 % of pediatric femur fractures [1–3]. The mechanism of injury, treatment, and associated complications are significantly different from femoral shaft and intertrochanteric femur fractures, owing to the strong muscle forces, bending moments, and complex fracture patterns that can occur with subtrochanteric femur fractures. Obtaining and maintaining fracture reduction is challenging secondary to flexion, abduction, and external rotation of the proximal fragment, relative to the distal fragment. Treatment selection is based on patient age, weight, femoral canal size, fracture stability,

associated injuries, and surgeon experience. Few studies have evaluated the outcomes and complications of treatment of subtrochanteric femur fractures in children.

Classification

There is no consensus in the literature on the definition of a pediatric subtrochanteric femur fracture. Several definitions exist, including any fracture that is located in the proximal quarter of the femoral shaft or within 3 cm of the lesser trochanter [2, 4]. However, some subtrochanteric femur fractures do not fit perfectly into this classification, with fracture lines extending proximal to the lesser trochanter or distally into the diaphysis. Pombo and Shilt identified a pediatric subtrochanteric femur fracture as a fracture that is located within the proximal 10 % of the total femur length below the lesser trochanter (Fig. 6.1). This formula is a modification of one adult definition of a subtrochanteric femur fracture, which includes any fracture that occurs within 5 cm of the lesser trochanter, based on the average length of the adult femur [5]. Pombo and Shilt's modification is the authors' preferred definition, as it takes into account the difference in femur lengths at various ages, as well as the difference in femur lengths among children of the same age.

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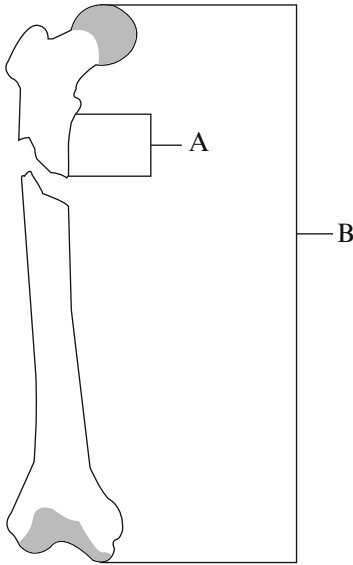e-mail: yingyuli@med.umich.edu

Fig. 6.1 The authors prefer this method to classify subtrochanteric femur fractures. A full-length anteroposterior femur radiograph is used to determine the total length of the femur (*B*), which is defined as the distance between the top of the femoral head and the medial femoral condyle. Next, the distance between the inferior aspect of the lesser trochanter and the fracture site is measured (*A*). If $(A/B) \times 100 = 10\%$ or less of the total length of the femur, the fracture is classified as subtrochanteric

Fig. 6.2 (**a**) AP and (**b**) lateral diagrams of the muscle forces in a subtrochanteric femur fracture. The subtrochanteric region of the femoral shaft is almost completely encased in a muscular envelope. The quadriceps and hamstrings span the proximal femur, and contribute to femoral shortening. The integrity of the trochanters influences fracture deformity. If the majority of the fracture is below the lesser trochanter, the proximal segment typically externally rotates, flexes, and abducts due to the muscular pull of the short external rotators, iliopsoas, and hip abductors. The hip adductors medialize the distal shaft of the femur. In contrast, if the lesser trochanter is involved in the fracture, this results in decreased flexion and external rotation deformities of the proximal fragment produced by the psoas muscle

Anatomy

Knowledge of the proximal femoral anatomy is crucial in order to understand the deforming forces that must be overcome to achieve anatomic alignment. The subtrochanteric region of the femoral shaft is almost completely encased in a muscular envelope. The quadriceps and hamstrings span the proximal femur, and contribute to the femoral shortening that occurs after a subtrochanteric femur fracture (Fig. 6.2). The integrity of the trochanters influences fracture deformity. If the majority of the fracture is below the lesser trochanter, the proximal segment typically externally rotates, flexes, and abducts due to the muscular pull of the short external rotators, iliopsoas, and hip abductors, respectively. The hip adductors, in turn, generally medialize the distal shaft of the femur, as shown in Fig. 6.2. In contrast, if the lesser trochanter is involved in the distal fracture fragment, this results in
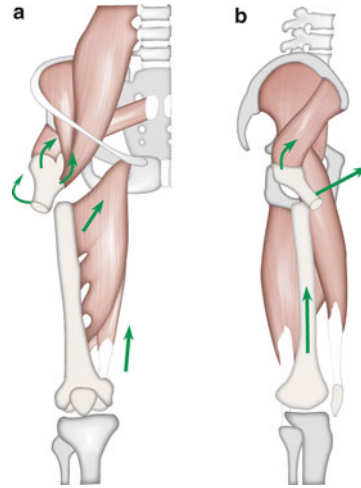
decreased flexion and external rotation deformities of the proximal fragment produced by the psoas muscle. Understanding the pathophysiology of the fracture is crucial to obtain proper reduction, since longitudinal traction alone is unlikely to correct the deformity. The treating surgeon should anticipate the need to utilize several reduction techniques, either through positioning or externally applied forces, to control the fracture segments and obtain proper alignment.

Biomechanics

The majority of the studies evaluating the biomechanics of the subtrochanteric region have been conducted in adult cadaveric and computer models. Although there are many similarities in the stresses seen in the subtrochanteric region, the results of these studies cannot be fully applied to

a pediatric model because the primarily cartilaginous skeleton can better distribute stresses. During ambulation, the femur is subjected to high compressive, tensile, and torsional forces as a result of body weight and the multiple deforming muscle forces exerted on the proximal femur. The majority of these forces are concentrated in the subtrochanteric region [6]. In 1917, Koch et al. created a mathematical beam model of a femur, which was represented as a curved beam with a 100-pound force applied at the femoral head. The authors found that the highest stresses in compression occurred just at the base of the medial subtrochanteric region, and in tension, just below the greater trochanter. This work has been further elaborated on and substantiated by several researchers using various methods, ranging from finite element analysis to 3-D CT modeling [7, 8]. In general, the fracture pattern is determined by the magnitude of the applied load, the rate of load application, and the local strength of the femur.

