Femur Fractures in Neonates, Infants and Toddlers with or Without Child Abuse

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Introduction

Femur fractures in the neonate, infant, and toddler have a subset of unique challenges. The very young child has a dramatic and rapid healing response. Long-term outcomes for femur fractures in this age group are good, and treatment is typically non-surgical. Child abuse and metabolic/developmental conditions must be considered in these patients as well.

Birth Trauma/Neonatal Fractures

Obstetric Fractures

The obstetric femur fracture is specific to the event of delivery, in both vaginal and abdominal births (via C-section). While risk factors exist that can predispose a fetus to a fracture during delivery, it can occur in a normal child during an

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otherwise normal delivery. Neonatal femur fractures, or fractures that occur shortly after birth, tend to occur in children with additional risk factors, such as prematurity, child abuse, metabolic conditions related to prematurity, and underlying conditions such as osteogenesis imperfecta (OI).

Despite the excellent healing and remodeling potential for these injuries, they can create stress and concern for the family following the birth of their child. While no prospective studies currently exist, one retrospective review from Ireland determined an incidence of 0.13 per 1000 live births at their hospital [1]. Historically speaking, obstetrical femur fractures were typically considered iatrogenic from excessive traction and/or torque during a difficult breech delivery or attempts at version [2–10]. With Caesarean section becoming more routine for fetuses in the breech position [8, 11], most recent studies have reported fractures occurring during Caesarian delivery for breech, and occasionally for non-breech, presentation [2, 3, 7, 12–28]. While rare, femoral fractures have been reported during vaginal delivery for cephalic presentation as well [1, 3].

Mechanism

The common mechanism for most obstetric-related fractures appears to be excessive traction and/or torque during a difficult delivery. For a vaginal breech delivery, traction on the thigh after the breech is fixed at the pelvic inlet or

improper handling during shoulder and arm delivery can cause the fracture. While Caesarian delivery for breech presentation is thought to lessen the risk of femur fractures during delivery, there is some thought that since abdominal and vaginal delivery methods are similar, the risk of femur fracture from Caesarian delivery persists [22, 27]. External cephalic version of the infant in utero has also been implicated [9].

In modern times, Caesarian section has become the common method of delivery for fetuses in the breech position [8, 11]. As such, most current reports of obstetric femur fractures involve Caesarian delivery. There are likely several ways during a difficult breech extraction that a femur fracture can occur. Commonly cited risk factors, as shown in Table 3.1, include small uterine incisions [4, 16, 20, 22, 26], large or very small birth-weight babies [3, 12, 14, 22, 23, 29], an impacted extremity in the pelvis during extraction [17, 20], uterine fibroids [4, 17], twin pregnancies [1], inadequate uterine relaxation [20], and associated metabolic- and neuromuscular-related conditions, etc. [29–34]. In some reports, no risk factor is identified [17, 20, 21, 25, 27, 28].

Location

Most obstetric-related fractures occur in the femoral shaft [1], however, fractures along the entire length of the femur have been reported. Notable reports in the literature include physeal separations of the proximal [6, 12, 35–40] and distal [6, 21, 29, 33, 36, 41] femoral epiphyses, distal metaphyseal fractures [7, 9, 25], and subtrochan-
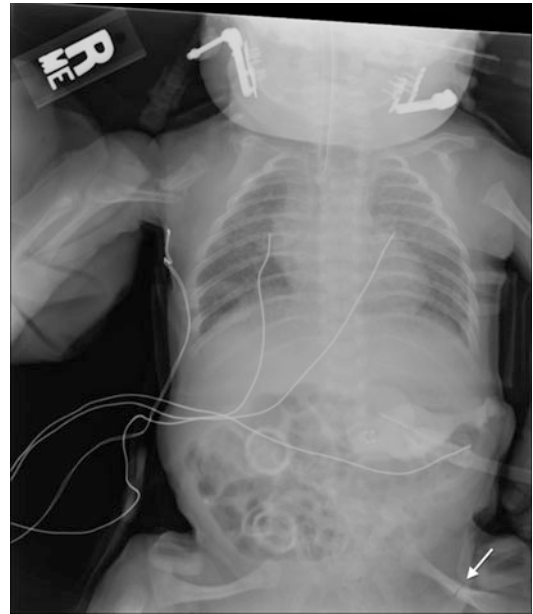
Fig. 3.1 Atraumatic subacute left femur fracture (*arrow*) in a neonate with multisynostic osteodysgenesis that was picked up incidentally on a chest and abdomen X-ray. Also noted are the characteristic bilateral humeroradial synostoses with an associated humerus fracture, right femoral bowing, bilateral teratologic hip dislocations, and evidence of obstructive micrognanthia s/p jaw distraction. The patient was in the NICU at the time of the fractures. Used with permission of the Children's Orthopaedic Center, Los Angeles, CA

teric fractures [27]. The proximal femoral epiphyseal fracture in the neonate is unique in that the femoral head and neck as well as the greater and lesser trochanters are avulsed off as one piece from the proximal shaft [40].

Neonatal Fractures

Femur fractures in the neonatal period (first few weeks of life) often occur in settings and/or conditions such as OI, prematurity, and child abuse [15, 30, 32, 42–45] (Fig. 3.1). With the exception of the abused child, these children are often hospitalized when the fracture occurs, which can result from minor extremity manipulation [1, 15, 32, 33, 42, 45–47]. Very low birth weight (VLBW) infants (<1500 g) have been reported to have a total fracture incidence of 2–10 % [46, 48].

Table 3.1 Risk factors for obstetric femur fracture

Risk factors	Diseases/conditions
Large or small birth weight babies	Osteogenesis imperfecta
Small uterine incisions during C-section	Cerebral palsy
Uterine fibroids	Multisynostotic osteodysgenesis
Impacted extremity in pelvis during abdominal extraction	Spinal muscular atrophy
Inadequate uterine relaxation	Spina bifida/myelomeningocele
Twin pregnancies	

This may be an underestimate, as some fractures (ex: rib fractures) likely go undiagnosed [46, 48]. When femoral fractures occur in VLBW infants, they tend to be in the metaphysis or diaphysis [15, 30, 32, 42, 45–48]. Determining the cause of the fracture may require a more thorough workup, for the reasons listed above. Often these patients will require a head-to-toe physical examination to look for associated abnormalities, including lab work, imaging, and a multidisciplinary team approach to find an underlying cause. If an otherwise healthy, term neonate has a femur fracture, child abuse should be suspected [34, 49–53].

Physiologic Factors

In preterm neonates, rickets has been recognized and described as a risk factor for fracture in VLBW infants [46, 48, 54]. The incidence of rickets in this population is not well known but reports suggest that at least 10–20% of preterm neonates that weigh <1000 g have radiographic signs of rickets [54, 55]. Further, preterm neonates with alkaline phosphatase (ALA) levels >1000 IU/L may have a 50–60% incidence of rickets [54]. Conditions in the preterm neonate that may cause or exacerbate rickets include cholestasis (which impairs metabolic production of Vitamin D), bronchopulmonary dysplasia (in which the infant is given steroids and/or loop diuretics which tend to increase urinary excretion of calcium), and prolonged parenteral feeds that have not been properly supplemented with calcium, phosphorus, and Vitamin D [43, 46, 54]. While an in-depth discussion of the physiology of rickets is beyond the scope of this chapter, the recognition of it in this patient population is paramount so that appropriate supplementation with calcium, phosphate, and Vitamin D can occur to reverse the rickets and prevent further fractures [43, 54]. Often, pre-pumped breast milk and/or formula can be fortified with these vitamins and minerals specifically for preterm neonates, and parenteral feeds can be altered to increase the availability of these nutrients [54].

Presentation and Diagnostic Modalities

Most patients in this age group with femur fracture present with "pseudoparalysis," or unwillingness to move the affected extremity. Swelling and tenderness to palpation are typically present as well. Notably, this is also how an orthopedic infection such as osteomyelitis or septic arthritis presents in this age group and should therefore be on the differential diagnosis [56–58]. While the vast majority of femur fractures are easily diagnosed via plain radiographs, physeal fractures in this early age group may be missed using this modality [6, 12, 21, 29, 41, 59]. In these situations, the clinician should consider other diagnostic tools such as magnetic resonance imaging (MRI) and ultrasound (US) [29, 37, 59], which are useful for physeal injuries as well as for detecting infection. Computed tomography (CT) can also be utilized [29], but should be a third option due to radiation exposure and the degree to which femoral structure remain non-ossified in this age group. Arthrography can also be considered as an adjunct if other modalities are unavailable [29]. Laboratory tests such as C-reactive protein, erythrocyte sedimentation rate and white blood cell counts should be ordered if an infection is suspected.

Infantile and Toddler Fractures

As children exit the neonatal phase of life, they become more mobile and start crawling and eventually walking. This mobility increases their risk of sustaining an accidental femur fracture, usually from a fall [60–62]. Child abuse is still a significant cause of injury in this age group, and the clinician must keep this possibility in mind [60–64]. This is particularly true if the child is not yet walking. In the pre-ambulatory period of life, the child generally cannot generate enough energy on his or her own to sustain a femur fracture. Thus, most femur fractures in the pre-ambulatory age group are secondary to non-accidental trauma (NAT), high-energy trauma such as falls (typically

a fall by a caregiver or a crawling child who falls down stairs, as opposed to a fall in an ambulatory child), motor vehicle accidents, and conditions of bone fragility, such as OI [33, 34, 43, 47, 60–63, 65–69]. Femoral fractures as they relate to child abuse will be discussed in a later section. Once the child begins walking, twisting mechanisms from accidental trauma become more common, although child abuse is still frequently seen [62, 70–72].

Epidemiology

There is some variation in how the incidence of pediatric femur fractures is reported. The Hospital Discharge Database of the Maryland Health Services Commission was reviewed between 1990 and 1996 and determined an annual fracture rate of 25.5/100,000 in children <2 years of age in the state of Maryland [73]. A study analyzing the 2000 Healthcare Cost and Utilization Project Kids' Inpatient Database (KID) reported that of 10.8 % of all femur fractures occurred in children <2 years of age [62]. This database records data on pediatric hospital discharges for most U.S. states. A month-by-month analysis of the 1997 KID database showed a bimodal distribution of femur fracture incidence with a peak occurring around 3 months of life and again around 20–40 months [61]. The rate of fracture for children less than a year of age was 43/100,00; for children at 1 year of age the rate was 33/100,000; and a rate of 42/100,000 was observed for children 2 years old. A review of the Colorado Trauma Registry between 1998 and 2001 determined a rate of 29.4/100,000 person-years in the 0–3 age group in that state [71]. A Swedish study examined femoral fractures from their Inpatient Care Register and determined an incidence of just less than 2 per 10,000 person-years for children <2 years old [63].

In all studies examined, males sustained the majority of fractures. In older age groups, males sustained as much as 70 % or more of all femur fractures. In the infant and toddler age group, however, the fracture rate between genders was much closer. The 2000 KID database study deter-

mined that females accounted for 40 % of fractures in the 0–2 age group [62]. The previously mentioned Swedish study found an equal rate of fracture among genders in the 0–1 and 2–3 year age groups [63]. The Maryland and Colorado studies also found near equal annual fracture rates between genders in the first year of life, as did the 1997 KID database study [61, 66, 71, 73]. The 1997 KID database study, which looked at fracture rate by month, also found a peak in fracture rate around 3 months of age in both genders during the first year of life. With children of ages greater than 2 years, females had an overall lower rate of fracture consistent with older age group demographics. All authors suggested this closer gender gap was likely due to the high incidence of child abuse seen in infants and young children [61–63, 71, 73].

Race and socioeconomic status also affect fracture rates. This tends to hold true for all age groups. The Colorado and Maryland studies examined this and found that racial minority patients, patients with low socioeconomic status, and patients with single mothers as head-of-household were at more risk of sustaining a femur fracture [71, 73].

Mechanism and Location

Femur fractures in infants and toddlers are most frequently due to falls and child abuse [43, 50, 60, 62, 68, 71, 73–78]. In patients less than 3 years, approximately 50–65 % of all accidental femur fractures are attributed to falls [62, 71, 73]. Less frequent are motor vehicle accidents and pedestrian vs. auto accidents [60, 62]. About 65–70 % of femur fractures in children <2 years occur in the femoral shaft [62, 71, 76]. In accidental trauma, especially in children who do not yet ambulate, it is common for the patient's caretaker or older sibling to fall while carrying the child or fall onto to the child [67, 69]. In these situations, fractures are typically buckle/impaction fractures of the distal metaphysis or spiral/long oblique or transverse/short oblique fractures of the mid-shaft [69]. Fewer accidental femur fractures (and for that matter, fractures due to

child abuse) occur in the proximal femur or distal epiphysis. When they do, they are typically, but not always [53], related to a high-energy mechanism such as being involved in a car accident or being struck by a car or other fast-moving object [62, 69, 71, 76].

Treatment

Treatment is often dictated by age and/or weight of the child, despite lack of any reports describing a weight-based algorithm [79].

Obstetric and Neonatal Fractures

Traction and long leg or spica casting for shaft and metaphyseal femur fractures in neonatal and obstetric fractures have been described [1, 9, 20, 28, 45, 47, 80]. However, more recent reports describe use of a Pavlik harness for these fractures [64, 79, 81–83], and the authors prefer the Pavlik harness technique for these fractures in patients who are large enough to fit in one, which typically excludes premature infants. The technical details for using the Pavlik harness are described below. Traction (e.g. Gallow's [45] or Bryant's [40]) has largely fallen out favor in the United States due to compartment syndrome risk [84] and need for prolonged immobilization [45]. While this is an option, the authors prefer splinting of these injuries. Splinting is typically makeshift and can include a plaster slab and bias wrap, but can also be successfully accomplished with something as simple as a tongue depressor and a gauze wrap. The latter may be more appropriate for the VLBW infants because the weight of a plaster splint may be excessive. It is vitally important that the limbs are not wrapped too tight, and that frequent neurovascular checks are performed. Gentle elevation may help control swelling. The authors do not typically perform spica casting for femur fractures in this patient group.

Epiphyseal injuries in this group have been treated with closed and open methods [4, 6, 12, 21, 29, 36, 37, 41, 59]. It is difficult to draw firm conclusions about treatment for these injuries

because most literature is in the form of case reports and many reports are at least 30 years old [6, 7, 12, 39, 41, 85]. This entity is either being seen less or is being reported less often today. Some authors speculate this may be due to improved obstetric practices [38].