Mechanism of Injury

The incidence of femur fractures has increased in recent decades, which likely correlates with greater participation in organized sports and physical extracurricular activities [9]. The osseous failure in subtrochanteric fractures may be due to pure torsion, or a combination of torsion and bending. These fractures are found across all age groups and are attributable to a number of mechanisms. High-energy trauma is the most common mechanism, such as motor vehicle accidents or falls. There is an asymmetric age- and gender-related distribution of subtrochanteric femur fractures, with these injuries occurring more frequently in younger children [2, 4, 10] and males [2, 4, 11].

Evaluation

History

A complete history is vital to the proper management of a patient with a subtrochanteric femur fracture. This can be obtained from the patient,

family members, and emergency medical personnel. The pertinent pieces of information that must be documented are the patient's age, mechanism of injury, need for extrication, and any comorbid conditions. Nonaccidental trauma should always be considered in a nonambulatory child. Although fractures associated with nonaccidental trauma are more common in the distal femur, the evaluating physician should assess for signs suggestive of child abuse, such as bruises, burns, late presentation, or fractures in various stages of healing [12]. If the subtrochanteric femur fracture resulted from a low-energy mechanism, evaluation for a pathologic bone condition should be conducted.

Physical Examination

The patient with a subtrochanteric femur fracture usually presents with a lower extremity that is shortened, flexed, and externally rotated secondary to the deforming muscles forces. The extremity should be inspected for any skin disruption, which may indicate an open fracture. The circumference of the hip and thigh should be evaluated and monitored for potential compartment syndrome or an expanding deep hematoma. The knee should be assessed for ligamentous injury and a thorough vascular examination should be performed, including the popliteal, dorsalis pedis, and posterior tibial pulses. The sciatic nerve is in close proximity to the subtrochanteric region, and documentation of the motor and sensory function of the tibial and peroneal nerves is required. The contralateral lower extremity can be assessed to evaluate relative leg lengths. It is imperative to perform a detailed evaluation for other sites of discomfort that may be masked by pain from the femur fracture. A methodical examination of all extremities and the pelvis should be performed to assess for associated fractures. Associated injuries are common in young patients with a high-energy mechanism of injury. Ipsilateral noncontiguous pelvic injuries and other ipsilateral fractures can occur.

It is uncommon for patients with isolated femoral fractures to have hemodynamic insufficiency,

and aggressive volume support is usually not needed. Further investigation into associated abdominal, thoracic, or cranial etiology is warranted in patients who are hypotensive, hypovolemic, or anemic. A study assessing 149 children who sustained a femur fracture secondary to a motor vehicle accident found that 18.5 % of patients had an associated soft-tissue injury, 5 % had an intra-abdominal injury, and 14 % had a head injury [13].

Radiographic Studies

Radiographic evaluation should begin with an anteroposterior (AP) pelvis radiograph, and full-length AP and lateral radiographs of the entire femur. Traction radiographs may be helpful to delineate subtle fracture lines, although these may be difficult to obtain in the acute injury setting. Fracture pattern, comminution, bone loss, and associated fractures should be assessed. Signs of an underlying pathologic bony process should be noted, such as osteopenia or a radiolucent lesion. If nonaccidental trauma is suspected, a skeletal survey should be obtained to evaluate for additional fractures. This should consist of AP radiographs of the long bones of all four extremities, AP and lateral views of the thoracolumbar spine, and an AP and lateral skull series. A single radiograph of the entire child is not sufficient, as this is likely to miss fractures [14].

Computed tomography (CT) is not usually necessary in the routine evaluation of subtrochanteric femur fractures. Magnetic resonance imaging may be indicated if a pathologic fracture or stress fracture is suspected. If there is concern

for vascular compromise, ankle-brachial indices are a quick subjective measurement of limb perfusion that can be obtained in the trauma bay.

Management Principles

The timing of definitive fixation is dictated by the patient's hemodynamic stability and associated injuries. Although the treatment of subtrochanteric femur fractures has been predominantly age-based (Table 6.1), the treating surgeon must take into account the patient's body habitus and skeletal age. Treatment failures occur when there is a mismatch between the biomechanical demands of the fracture and construct stability. In general, overriding of the fracture segments by 2 cm or more indicates disruption of the periosteal sleeve and can be used as an indicator of fracture stability. The ideal device for stabilization of subtrochanteric fractures is an implant that resists the tendency for shaft medialization, as well as external rotation, flexion, and varus angulation of the proximal fragment [15].

Fracture malalignment is a commonly reported complication from subtrochanteric femur fractures [16–21]. The majority of the criteria used for acceptable shortening and angulation at the fracture site originate from the femoral shaft literature. Caution should be used when applying these principles to the assessment of subtrochanteric femur fractures because functional outcome studies assessing proximal femur angular deformities are lacking. In general, fracture shortening is tolerated in children younger than 10 years of age because of the physiologic growth stimulation that occurs during fracture healing and subsequent

Table 6.1 Recommended treatment options for pediatric subtrochanteric femur fractures

Age	Pavlik harness	Spica cast	External fixation	Flexible intramedullary nailing	Open plating	Submuscular plating	Rigid intramedullary nailing
≤6 months	+++	++	–	–	–	–	–
6 months to 5 years	–	+++	+	++	++	++	–
5–11 years	–	–	+	++	++	+++	–
≥11 years	–	–	–	–	++	++	+++

+ authors' least preferred option, ++ authors' accepted option, +++ authors' preferred option

femoral overgrowth following such fractures [2, 4, 22–24]. Therefore, 1.0–1.5 cm of shortening is considered acceptable in this young age group.