Distal femoral physeal fractures are typically treated with closed reduction and immobilization, or even immobilized in situ and allowed to remodel. Sometimes, there is a delay in diagnosis such that callous formation has already occurred and the physician has no choice but to allow the fracture to remodel. Riseborough et al. included five patients with obstetric distal femoral physeal fractures in a larger study of these injuries in a mixed age group of pediatric patients [10]. All fractures were treated closed without an attempt at reduction. While functional outcomes are not detailed in the manuscript the authors note that only one patient out of the five with obstetric fractures had a significant leg length difference of 2.8 cm, which the authors believed was due to anisomelia [10]. Other case reports and small series demonstrate good outcomes with no clinically significant growth disturbances, angular deformities or functional impairments [21, 44, 59]. There are reports of fractures managed conservatively with no reduction attempt that resulted in clinically significant leg length discrepancies at long-term follow-up [36]. Case reports of closed reduction and pinning of these injuries with a smooth Kirschner wire have demonstrated good results with no growth disturbances noted [29, 44]. Making treatment recommendations from this is difficult. Minimally displaced distal femoral physeal fractures likely do well with conservative management with in situ immobilization, while highly displaced fractures (i.e., where the epiphysis is displaced 100 % or more), should have an attempt at reduction and potential surgical stabilization. If the fracture is older than 5–7 days or the age of the fracture is uncertain, it may be best to treat with in situ immobilization to minimize further damage to the growth with attempts at reduction, though there is no literature to support this recommendation.

Proximal epiphyseal fractures, sometimes called proximal femoral epiphysiolysis, owing to

the unique fracture pattern described above, are similarly rare. Ogden et al. reported on seven neonatal proximal femoral physeal injuries, five of which were from obstetric injury and two from child abuse [40]. Six were treated in traction followed by either an abduction brace or cast, while one was casted from the outset. All but two of the fractures fully remodeled with no functional deficits. One patient had mild residual deformity with no functional deficits and the remaining patient, who was a child abuse victim, had complete proximal physeal arrest by 5 years of age and had undergone multiple corrective procedures [40]. The remainder of the literature tends to report similar findings in which most of these injuries remodel fully with little to no sequelae [6, 12, 37–39, 85, 86]. The remainder most often develop a coxa vara deformity, as well as possible rotational deformities or leg length discrepancies that may require corrective procedures [35, 36, 40]. There are reports of operative fixation of these injuries but the numbers are too few to determine if these results are any different than conservative treatment [35, 87]. As with distal femoral physeal injuries, if the fracture is 5–7 days old or of uncertain age, in situ immobilization is the preferred treatment, as manipulation may cause iatrogenic injury to the growth plate.

Infant and Toddler Fractures

The two mainstay treatments for diaphyseal femur fractures in this age group are the Pavlik harness and the spica cast; with the harness typically being reserved for patients less than 6 months to a year and spica casting for patients greater than 6 months of age. Recently, the American Academy of Orthopaedic Surgeons (AAOS) published a clinical practice guideline for the treatment of pediatric diaphyseal femur fractures. The clinical workgroup considered a Pavlik harness an option for treatment along with a spica cast for patients less than 6 months of age [64, 79]. They further recommended early spica casting vs. traction followed by delayed spica casting for patients aged 6 months to 5 years [79]. These were Grade C and B recommendations,

respectively based on relative paucity of literature. Most subtrochanteric femur fractures can be managed with these modalities in the infant and toddler age group as well but further discussion of these fractures as well as other metaphyseal and epiphyseal fractures will be reserved for other chapters. The technical details of spica cast application and care are dealt with in a subsequent chapter as well, so the remaining discussion in this section will focus on the Pavlik harness.

Pavlik Harness

Stannard et al. first reported use of the Pavlik harness for obstetric and neonatal femur fractures in 1995. They produced a prospective cohort study of 16 fractures in 14 patients with a minimum 12-month follow-up (range 12–30, mean 20) in 11 patients. Age of the patients ranged from birth to 18 months. One patient with OI had three femoral fractures. All were treated with a Pavlik harness. All fractures were proximal or mid-shaft and all united in acceptable alignment with less than 1 cm of shortening [82]. Union was achieved by 4–5 weeks in all fractures, and the harness was discontinued at that time. No complications such as femoral nerve palsy, skin breakdown, etc. were reported. At final follow-up, no malunions or leg length discrepancies >1 cm were noted. The authors felt this treatment was appropriate for patients <4–6 months of age if size appropriate, fractures of the proximal or middle shaft, and shortening of <2 cm.

Podeszwa et al. later reported on treating children up to 1 year of age in a Pavlik harness. They retrospectively compared 24 patients under 1 year of age with a femoral shaft fracture treated with a Pavlik harness to 16 similarly aged patients treated with a spica cast [83]. The patients differed significantly with regard to age and weight. The Pavlik harness group had an average age of 3.6 ± 3.8 months (range 1 week to 12 months) vs. 6.5 ± 3.7 months (range 1 week to 12 months) ($p = 0.028$) for the spica cast group. The average weight for patients treated with a Pavlik harness was 5.6 ± 2.1 kg vs. 7.7 ± 3.3 kg ($p = 0.027$) for the spica cast group. All fractures were either spiral or transverse shaft fractures. Average follow-up

was very short at 4 weeks. Both groups showed complete healing at their final follow-up appointment. Six (38 %) of the spica cast patients had complications and all were skin-related issues that resolved with local wound care. There were no complications in the Pavlik harness group. These authors surmised that patients up to 1 year of age with femoral shaft fractures were candidates for Pavlik harness treatment. Flynn and Schwend published a review article subsequent to these studies in 2004 and recommended the Pavlik harness as the preferred treatment for patients ≤6 months of age with proximal third or shaft fractures [88].

Very recently, Rush et al. published a retrospective review looking at longer term functional and radiographic outcomes of patients less than 6 months of age with a diaphyseal femur fracture treated in a Pavlik harness [89]. They reviewed 10 patients with an average follow-up of 5.2 years (range 2.6–7.3). The initial age at time of treatment was 2.2 months (range 2.6 weeks to 5.8 months). Patients were treated in a Pavlik harness on average of 43 days and there were no complications reported. Four patients were victims of child abuse. At final follow-up there were no functional deficits, limitations, or complaints noted. There were no clinical angular deformities and there was one patient with an asymptomatic 7 mm leg length discrepancy. The authors did not note whether the affected extremity was long or short. At the time of injury, the average coronal plane deformity was 12° varus (range 0–30°) and sagittal plane deformity was 9° procurvatum (range 0–26°). Average fracture shortening was 2 mm (range 0–7 mm). At final follow-up, coronal plate deformity was, on average, 3° valgus (range 0–8°) and residual sagittal plane deformity was 5° (range 0–24°). The authors noted that the subgroup of patients with >20° of angulation in any plane at the time of injury tended to have larger residual radiographic deformity (5° valgus, 11° procurvatum) present at final follow-up. The authors did not specify how many patients comprised this subgroup. Further, the authors inferred appropriate rotational alignment based on foot progression angles between 5° and 15° external during follow-up gait analysis. The

authors concluded that Pavlik harness treatment was safe and effective for diaphyseal femur fractures in this age group but that patients with high levels of initial fracture displacement may need longer term follow-up in case a significant angular deformity persists.

The authors consider Pavlik harness treatment the first option for femoral shaft fractures in patients who will fit in one. This generally lends to a cut-off age around 6 months in full-term infants. This age limit may be higher in a patient who was born pre-term and is still of appropriate size for the harness.

Fitting the Harness

Pavlik harness application is routine for most pediatric orthopedists. However, for the adult orthopedist who finds him/herself in the awkward position of needing to apply the harness, appropriate placement is not too difficult. The centerpiece of the harness is the belt that goes around the lower costal margin. Attached to this are the shoulder straps superiorly and the leg and foot harnesses inferiorly (Fig. 3.2). The harness is placed on a flat surface and unfolded. The infant is placed on top of the harness such that the belt strap lies at the lower aspect of the posterior rib cage. The belt is typically Velcro and is fastened in such a way that the practitioner can easily get two to three fingers under the strap in the anterior chest. This is an easy rule of thumb to follow to prevent applying the belt too tightly. The shoulder straps are generally fastened next. These straps should be firmly secured but not too tightly to prevent skin irritation. Next, the lower extremities are placed in the foot harnesses and secured. There should be about one fingerbreadth of slack in the Velcro straps for the legs. At this point, the fracture is reduced, typically with flexion and external rotation of the extremity, and the straps connecting the foot harnesses to the belt are secured (Fig. 3.3). It should be noted that positioning for fracture reduction should be determined on a case-by-case basis. Early reports depict high levels of flexion to obtain reduction, especially in more proximal fractures [82]. More recent reports tend to recommend hip flexion around 80–90° [83, 89].

Fig. 3.2 Pavlik harness. The centerpiece is the costal/thoracic strap with the shoulder straps above and the leg and foot straps below. Used with permission of the Children's Orthopaedic Center, Los Angeles, CA

Fig. 3.3 Pavlik harness applied to infant. The amount of laxity needed in specific straps is marked to allow the parents to adjust at home if needed. Used with permission of the Children's Orthopaedic Center, Los Angeles, CA

Reduction can be checked during harness application with fluoroscopy, and/or afterward with a conventional radiograph. For the first several days, a pillow or similar soft support is placed underneath the affected extremity to aid in the patient's comfort [83]. A summary of harness application is depicted in Table 3.2.

Generally, the patient should be seen back within a week to 10 days for a follow up X-ray, and any adjustment to the harness can be made at this time if the fracture has lost reduction. The harness should be worn full time for 4–5 weeks and/or until abundant callus formation is seen on the X-ray. Given the massive remodeling potential in this age group, a large amount of displacement can be tolerated.

Like any intervention, there are potential complications with harness treatment. The most notable is femoral nerve palsy [90]. While this has been reported in the developmental hip dysplasia literature, it has not yet been reported in the

Table 3.2 Summary and pearls for Pavilic harness application for femur fractures

1. Lay out harness on sturdy but comfortable surface.
2. Lay infant on top of harness.
3. Fasten torso strap first, leave room for two fingers underneath strap.
4. Fasten shoulder straps, leave room for one finger underneath strap.
5. Apply leg strap for unaffected limb. Flex hip to 80–90° and fasten straps.
6. Reduce fracture on affected limb and fasten leg strap in that position.
7. Use X-rays as needed for assistance in reduction.
8. Be wary of hip flexion beyond 90°.
9. Use pillow under hip for several days for comfort.

infantile femur fracture literature. One should still expect this as a possible complication given the low numbers of patients reported in the femur fracture literature. Since pseudoparalysis of the affected extremity is a hallmark finding for femur

fractures in this age group, it can be very difficult to get a baseline nerve examination prior to Pavlik harness application and also after several days of harness treatment. Femoral nerve palsy is thought to be associated with higher levels of hip flexion so the practitioner should be mindful of flexing the hip high for a reduction.

Child Abuse

Child abuse is one of the most troubling diagnoses to deal with in the medical profession. In the case of physical abuse, it is often an orthopedic injury that brings the child's diagnosis to the attention of a medical provider. Femur fracture, depending on the source, is often considered the most common long bone fracture to occur in non-accidental trauma (NAT). Determining cases of child abuse from accidental trauma in very young patients can be difficult and requires a multi-disciplinary team. Incorrect diagnosis can emotionally scar a family, but missing a diagnosis can be fatal for the child as most patients who die from abuse have a history of previous medical encounters for suspicious injuries.

Epidemiology

In 2011, there were an estimated 681,000 unique child abuse victims, or 9.1 victims per 1000 children in the population [91]. The birth-to-1-year age group represented the highest rate of victimization at 21.2 per 1000 [91]. Boys (49 %) and girls (51 %) are abused at roughly the same rate. Most abuse cases in the U.S. are comprised of three ethnic groups: Caucasian, Hispanic, and African-American, with respective percentages of 44 %, 22 %, and 21.5 % [91]. Given the percentage of each ethnic group in the population, there appears to be a higher rate of abuse among African-American children than Caucasian or Hispanic children [92–94]. Neglect is the most common form of child abuse, accounting for close to 80 % of all cases. Surprisingly, physical abuse only accounts for 20 % of all child abuse cases, and sexual abuse accounted for about

10 %. Based on these percentages, it is clear that some children are victims of more than one type of abuse [91–93]. Four children die from child abuse every day, and this number may be under-reported. [91]. Eighty percent of children who die from abuse are under age 4, and 78 % of the time the fatality was caused by one or more parent [91].

There is a strong correlation between long bone fracture in infants and toddlers and child abuse [95, 96]. There is some debate as to whether the femur is the most frequently fractured long bone in this setting, with the humerus and the tibia cited as well [34, 96, 97]. Regardless, a femur fracture is often the injury that brings the battered child to the attention of a healthcare provider. In the infant and toddler age group, the rate of child abuse-associated femoral fracture is anywhere from 10 to 80 % [34, 62, 64–66, 71, 73, 76, 79, 98]. Studies with level II evidence cite a rate of 12–14 % in children aged 0–3 years [71, 73]. In infants who do not yet ambulate, child abuse has been cited to be the cause in up to 60–90 % of femur fractures [52, 66, 75, 95]. Regardless of the exact number, non-accidental trauma is all too common in infants and toddlers, and the practitioner should always be on high alert when these patients present to the emergency department with a femoral fracture. If not recognized, these victims are often beaten repeatedly and death is a very real possibility [77, 99–101]. More than 1500 children each year died from abuse and neglect in 2010 and 2011 [91, 92]. Furthermore, victims of child abuse have higher rates of adult criminal behavior, drug and alcohol abuse, and violent behavior, including being the perpetrators of child abuse [92, 93]. Appropriate recognition and action on the part of the physician can hopefully help minimize this truly disturbing phenomenon.

Presentation

There are several signs that have been put forth in the literature as being suspicious for abuse. The first and easiest thing to look at is patient age. The risk of non-accidental trauma, as stated

above, is much higher for children who do not ambulate. Furthermore, based on the statistics discussed above, any infant or toddler with a femur fracture should raise suspicion. To put a final point on this, the AAOS has issued a clinical practice guideline stating that all patients less than 3 years of age with a femur fracture should be evaluated for child abuse [64, 79]. This was the only "Grade A" recommendation from the practice guideline.