Due to the remodeling potential of the femur, coronal and sagittal malalignment can be tolerated up to 20–25° before abductor function becomes compromised [2, 4, 22, 25–27]. Jeng et al. followed 15 children treated with 90–90 traction for a subtrochanteric femur fracture for approximately 6.5 years. Remodeling of coronal angulation was 50 % or more in all cases. However, the average age of patients in the study was 4.5 years, making it difficult to extrapolate the results to adolescents who have decreased growth and remodeling potential [2].

Unlike coronal or sagittal angular deformities, torsional deformities have been found to have less remodeling potential but are generally well compensated by patients [28]. The treating surgeon should carefully scrutinize preoperative and intraoperative imaging, which may include the relationship of the lesser and greater trochanters of the contralateral side, or that of one or both of the trochanters to the distal femoral condyles, to accurately assess the rotational deformity and attempt to correct this during treatment.

Nonoperative Management

Pavlik Harness

The Pavlik harness is the preferred treatment for femoral shaft fractures in children 6 months of age and younger. Notably, however, there are no published reports of pediatric subtrochanteric femur fractures treated with a Pavlik harness. The thick periosteum in this age group results in relative fracture stability. Several authors have reported excellent functional outcomes after Pavlik harness treatment of femoral shaft fractures due to the robust fracture remodeling potential in the infant and toddler [29, 30]. Podeszwa et al. assessed the radiographic and functional results of 40 children under 1 year who had sustained a femur fracture; 24 patients were treated with a Pavlik harness, while 16 patients were treated in a spica cast. They found no difference in radiographic outcomes between the two

Table 6.2 Technical tips for Pavlik harness treatment

Anesthesia:	None
Position:	Supine
Steps:	• Traction is applied to the affected limb while an assistant places the shoulder straps, chest band, and the normal limb in the stirrup.
	• The hip of the affected limb is flexed approximately 80° and is abducted no more than 50°.
	• Pillow or blankets can be used to help prevent the affected leg from falling into abduction when at rest.
Postoperative care:	• Weekly follow-up until the fracture is healed.
	• AP and lateral radiographs are obtained at each visit.
	• Adjustments are made to Pavlik harness based on radiographs.
	• Duration of treatment is usually 3–4 weeks in the young infant.

groups. Approximately one-third of the spica cast patients had a skin complication, which was not seen in the Pavlik harness group [29, 31]. Although a similar study has not been performed in subtrochanteric fractures, we recommend a Pavlik harness for children 0–6 months of age (Table 6.2).

Hip Spica Cast

There is a paucity of data regarding the use of spica casting in the treatment of pediatric subtrochanteric femur fractures. Similar to femoral shaft fractures, children 6 months to 5 years of age can be considered for spica cast treatment. However, because unstable femoral shaft fractures have been shown to displace with spica cast treatment [31, 32], determination of fracture stability is equally, if not more, important when determining the optimal treatment for subtrochanteric femur fractures. The majority of subtrochanteric fractures are difficult to manage with closed means, secondary to the strong deforming muscle forces and high-energy mechanism of injury. Jarvis et al. evaluated 13 skeletally immature adolescents who had undergone treatment of a subtrochanteric femur fracture. Ten patients were treated operatively with a variety of different techniques, while three patients were
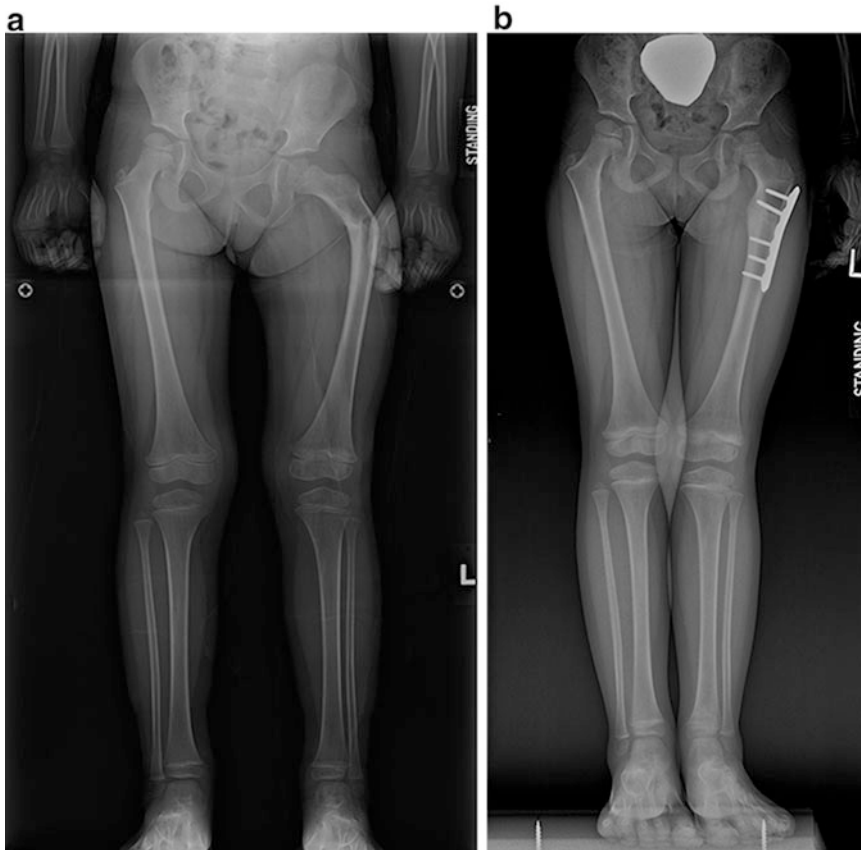
Fig. 6.3 (**a**) Standing AP lower extremity radiographi of a 3-year-old female who sustained a subtrochanteric femur fracture after jumping from a bed. The patient was treated in a spica cast for 8 weeks at an outside facility and was seen as a second opinion for a leg length discrepancy 6 months later. (**b**) Patient 15 months following a subtrochanteric osteotomy