Like any thorough work-up, a detailed history is central to steering the physician toward the correct diagnosis. In the setting of abuse, the caregiver will often give an inconsistent story, describe a mechanism of injury that is not plausible, or claim to have not witnessed any injury [76, 77, 93, 99, 100, 102]. Furthermore, elucidating any past injuries or emergency room visits is important, as abuse victims tend to be brought to the hospital on multiple occasions [93, 102]. The past medical history is important to rule out metabolic or structural conditions, such as OI, that predispose children to fracture [33, 103, 104]. While honesty may not be a top priority for a child abuse perpetrator, the social situation should be thoroughly explored to determine if there is drug and alcohol abuse in the home and if the caregivers are of low socioeconomic status. These have been found to be associated with child abuse [52, 77, 91–93, 105].

Type of Fracture

Fractures along the entire length of the femur have been reported in the setting of child abuse [38, 40, 52, 53, 75, 106–109]. A femoral shaft fracture is considered the most common type of femur fracture to present in the setting of child abuse (Fig. 3.4), and likely represents up to 80–90 % of all femur fractures in this setting [75, 96]. The exact type of shaft fracture (spiral, transverse, oblique, etc.) is debated with no clear pattern being most indicative [75, 96, 97, 110]. The shaft fractures have mainly been described in the middle and distal third of the shaft [75, 77, 96, 102]. Twenty percent of shaft fractures may be proximal [77]. Careful X-ray interpretation is important, as there are some lesions that can be

Fig. 3.4 Solitary oblique mid shaft femur fracture in a 15-month-old female with confirmed child abuse. Used with permission of the Children's Orthopaedic Center, Los Angeles, CA

Table 3.3 Differential diagnosis of child abuse

Accidental injury	*Other*:
Birth trauma	Congenital insensitivity to pain
Osteogenesis imperfecta	Coagulation disorders: • Hemophilia • von Willebrand etc.
Caffey disease	*Normal radiographic variants*:
Rickets	Angulation of ossifying metaphysis
Congenital syphilis	Cortical irregularity
Leukemia	Spurring
	Juxtaphyseal variants

Adapted with permission from Kocher MS and Kasser JR. Orthopaedic Aspects of Child Abuse. JAAOS 2000;8(1):10–20

mistaken for a fracture that may represent other conditions [102]. Table 3.3 summarizes a differential diagnosis for child abuse.

Imaging

Imaging of NAT follows the same principles as described above for accidental trauma. However,

in suspected NAT femoral injuries, a skeletal survey should be ordered [112]. A skeletal survey consists of AP radiographs of all parts of the extremities (e.g. hand, forearm, arm) and AP and lateral X-rays of the axial skeleton and skull. The use of radionuclide imaging has been described to help in detection of associated injuries and to help determine the age of an injury [113–115]. This modality, while useful, may have limitations due to cost, time involvement, and limited availability, but should be considered as an adjunct if abuse is suspected but a skeletal survey is negative [102, 116]. If unavailable, a follow-up skeletal survey can be ordered 2–3 weeks after the initial survey to see if there are healing fractures with associated callus. If there is suspicion for a diagnosis other than child abuse based on initial radiographs, then appropriate imaging (MRI, CT, etc.) and blood work, etc. may be indicated [102].

Associated Injuries

If a child presents to a caregiver with a suspicious femoral fracture (or any injury suggestive of child abuse), a search for other injuries is warranted. Bruises and other skin lesions are the most common finding in child abuse. By looking at the pattern of bruising and the age of the child, the suspicion of child abuse can be tailored appropriately [93]. A general rule of thumb is that if the child is not yet developed enough to cruise, any bruising should warrant suspicion for child abuse [117]. Further, bruising around the thorax, neck, ears, and genitals are suggestive of abuse in any child less than age 4 [118, 119]. Lastly, sharply demarcated bruises or patterned bruising should raise suspicion as well, as this may suggest trauma from an object or restraining device [93, 118].

Fractures are second only to bruises in frequency in the setting of NAT [49, 93, 102, 120]. Long bone fractures are most common, with the humerus and tibia most frequently seen in addition to the femur, as mentioned above [13, 74, 78, 93, 95–97, 100, 102, 110, 120]. While fractures in multiple stages of healing are highly specific

for abuse, up to 50 % of battered children present with only a single fracture [96]. Rib fractures alone, especially posterior rib fractures, have been shown to have 95 % positive predictive value (PPV) for child abuse in children less than 3 years of age. In the appropriate setting and history, the PPV for rib fractures goes to 100 % (Fig. 3.5a–c) [93, 102]. Sometimes, the rib fractures are missed on X-ray and can only be detected as the fractures heal and form callus [102, 121]. Other less common fractures in child abuse include the clavicle and hand and foot fractures [102]. As mentioned earlier, corner fractures or CMLs are highly specific for child abuse [111]. In addition to the distal femur, these have been documented on the proximal and distal tibia as well as the distal radius and ulna [96, 97, 102, 106, 122]. Other highly specific fractures for NAT include scapular, spinous process, and sternal fractures [123]. In addition to spinous process fractures, spine fractures typically are asymptomatic vertebral compression fractures that are picked up on skeletal survey. They are also quite rare in NAT but are helpful in diagnostic confirmation since they are also very uncommon as a result of accidental injuries in infants and toddlers [34, 110].

Head injuries are the most frequent cause of long-term morbidity and mortality in NAT and include skull fractures, subdural hematomas, and retinal hemorrhages [93, 102]. The combination of subdural hematomas and rib fractures is known as the "shaken baby syndrome." Skull fractures that are depressed, bilateral, complex, and/or cross suture lines are associated with abuse (Fig. 3.6). Subdural hematomas that are in the posterior fossa, in multiple locations, or are associated with cerebral edema are also associated with child abuse [93, 124]. Head trauma often leads to long-term neurologic sequelae such as seizure disorders, learning disabilities, delayed development, and motor dysfunction [93, 102, 124].

Other injuries seen in NAT include burns and bites, and are more common than one may first think [93]. Visceral organ injuries are rare, but tend to carry a mortality rate of approximately 40–50 % [125, 126].
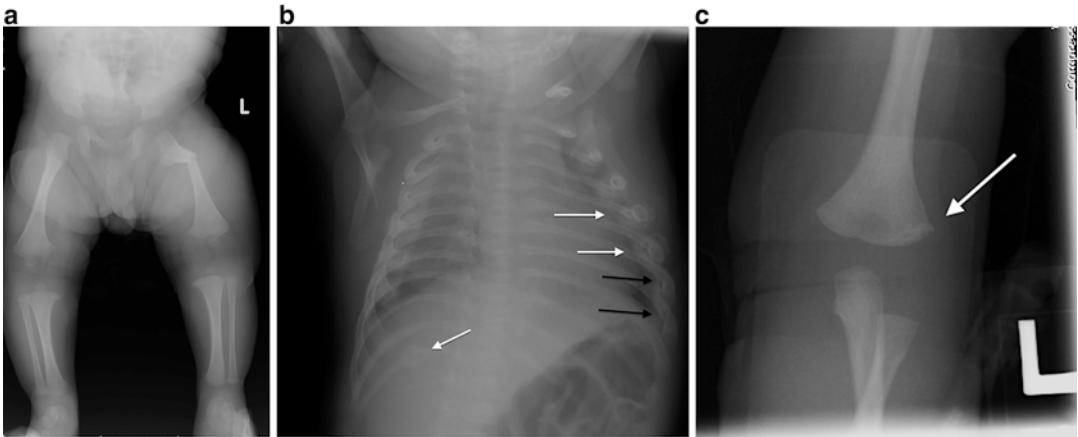
Fig. 3.5 Multiple injuries in a child abuse victim who presented to the ED with a femur fracture. (**a**) Left subtrochanteric femur fracture. (**b**) Multiple rib fractures in various stages of healing. The *black arrows* point to more recent fractures and the *white arrows* point to fractures with abundant callus. (**c**) Small, healed lateral distal humeral corner fracture. Used with permission of the Children's Orthopaedic Center, Los Angeles, CA

Fig. 3.6 Bilateral skull fractures in an abused child. Used with permission of the Children's Orthopaedic Center, Los Angeles, CA

Risk Factors for NAT

When evaluating a child with a femoral fracture for child abuse, the clinician should assess the presence of associated risk factors. Baldwin et al. evaluated a series of femur fractures in patients younger than 4 years of age. They determined risk factors of a suspicious history, radiographic evidence of prior injury, and age less than 18 months to be significant risk factors for abuse. When no risk factor was present, the risk of abuse was 4 %. When one, two, or three risk factors were present, the risk climbed to 29 %, 87 %, and 92 %, respectively [77]. Other risk factors noted in the literature include low socioeconomic status [91–93], being on Medicaid insurance or being uninsured [52], single-parent households or having a partner in the house who is not a parent [92], drug and alcohol abuse in the caregivers [91, 92], multiple trips to the ED [93, 100], delay in presentation [76, 93, 100], associated injuries [76, 93, 100, 102], and children with special needs (Table 3.4) [102].

Treatment

Treatment of femoral fractures in the setting of child abuse follows the same principles as treating accidental trauma discussed above. Often, the battered child will have more than one injury, so a multidisciplinary team is needed to provide comprehensive care as well as arrange a safe disposition for the child after he/she leaves the hospital. As a general rule, no child less than age 2 with a femur fracture should be discharged from the hospital without a further investigation. Social Services consult is mandatory in the setting of abuse or

Table 3.4 Risk factors for child abuse when evaluating a femur fracture in a child

- Suspicious or inconsistent story
- Delay in presentation
- Implausible mechanism of injury
- Multiple trips to ED
- Low socioeconomic status
- Government insurance or no insurance
- Single-parent household or live-in non-parent partner
- Drug and/or alcohol abuse in caregivers
- Fracture in child less than 3–4 years
- Fractures in multiple stages of healing
- Presence of highly specific fractures
    - Posterior rib
    - Corner fractures
    - Scapula
    - Spinous process
- Associated injuries
    - Bruises: thorax, neck, ears, genitals
    - Burns
    - Skull fracture
    - Retinal hemorrhage
    - Subdural hematoma
    - Visceral injury (uncommon)

suspected abuse. The resources and expertise of Social Services are much more extensive than a practicing surgeons' and should be used given the complexity of issues such as investigation into the social scenario as well as potential placement issues.

Conclusions

Femoral fractures in the infant and toddler are generally well tolerated, but attention to detail will help to ensure good outcomes. There are unique aspects and considerations for these patients based on their mechanism of injury, stage of development, and home surroundings. Non-operative care is standard, and the Pavlik harness has made neonata and infantile fracture treatment more convenient for parents and caregivers alike.

Child abuse is a disturbing and unfortunate reality in this age group, and physicians and other healthcare workers must act as a team to diagnosis, treat, and protect these children. By the time

the diagnosis is made, physical and psychological long-term damage may already be done, but we must do our best to minimize ongoing or further injury to these children.

References

1. Morris S, Cassidy N, Stephens M, McCormack D, McManus F. Birth-associated femoral fractures: incidence and outcome. J Pediatr Orthop. 2002;22(1): 27–30.
2. Bhat BV, Kumar A, Oumachigui A. Bone injuries during delivery. Indian J Pediatr. 1994;61(4):401–5.
3. Nadas S, Gudinchet F, Capasso P, Reinberg O. Predisposing factors in obstetrical fractures. Skeletal Radiol. 1993;22(3):195–8.
4. Ehrenfest H. Birth injuries of the child. New York: Appleton-Century-Crofts; 1922.
5. Pavlik A. Treatment of obstetrical fractures of the femur. J Bone Joint Surg Am. 1939;21(4):939–47.
6. Shulman BH, Terhune CB. Epiphyseal injuries in breech delivery. Pediatrics. 1951;8(5):693–700.
7. Clarke TA, Edwards DK, Merritt A, Young LW. Radiological case of the month. Neonatal fracture of the femur: iatrogenic? Am J Dis Child. 1982;136(1):69–70.
8. Hannah ME, Hannah WJ, Hewson SA, Hodnett ED, Saigal S, Willan AR. Planned caesarean section versus planned vaginal birth for breech presentation at term: a randomised multicentre trial. Term Breech Trial Collaborative Group. Lancet. 2000;356(9239): 1375–83.
9. Papp S, Dhaliwal G, Davies G, Borschneck D. Fetal femur fracture and external cephalic version. Obstet Gynecol. 2004;104(5 Pt 2):1154–6.
10. Riseborough EJ, Barrett IR, Shapiro F. Growth disturbances following distal femoral physeal fracture-separations. J Bone Joint Surg Am. 1983;65(7): 885–93.
11. Ghosh MK. Breech presentation: evolution of management. J Reprod Med. 2005;50(2):108–16.
12. Denes J, Weil S. Proximal epiphysiolysis of the femur during caesarean section. Lancet. 1964;1(7339):906–7.
13. Cumming WA. Neonatal skeletal fractures. Birth trauma or child abuse? J Can Assoc Radiol. 1979;30(1):30–3.
14. Kellner KR. Neonatal fracture and cesarean section. Am J Dis Child. 1982;136(9):865.
15. Pickett III WJ, Johnson JF, Enzenauer RW. Case report 192. Neonatal fractures mimicking abuse secondary to physical therapy. Skeletal Radiol. 1982; 8(1):85–6.
16. Banagale RC. Neonatal fracture and cesarean section. Am J Dis Child. 1983;137(5):505.
17. Barnes AD, Van Geem TA. Fractured femur of the newborn at cesarean section. A case report. J Reprod Med. 1985;30(3):203–5.

18. Vasa R, Kim MR. Fracture of the femur at cesarean section: case report and review of literature. Am J Perinatol. 1990;7(1):46–8.

19. Nadas S, Reinberg O. Obstetric fractures. Eur J Pediatr Surg. 1992;2(3):165–8.

20. Awwad JT, Nahhas DE, Karam KS. Femur fracture during cesarean breech delivery. Int J Gynaecol Obstet. 1993;43(3):324–6.

21. Jain R, Bielski RJ. Fracture of lower femoral epiphysis in an infant at birth: a rare obstetrical injury. J Perinatol. 2001;21(8):550–2.