treated nonoperatively with a spica cast. At final follow-up, all of the patients who were treated nonoperatively had unsatisfactory outcomes, with fracture malalignment ranging from 8 to 16° and subsequent leg length inequalities. The authors concluded that internal fixation was more effective than nonoperative treatment of subtrochanteric femur fractures in skeletally immature adolescents [33]. Although children younger than 5 years have increased remodeling potential compared with adolescents, and are more likely to have a good outcome when managed in a spica cast, we advise careful assessment of fracture stability when deciding between spica cast versus operative management of a subtrochanteric femur fracture in this age group. Close radiographic and clinical follow-up is necessary if cast treatment is undertaken (Fig. 6.3a, b), as skin-related complications are also common with spica casting (Table 6.3).

Operative Management

External Fixation

External fixation for treatment of subtrochanteric fractures is generally reserved for open fractures, fractures with associated neurovascular injury, and polytrauma patients [34]. One advantage of external fixation is the ability to perform serial adjustments if the reduction is inadequate. In uniplanar constructs, lateral half-pin frames allow for control of the fracture, as well as mobilization of adjacent joints. Multiplanar external fixators

Table 6.3 Technical tips for spica cast application

Anesthesia:	General with muscle relaxation.
Position:	Supine on a spica table.
Steps:	• Long leg cast is applied first and after it sets incorporate into the torso cast.
	• Applying the long leg cast first allows the surgeon to pull traction through affected extremity with minimal formation of pressure points in the casting material.
	• Important to maintain the knee in 45–60° of flexion and the hip in 45° of flexion during cast application.
	• The foot can be included in the cast in neutral position or left out.
	• Fiberglass is the material of choice. It is soaked in room-temperature water and then rolled using the stretch–relax technique [55] to avoid excessive skin pressure.
	• Assistants should be advised to use the flats of their hands to support the limb during cast application. This prevents indentations in the cast that may cause pressure points and subsequent sores.
	• Cast molding should be performed under fluoroscopy to ensure that proper alignment is maintained.
Postoperative care:	• In general, a good rule of thumb for cast trimming is to leave enough room posteriorly that a caudal block can be given.
	• The perineal area must be trimmed so that adequate room exists for double diapering.
	• Length of time for cast treatment can be determined by patient age in years plus 2 weeks, for a maximum of 12 weeks.
	• Close follow-up is necessary. The patient is seen every 2–3 weeks until completion of cast treatment.
	• Need to monitor for shortening and varus at fracture site.
	• Need to carefully monitor for skin problems and adequate room for growth.
Other:	• A waterproof cast liner instead of stockinette can decrease skin breakdown.
	• Hip spica casts can be augmented with a connecting bar. This may be beneficial in preventing mechanical failure of the cast.
	• Windows can be cut in the abdominal area for decompression or examination purposes.

allow the adjustment to occur in three planes. With the advent of flexible nails, external fixation is now more commonly used as an initial temporizing measure, rather than for definitive fixation. Although external fixation allows for potential adjustment of fracture position after original operation, better functional outcomes have been demonstrated with femoral shaft fractures treated with flexible nails, with decreased time to full-weight bearing, return to full range of motion, and return to school [34, 35]. No studies have specifically compared external fixation and flexible nailing of pediatric subtrochanteric femur fractures. Refracture after frame removal and pin tract infections are potential complications of external fixation. Wani et al. treated 45 displaced femur fractures in children with external fixation and reported pin tract infections in 47 % (Table 6.4) [36].

Flexible Intramedullary Nailing

Flexible intramedullary nailing is currently the most widely used technique for treatment of femoral shaft fractures in children 5–11 years of age, and remains highly applicable to subtrochanteric fractures as well. This is a minimally invasive, simple, economical, and safe technique. Titanium elastic nailing has demonstrated the best outcomes in patients with length-stable femur fractures in the middle 60 % of the diaphysis who weigh less than 49 kg [16–20, 37–39]. There are only a few reports in the literature on the treatment of pediatric subtrochanteric femur fractures with flexible intramedullary nailing [16–19, 21, 38, 39]. Pombo and Shilt examined 13 patients with an average age of 8.7 years, with subtrochanteric femur fractures treated with titanium elastic nails [5]. They classified their results according to the Titanium Elastic Nails Outcome

Table 6.4 Technical tips for external fixation

Anesthesia:	General with muscle relaxation.
Position:	Supine on a radiolucent table.
Implant selection:	• Steinmann pins can be either a 5-mm standard adult half-pin or a 4-mm half -pin for smaller children.
	• Carbon fiber rods are preferred for their radiolucency.
	• Two bars are appropriate for length-unstable fracture patterns.
	• Two pin–bar clamps are placed on each bar.
Steps:	• Fluoroscopy directs safe and strategic half-pin insertion, as well as manipulative reduction.
	• The initial far distal lateral half-pin is placed first in the distal fracture fragment.
	• The pin is placed through a 1-cm stab wound with the use of a sleeve system.
	• A pin-to-pin connector can then be placed on the initial distal pin. This will allow the surgeon to see where the second distal half-pin needs to be inserted in the lateral aspect of the femur.
	• Next, two half-pins are placed in the proximal fragment, generally around the greater trochanter, in a similar fashion.
	• The length of connecting bar is then selected.
	• Manual traction is applied.
	• The reduction is perfected and the two end pin clamps are tightened to the connecting bars.
	• The bar is positioned in line with the femoral shaft laterally and at least two finger breadths from the skin to allow for any thigh swelling.
	• A short intermediate connecting bar can be added if one of the half-pins was placed at an angle. This configuration also allows for easier adjustment of the fracture reduction after the frame has been applied.
Postoperative care:	• Pin site care is instituted the day after surgery.
	• Sterile, saline-moistened, cotton-tipped applicators are used to for pin site care two to three times daily.
	• Toe-touch weight-bearing is advised for 6 weeks after surgery. The patient is restricted to isometric strengthening exercises for 6 weeks.
	• Weight-bearing is advanced when radiographic healing is evident.
	• When fracture callus is present spanning all four cortices on biplanar radiographs, the external fixation device and pins can be removed.
Other:	• The soft tissues adjacent to the pins may need to be incised to allow unrestricted hip and knee range of motion.
	• Entrapped Steinmann pins in the IT band can decrease knee range of motion.
	• The surgeon should passively range the hip and knee in the operating room, and ensure that the skin and deep tissues are adequately released.