22. Garcia Garcia IE, de la Vega A, Garcia FL. Long bone fractures in extreme low birth weight infants at birth: obstetrical considerations. P R Health Sci J. 2002;21(3):253–5.

23. Al-Habdan I. Birth-related fractures of long bones. Indian J Pediatr. 2003;70(12):959–60.

24. Alexander JM, Leveno KJ, Hauth J, Landon MB, Thom E, Spong CY, et al. Fetal injury associated with cesarean delivery. Obstet Gynecol. 2006;108(4):885–90.

25. O'Connell A, Donoghue VB. Can classic metaphyseal lesions follow uncomplicated caesarean section? Pediatr Radiol. 2007;37(5):488–91.

26. Matsubara S, Izumi A, Nagai T, Kikkawa I, Suzuki M. Femur fracture during abdominal breech delivery. Arch Gynecol Obstet. 2008;278(2):195–7.

27. Cebesoy FB, Cebesoy O, Incebiyik A. Bilateral femur fracture in a newborn: an extreme complication of cesarean delivery. Arch Gynecol Obstet. 2009;279(1):73–4.

28. Capobianco G, Virdis G, Lisai P, Cherchi C, Biasetti O, Dessole F, et al. Cesarean section and right femur fracture: a rare but possible complication for breech presentation. Case Rep Obstet Gynecol. 2013;2013:613–709.

29. Krosin MT, Lincoln TL. Traumatic distal femoral physeal fracture in a neonate treated with open reduction and pinning. J Pediatr Orthop. 2009;29(5):445–8.

30. Buonuomo PS, Ruggiero A, Zampino G, Maurizi P, Attina G, Riccardi R. A newborn with multiple fractures as first presentation of infantile myofibromatosis. J Perinatol. 2006;26(10):653–5.

31. Burke SW, Jameson VP, Roberts JM, Johnston II CE, Willis J. Birth fractures in spinal muscular atrophy. J Pediatr Orthop. 1986;6(1):34–6.

32. DeLozier CD, Antley RM, Williams R, Green N, Heller RM, Bixler D, et al. The syndrome of multisynostotic osteodysgenesis with long-bone fractures. Am J Med Genet. 1980;7(3):391–403.

33. Paterson CR. Osteogenesis imperfecta and other bone disorders in the differential diagnosis of unexplained fractures. J R Soc Med. 1990;83(2):72–4.

34. Beals RK, Tufts E. Fractured femur in infancy: the role of child abuse. J Pediatr Orthop. 1983;3(5):583–6.

35. Prevot J, Lascombes P, Blanquart D, Gagneux E. Labor trauma-induced epiphysiolysis of the proximal femur. 4 cases. Z Kinderchir. 1989;44(5):289–92.

36. Caterini R, Farsetti P, d'Arrigo C, Ippolito E. Unusual physeal lesions of the lower limb. A report of 16 cases with very long-term follow-up observation. J Orthop Trauma. 1991;5(1):38–46.

37. Sferopoulos NK, Papavasiliou VA. Proximal epiphyseal separation of the femur in the newborn: early ultrasonic diagnosis. Rev Chir Orthop Reparatrice Appar Mot. 1994;80(4):338–41.

38. Jones JC, Feldman KW, Bruckner JD. Child abuse in infants with proximal physeal injuries of the femur. Pediatr Emerg Care. 2004;20(3):157–61.

39. Theodorou SD, Ierodiaconou MN, Mitsou A. Obstetrical fracture-separation of the upper femoral epiphysis. Acta Orthop Scand. 1982;53(2):239–43.

40. Ogden JA, Lee KE, Rudicel SA, Pelker RR. Proximal femoral epiphysiolysis in the neonate. J Pediatr Orthop. 1984;4(3):285–92.

41. Burman MS, Langsam MJ. Posterior dislocation of lower femoral epiphysis in breech delivery. Arch Surg. 1939;38(2):250–60.

42. Phillips RR, Lee SH. Fractures of long bones occurring in neonatal intensive therapy units. BMJ. 1990;301(6745):225–6.

43. Grant P, Mata MB, Tidwell M. Femur fracture in infants: a possible accidental etiology. Pediatrics. 2001;108(4):1009–11.

44. Mangurten HH, Puppala B, Knuth A. Neonatal distal femoral physeal fracture requiring closed reduction and pinning. J Perinatol. 2005;25(3):216–9.

45. Matthews JJ, Cox PJ. Gallow's traction in an incubator for treatment of neonatal femoral fracture. Ann R Coll Surg Engl. 2008;90(1):74–5.

46. Amir J, Katz K, Grunebaum M, Yosipovich Z, Wielunsky E, Reisner SH. Fractures in premature infants. J Pediatr Orthop. 1988;8(1):41–4.

47. Sutcliffe JR, Wilson-Storey D, Mackinlay GA. Children's femoral fractures: the Edinburgh experience. J R Coll Surg Edinb. 1995;40(6):411–5.

48. Dabezies EJ, Warren PD. Fractures in very low birth weight infants with rickets. Clin Orthop Relat Res. 1997;335:233–9.

49. Coffey C, Haley K, Hayes J, Groner JI. The risk of child abuse in infants and toddlers with lower extremity injuries. J Pediatr Surg. 2005;40(1):120–3.

50. Kemp AM, Dunstan F, Harrison S, Morris S, Mann M, Rolfe K, et al. Patterns of skeletal fractures in child abuse: systematic review. BMJ. 2008;337:a1518.

51. van As AB, Garach SR. Femur fractures in infants. S Afr Med J. 2008;98(1):23–4.

52. Shrader MW, Bernat NM, Segal LS. Suspected non-accidental trauma and femoral shaft fractures in children. Orthopedics. 2011;34(5):360.

53. Pastor AJ, Gupta A, Press CM, Gourineni P. Femoral neck fracture as the sentinel sign of child abuse in an infant: a case report. J Pediatr Orthop B. 2012;21(6):587–91.

54. Abrams SA. Calcium and vitamin d requirements of enterally fed preterm infants. Pediatrics. 2013;131(5): e1676–83.

55. Lyon AJ, McIntosh N, Wheeler K, Williams JE. Radiological rickets in extremely low birth-weight infants. Pediatr Radiol. 1987;17(1):56–8.

56. Morrissy RT. Bone and joint infection in the neonate. Pediatr Ann. 1989;18(1):33–4. 36–8, 40–4.

57. Offiah AC. Acute osteomyelitis, septic arthritis and discitis: differences between neonates and older children. Eur J Radiol. 2006;60(2):221–32.

58. Dessi A, Crisafulli M, Accossu S, Setzu V, Fanos V. Osteo-articular infections in newborns: diagnosis and treatment. J Chemother (Florence, Italy). 2008;20(5):542–50.

59. Eliahou R, Simanovsky N, Hiller N. Fracture-separation of the distal femoral epiphysis in a premature neonate. J Ultrasound Med. 2006;25(12):1603–5.

60. Wellington P, Bennet GC. Fractures of the femur in childhood. Injury. 1987;18(2):103–4.

61. Brown D, Fisher E. Femur fractures in infants and young children. Am J Public Health. 2004;94(4): 558–60.

62. Loder RT, O'Donnell PW, Feinberg JR. Epidemiology and mechanisms of femur fractures in children. J Pediatr Orthop. 2006;26(5):561–6.