Scoring system [16]. There were no poor results. The only complications were leg length inequalities of 1.6 cm or less in two patients, which were attributed to physiologic overgrowth. The authors recommended advancing the lateral nail into or just distal to the greater trochanter apophysis, and advancing the medial nail into the femoral neck just short of the proximal femoral physis (Fig. 6.4a, b). This modification in technique may increase rotational and angular stability by decreasing the forces across the fracture site. The authors also suggested intraoperative stressing of the fracture after fixation to determine whether postoperative immobilization is necessary [5].

Stainless steel flexible intramedullary nails may be an alternative to titanium elastic nails for treatment of pediatric subtrochanteric femur fractures [19, 40]. Unlike titanium elastic nails, which are not optimal for length-unstable fractures, stainless steel nails have demonstrated good results in the treatment of length-stable and length-unstable pediatric femoral shaft fractures [40]. Distal locking of the stainless steel nail increases rotational control, and may prevent

fracture shortening with a subsequent reduction in complications in length-unstable fractures [41]. Stainless steel nails have not been specifically studied in pediatric subtrochanteric femur fractures. The authors' technical tips in flexible intramedullary nailing of pediatric subtrochanteric femur fractures can be found in Table 6.5.

Plating

Plate fixation is an alternative method of fixation in children 5–11 years of age with length-unstable femur fractures, children who weigh more than 49 kg, and children over 11 years who have a femoral canal that is too narrow for rigid intramedullary nailing. Traditional open plating and

Fig. 6.4 (**a**, **b**) A 4-year-old male who sustained bilateral femur fractures after MVC. (**a**) A right displaced and shortened subtrochanteric femur fracture. (**b**) Patient 6 weeks after flexible nailing of the fracture
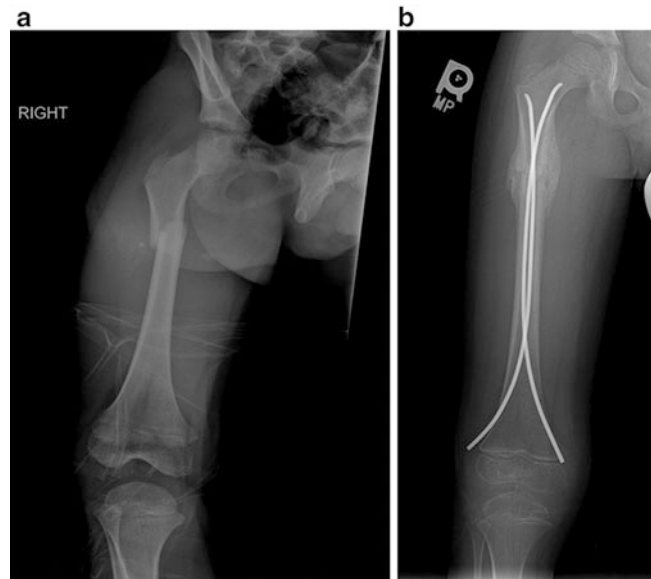
Table 6.5 Technical tips for flexible intramedullary nailing

Anesthesia:	General with muscle relaxation.
Position:	Supine on a radiolucent table.
Implant selection:	• Nail size is determined using the following equation: 1 cm is subtracted from the smallest femoral canal diameter measured on preoperative AP and lateral radiographs, and the result divided by 2.
	• This measurement correlates with the size of the individual nails.
	• Alternatively, one can use 40 % of the narrowest canal diameter to determine nail size.
	• Two nails of equal diameter are used in all cases to balance the forces across the fracture site and prevent angular deformity.
Exposure:	• Fluoroscopy is used to locate the nail insertion site, which is 2.5 cm proximal to the distal femoral physis.
	• An incision is made on the lateral aspect of the distal thigh from the level of proposed nail insertion and is carried 2 cm distally.
	• The subcutaneous tissues and IT band are opened in line with the skin incision, exposing the lateral aspect of the distal femoral metaphysis.
	• The lateral cortex is opened with a drill or a sharp awl.
	• The drill or awl is then redirected cephalad so that it makes a 10-degree angle with the lateral cortex.
	• This will allow the nail to glance off the far cortex as it is advanced and facilitate passage of the nail in the canal.

Table 6.5 (continued)

Steps:	• A slight bend is placed at the tip of the nail to facilitate advancement of the nail beyond the far cortex and to assist with fracture reduction.
	• The nail is then inserted in the starting hole and the intramedullary position verified using fluoroscopy.
	• If the proximal fracture fragment is significantly displaced, a Steinmann pin can be placed percutaneously into the proximal fragment. The proximal fragment can then be easily manipulated to facilitate fracture reduction.
	• The fracture is reduced and the lateral nail is advanced across the fracture site.
	• Next, a medial incision is made, and a nail of equal diameter is placed and advanced into the proximal fragment.
	• Alternatively, both nails can be inserted up to the fracture site and then advanced sequentially across the fracture, making sure that the nails do not bend.
	• If titanium elastic nails are used, advancement of the tip of the lateral nail into or just distal to the greater trochanteric apophysis, and advancement of the tip of the medial nail into the femoral neck just short of the proximal femoral physis may increase fracture stability.
	• When the nails are approximately 1 cm from their final position, the nails are trimmed outside the skin.
	• Final impaction is then performed with a tamp, leaving 1 cm of nail outside the bone.
	• The nail tip should not be bent away from the cortex to minimize soft tissue irritation.
	• Knee range-of-motion should be checked postoperatively to make sure that the nail tips are not impeding motion.
Postoperative care:	• Supplemental external immobilization, such as a knee immobilizer, may be necessary.
	• Hip and knee range-of-motion exercises can be performed immediately.
	• Toe-touch weight-bearing is advised for 4–6 weeks after surgery.
	• Weight-bearing is advanced when radiographic healing is evident.
	• Nails can be removed at 6–12 months postoperatively.

submuscular plating have been described for the treatment of pediatric subtrochanteric femur fractures [42, 43]. Traditional open plating requires more extensive soft tissue dissection, longer operating times, greater blood loss, and potential disruption of periosteal blood flood, thereby increasing the risk of delayed union or nonunion. In cases where proximal fixation is limited, long oblique fracture patterns or patient-specific anatomic constraints, locking plates allow fixation into the femoral neck, optimizing surgical fixation.

Alternatively, submuscular plating uses a minimally invasive insertion technique. Submuscular plates may function as internal "external fixators." Indirect fracture reduction and increased biomechanical stability can be obtained with longer plates and fewer screws. The increased working length of a long plate leads to decreased strain on the construct and reduced pull-out force on the screws. Similar to placement of an external

fixator, one screw should be placed just proximal and one screw should be placed just distal to the fracture. The remaining screws should be spread wide apart for maximum stability. For subtrochanteric femur fractures, the plate is inserted through a proximal incision over the lateral thigh. The plate is then advanced extraperiosteally between the lateral femur and vastus lateralis in a proximal-to-distal direction. Subtrochanteric femur fractures may be better stabilized with a locking plate. There is biomechanical evidence that locking plates provide more stable fixation than titanium elastic nails in femur fractures (Fig. 6.5a, b) [44, 45].

Kanlic et al. evaluated 51 pediatric femur fractures treated with submuscular plating, 24 % of which were in the subtrochanteric region. No postoperative immobilization was used. All of the fractures healed. No wound healing problems or infections were found. Eight percent of patients had a leg length inequality with the affected limb

Fig. 6.5 (**a**, **b**) A 9-year-old male who fell while skiing. (**a**) The patient sustained a right displaced oblique subtrochanteric femur fracture. (**b**) Patient 6 months following submuscular plating

ranging from 23 mm shorter to 10 mm longer. However, none of the patients with subtrochanteric femur fractures experienced significant complications (Table 6.6) [46].

Rigid Intramedullary Nailing

Subtrochanteric femur fractures have been treated successfully with rigid intramedullary nailing in the adult population. These fractures may also be managed in adolescents using nails with a trochanteric entry point or lateral trochanteric entry point. Subtrochanteric femoral fractures have a short proximal fragment with a wide medullary canal, making standard locking techniques potentially inadequate to secure the short proximal fracture fragment. The wide medullary canal in the proximal femur increases the risk of the nail toggling due to lack of screw purchase; therefore, when appropriate a cephalomedullary nail should be used, because its screws engage the bone in the femoral neck. Malalignment of the proximal fragment may occur despite placement of the nail, which may be avoided by assuring an anatomic alignment and control of the proximal fragment during the procedure. The reconstruction femoral nail has a widened proximal section that incorporates one or more interlocking screws, designed to be placed into

the femoral neck. While not directly applicable to the pediatric population, a Cochrane Database review of 189 adults with subtrochanteric femur fractures found that intramedullary nails were associated with fewer fracture fixation complications and higher healing rates than fixed angle plates [47]. Rigid intramedullary nailing can be safely performed in children 11 years to skeletal maturity with a subtrochanteric femur fracture using a trochanteric or a lateral trochanteric entry point, provided the femoral canal is large enough to accommodate the nail [48–50]. A more recent study suggests that children aged 7–12 years may also be acceptable candidates for such newer lateral-entry nailing techniques [51]. The main technical difference between pediatric and adult rigid intramedullary nailing is in the starting point of the femoral nail. A piriformis starting point in a skeletally immature patient places the posteriorly based medial femoral circumflex vessels at risk, injuries to which could lead to avascular necrosis of the femoral head, a rare, but serious, complication. MacNeil et al. performed a systematic review of 19 articles and found an avascular necrosis rate of 2 % when the nail was inserted from the piriformis fossa, compared to 1.4 % from the tip of the greater trochanter, and no reported cases from the lateral aspect of the greater trochanter (Fig. 6.6a, b) [52] (Table 6.7).

Outcomes and Complications

There are few reports in the literature on the outcomes and complications of treatment of pediatric subtrochanteric femur fractures. Complications are related to the strong deforming muscle forces acting at the fracture site and the treatment method. The risk of various complications for each treatment method is listed in Table 6.8.

Flexible Intramedullary Nailing

Titanium elastic nails are currently accepted as the preferred treatment for femoral shaft fractures in children 5–11 years of age; however, they have

Table 6.6 Technical tips for open and submuscular plating

Open plating	
Anesthesia:	General with muscle relaxation.
Position:	Supine on a radiolucent table with a soft bump under the ipsilateral flank.
Implant selection:	• The plate is selected according to the size of the femur.
	• 3.5 mm or the 4.5 mm narrow stainless steel low-contact dynamic compression plate or proximal femoral locking plate.
	• Anatomic constraints of the proximal femur may necessitate plate contouring.
	• Depending on the fracture pattern and extent of comminution, plates with eight or more holes are chosen.
Exposure:	• A straight lateral incision is made over the fracture site and dissection carried down through the iliotibial band.
	• The vastus lateralis is retracted anteriorly, and care is taken to identify and ligate the perforating arteries and veins.
Steps:	• The fracture is reduced under direct visualization and held with a bone clamp.
	• Independent lag screws are inserted if lag screw application through the plate is not possible.
	• The goal is to get six cortices above and below the fracture.
	• If a locking plate is used, a fully threaded cortical screw is used to bring the plate to the bone. Fixed angled locking guides are then screwed into the plate to give the appropriate trajectory for the locking screws.
	• When possible bicortical screw fixation should be performed.
Postoperative care:	• No supplemental external immobilization is necessary.
	• Hip and knee range-of-motion exercises can be performed immediately.
	• Toe-touch weight-bearing is advised for 6–8 weeks after surgery.
	• Weight-bearing is advanced when radiographic healing is evident.
Submuscular plating	
Anesthesia:	General with muscle relaxation.
Position:	Supine on a radiolucent table or fracture table.
Implant selection:	• A 4.5 mm narrow stainless steel low-contact dynamic compression plate is appropriate for most patients. A proximal femoral locking plate can also be used.
	• The length of the plate is determined with the use of fluoroscopy.
	• The average plate length is 12–16 holes to allow for greater distance between the screws.
	• The plate is contoured to match the proximal metaphyseal flare.
Exposure:	• A 3 cm incision is made over the lateral aspect of the proximal femoral metaphysis and the iliotibial band is split.
	• The vastus lateralis is elevated anteriorly.
	• A Cobb elevator is passed extraperiosteally deep to the vastus lateralis to create a tunnel for the plate.
Steps:	• The plate is inserted into the submuscular interval.
	• Traction is applied to the extremity to maintain fracture length and the plate is advanced distally under fluoroscopic guidance.
	• Fluoroscopy is used to verify plate position and reestablishment of fracture length.
	• The plate is provisionally secured with Kirschner wires in the most distal and most proximal screw holes.
	• Insertion of an additional Kirschner wire through the middle of the plate can correct procurvatum at the fracture site.
	• The first screw is placed through the proximal incision. The remaining screws are placed percutaneously.
	• Indirect fracture reduction can be achieved by placing the second screw just proximal or distal to the fracture, where the femur is farthest from the plate.
	• The perfect circle technique on lateral fluoroscopy can assist with percutaneous screw placement.
	• The screws can be tagged with absorbable suture to assist with screw exchange if necessary.
	• Three screws proximal and distal to the fracture placed far apart provide adequate stability. No lag screws are necessary.

Table 6.6 (continued)

| *Postoperative care*:	• No supplemental external immobilization is necessary.
	• Hip and knee range-of-motion exercises can be performed immediately.
	• Toe-touch weight-bearing is advised for 6–8 weeks after surgery.
	• Weight-bearing is advanced when radiographic healing is evident.
	• Although implant removal in children remains controversial, there is evidence that patients with distal femoral shaft fractures treated with open or submuscular plating and plates that are placed ≤20 mm from the distal femoral physis are at risk of developing a distal femoral valgus deformity that may require further surgical intervention. [56]
	• Plates can be removed at 6 months postoperatively.
	• Removal of submuscular plates can be complicated by bony overgrowth at the tip of the plate, which may require more extensive exposure to remove the ingrown bone.
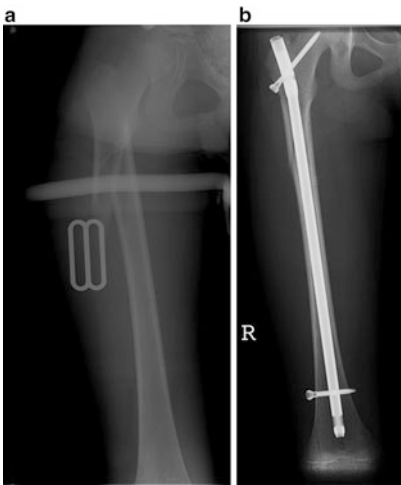
Fig. 6.6 (**a**, **b**) A 10-year-old female who fell while snow skiing. (**a**) Displaced and angulated subtrochanteric femur fracture. (**b**) 1 year following cephalomedullary femoral nailing of fracture through a trochanteric entry point

also been shown to be associated with a number of complications with fractures in the subtrochanteric region [16, 19, 20]. In fact, it was shown that almost a quarter of patients with proximal third femur fractures treated in such a way experienced complications [19]. Typically, those complications resulted from fracture displacement, and include leg-length differences, malunion, or irritating hardware [16–20, 53]. A need for additional surgery has been identified as a complication in children and adolescents with length-unstable fractures managed with titanium elastic nails [17, 18].

Narayanan et al. demonstrated that comminuted fractures had a five times greater risk of loss of reduction leading to reoperation or malunion.

Pediatric subtrochanteric femur fractures usually result from a high-energy mechanism of injury, which is more likely to produce an unstable fracture pattern. If titanium elastic nailing is selected as the treatment method, the lateral nail should be advanced into or just distal to the greater trochanter apophysis, and the medial nail should be advanced into the femoral neck just short of the proximal femoral physis. Pombo and Shilt reported no major complications and no poor results in their series of 13 pediatric patients with subtrochanteric femur fractures treated using this technique [5]. However, fracture stability should be assessed intraoperatively after fixation, and postoperative immobilization with a single-leg spica cast, hip-knee-ankle-foot orthosis, or knee immobilizer should be considered if residual instability is found.

Plating

Caird et al. reviewed 60 pediatric patients with femoral shaft fractures treated with open plating. Twenty-five percent of the fractures were in the proximal third of the femur. The overall complication rate was 10 %, which included one early implant failure, two refractures after the plate was removed, two symptomatic leg length inequalities, and one hypertrophic scar. Four of these patients required unplanned surgery. Three of the six complications occurred in fractures of the proximal third of the femur [54].

In a multicenter retrospective study, Li et al. compared titanium elastic nailing with plating

Table 6.7 Technical tips for rigid intramedullary nailing

Anesthesia:	General with muscle relaxation
Position:	Supine on a fracture table or lateral on a radiolucent table.
Implant selection:	Pediatric cephalomedullary femoral nail with a lateral trochanteric entry point
Exposure:	• A true AP radiograph of the proximal femur must be obtained prior to guide pin placement, which is accomplished by internally rotating the extremity.
	• The starting point is just lateral to the tip of the greater trochanter in the AP plane, and at the junction of the middle and posterior thirds of the femoral neck in the lateral plane.
Steps:	• Guide pin placement is percutaneous and can be initiated using a mallet to prevent inadvertent plunging into the piriformis fossa.
	• The guide pin is advanced using power to the level of the lesser trochanter.
	• An entry reamer is then utilized to initiate the starting hole for subsequent placement of the guide rod and intramedullary nail.
	• It is critical that adequate reduction of the subtrochanteric femur fracture is obtained prior to reaming to avoid malalignment following nail placement. If the proximal fracture fragment is significantly displaced, a Steinmann pin can be placed percutaneously into the proximal fragment. The proximal fragment can then be easily manipulated to facilitate fracture reduction.
	• Ream 1–1.5 mm greater than the diameter of the nail.
	• Proximal interlocking is performed with a screw placed percutaneously into the femoral neck using the guide. This screw should stop short of the proximal femoral physis if the physis is open.
	• Distal interlocking is carried out with one to two screws placed freehand using the perfect circle technique.
	• The addition of a second distal screw enhances the rotational stability of the construct and is important in unstable fractures [57].
Postoperative care:	• No supplemental external immobilization is necessary.
	• Progressive ambulation to full weight-bearing is encouraged, unless extenuating circumstances prevent adequate fracture fixation.
	• The nail can be removed at 12 months postoperatively.
	• Skeletally mature or near-mature patients do not routinely need to have their implants removed.
Other:	• Increased risk for internal rotation fracture malalignment when performed on a fracture table [58]. Use the patella to gauge rotation.
	• During interlock placement, it is important to make sure that the patella is facing the ceiling to obtain neutral alignment.

Table 6.8 Reported complications by treatment method

	LLD	Skin necrosis	Prominent implants	Infection	Malunion	Malrotation	Nonunion	Nerve injury
Hip spica cast	+	+	–	–	++	++	–	+
External fixation	+	–	–	+++	+	+	+	+
Flexible nails	+	–	++	+	++	++	+	+
Open plating	+	–	+	+	–	+	+	–
Submuscular plating	+	–	+	+	+	+	+	–
Rigid nails	+	–	+	+	–	++	–	–

LLD leg length discrepancy, + mild risk, ++ moderate risk, +++ high risk

Table 6.9 Comparison of complications of titanium elastic nailing and plating

	Titanium elastic nails	Plating	P
Fracture malalignment	4	1	–
Leg-length inequality	4	3	–
Pain from prominent implants	3	3	–
Knee stiffness	1	0	–
Cellulitis at insertion site	1	0	–
Saphenous nerve paresthesias	1	0	–
Skin maceration from cast	1	0	–
Total patients with complications	12[a] (48 %)	4 (14 %)	0.008

Adapted from Li Y, Heyworth BE, Glotzbecker M, et al. Comparison of titanium elastic nail and plate fixation of pediatric subtrochanteric femur fractures. J Pediatr Orthop 2013;33:232–8

[a]Three patients had more than one complication

for the treatment of subtrochanteric femur fractures in 54 school-aged children. The authors found that patients treated with titanium elastic nails had a significantly higher overall complication rate than patients treated with plating (48 % versus 14 %), but the major complication rate was similar (Table 6.9). Outcome scores were also significantly better in the plating group than in the nail group, but both groups had high rates of excellent and satisfactory results (97 % and 92 % respectively). Length of hospitalization and time to radiographic union were comparable between the two groups. Plating technique did not appear to influence the complication rate and outcome, as the open plating and submuscular plating groups demonstrated similar results [20].

Conclusion

Subtrochanteric femur fractures are rare in the pediatric population, and are a challenge to treat. There is a lack of agreement on the definition of a subtronchanteric fracture in this age subset, and a dearth of literature evaluating treatment outcomes. Despite the lack of definitive treatment algorithms,

there are some guidelines that should be followed. It is important to keep age and body size in mind when choosing a treatment option. The unique biomechanics around the subtrochanteric region and the torsion forces leading to injury are different than those seen in mid-shaft fractures, so must be taken into consideration. Corresponding injuries, fracture pattern, and rotational deformity are also important in determining the best course of care, and can be assessed through history and radiological examination. Pavlik harnesses are recommended for use in children 0–6 months of age. Spica casting is an acceptable form of treatment in children 6 months to 5 years of age with stable fractures. If the fracture is deemed too unstable, operative measures may be reasonable to pursue in this younger age group. The method of treatment in patients aged 5–11 years old is dependent upon stability, with flexible intramedullary nailing acceptable for stable fractures and open or submuscular plating viable options for more unstable fractures. Children aged 11 years to skeletal maturity are usually treated with rigid intramedullary nailing using a trochanteric or lateral trochanteric entry site. Finally, external fixation should be reserved for children with open fractures, polytrauma patients, and fractures with associated neurovascular injuries. There are complications and risks associated with all treatments, which should be discussed with the patient and family when considering the various care options.

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