63. Hedlund R, Lindgren U. The incidence of femoral shaft fractures in children and adolescents. J Pediatr Orthop. 1986;6(1):47–50.

64. Kocher MS, Sink EL, Blasier RD, Luhmann SJ, Mehlman CT, Scher DM, et al. American Academy of Orthopaedic Surgeons clinical practice guideline on treatment of pediatric diaphyseal femur fracture. J Bone Joint Surg Am. 2010;92(8):1790–2.

65. Anderson WA. The significance of femoral fractures in children. Ann Emerg Med. 1982;11(4):174–7.

66. Gross RH, Stranger M. Causative factors responsible for femoral fractures in infants and young children. J Pediatr Orthop. 1983;3(3):341–3.

67. Daly KE, Calvert PT. Accidental femoral fracture in infants. Injury. 1991;22(4):337–8.

68. Scherl SA, Miller L, Lively N, Russinoff S, Sullivan CM, Tornetta P III. Accidental and nonaccidental femur fractures in children. Clin Orthop Relat Res. 2000(376):96–105.

69. Pierce MC, Bertocci GE, Janosky JE, Aguel F, Deemer E, Moreland M, et al. Femur fractures resulting from stair falls among children: an injury plausibility model. Pediatrics. 2005;115(6):1712–22.

70. Schwend RM, Werth C, Johnston A. Femur shaft fractures in toddlers and young children: rarely from child abuse. J Pediatr Orthop. 2000;20(4):475–81.

71. 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(5):e543–52.

72. Docherty E, Hassan A, Burke D. Things that go bump … bump … bump: an analysis of injuries from falling down stairs in children based at Sheffield Children's Hospital. Emerg Med J. 2010;27(3): 207–8.

73. Hinton RY, Lincoln A, Crockett MM, Sponseller P, Smith G. Fractures of the femoral shaft in children. Incidence, mechanisms, and sociodemographic risk factors. J Bone Joint Surg Am. 1999;81(4):500–9.

74. Leventhal JM, Thomas SA, Rosenfield NS, Markowitz RI. Fractures in young children. Distinguishing child abuse from unintentional injuries. Am J Dis Child. 1993;147(1):87–92.

75. Rex C, Kay PR. Features of femoral fractures in non-accidental injury. J Pediatr Orthop. 2000;20(3):411–3.

76. Hui C, Joughin E, Goldstein S, Cooper N, Harder J, Kiefer G, et al. Femoral fractures in children younger than three years: the role of nonaccidental injury. J Pediatr Orthop. 2008;28(3):297–302.

77. Baldwin K, Pandya NK, Wolfgruber H, Drummond DS, Hosalkar HS. Femur fractures in the pediatric population: abuse or accidental trauma? Clin Orthop Relat Res. 2011;469(3):798–804.

78. Clarke NM, Shelton FR, Taylor CC, Khan T, Needhirajan S. The incidence of fractures in children under the age of 24 months—in relation to non-accidental injury. Injury. 2012;43(6):762–5.

79. Kocher MS, Sink EL, Blasier RD, Luhmann SJ, Mehlman CT, Scher DM, et al. Treatment of pediatric diaphyseal femur fractures. J Am Acad Orthop Surg. 2009;17(11):718–25.

80. Givon U, Sherr-Lurie N, Schindler A, Blankstein A, Ganel A. Treatment of femoral fractures in neonates. Isr Med Assoc J. 2007;9(1):28–9.

81. Anglen JO, Choi L. Treatment options in pediatric femoral shaft fractures. J Orthop Trauma. 2005;19(10):724–33.

82. Stannard JP, Christensen KP, Wilkins KE. Femur fractures in infants: a new therapeutic approach. J Pediatr Orthop. 1995;15(4):461–6.

83. Podeszwa DA, Mooney III JF, Cramer KE, Mendelow MJ. Comparison of Pavlik harness application and immediate spica casting for femur fractures in infants. J Pediatr Orthop. 2004;24(5):460–2.

84. Janzing H, Broos P, Rommens P. Compartment syndrome as a complication of skin traction in children with femoral fractures. J Trauma. 1996;41(1):156–8.

85. Azouz EM. Apparent or true neonatal hip dislocation? Radiologic differential diagnosis. Can Med Assoc J. 1983;129(6):595–7.

86. Lindseth RE, Rosene Jr HA. Traumatic separation of the upper femoral epiphysis in a new born infant. J Bone Joint Surg Am. 1971;53(8):1641–4.

87. Towbin R, Crawford AH. Neonatal traumatic proximal femoral epiphysiolysis. Pediatrics. 1979;63(3):456–9.

88. Flynn JM, Schwend RM. Management of pediatric femoral shaft fractures. J Am Acad Orthop Surg. 2004;12(5):347–59.

89. Rush JK, Kelly DM, Sawyer JR, Beaty JH, Warner Jr WC. Treatment of pediatric femur fractures with the pavlik harness: multiyear clinical and radiographic outcomes. J Pediatr Orthop. 2013;33(6):614–7.

90. Murnaghan ML, Browne RH, Sucato DJ, Birch J. Femoral nerve palsy in Pavlik harness treatment for developmental dysplasia of the hip. J Bone Joint Surg Am. 2011;93(5):493–9.

91. U.S. Department of Health and Human Services AfCaF, Administration on Children, Youth and Families, Children's Bureau. Child Maltreatment 2011. 2012.

92. Sedlak AJ, Mettenburg J, Basena M, Petta I, McPherson K, Greene A, Li S. Fourth National Incidence Study of child abuse and neglect (NIS-4). 2010.

93. Leetch AN, Woolridge D. Emergency department evaluation of child abuse. Emerg Med Clin North Am. 2013;31(3):853–73.

94. Lane WG, Rubin DM, Monteith R, Christian CW. Racial differences in the evaluation of pediatric fractures for physical abuse. JAMA. 2002;288(13):1603–9.

95. Thomas SA, Rosenfield NS, Leventhal JM, Markowitz RI. Long-bone fractures in young children: distinguishing accidental injuries from child abuse. Pediatrics. 1991;88(3):471–6.

96. King J, Diefendorf D, Apthorp J, Negrete VF, Carlson M. Analysis of 429 fractures in 189 battered children. J Pediatr Orthop. 1988;8(5):585–9.

97. Loder RT, Bookout C. Fracture patterns in battered children. J Orthop Trauma. 1991;5(4):428–33.

98. Dalton HJ, Slovis T, Helfer RE, Comstock J, Scheurer S, Riolo S. Undiagnosed abuse in children younger than 3 years with femoral fracture. Am J Dis Child. 1990;144(8):875–8.

99. Skellern CY, Wood DO, Murphy A, Crawford M. Non-accidental fractures in infants: risk of further abuse. J Paediatr Child Health. 2000;36(6):590–2.

100. Taitz J, Moran K, O'Meara M. Long bone fractures in children under 3 years of age: is abuse being missed in Emergency Department presentations? J Paediatr Child Health. 2004;40(4):170–4.

101. Trokel M, Waddimba A, Griffith J, Sege R. Variation in the diagnosis of child abuse in severely injured infants. Pediatrics. 2006;117(3):722–8.

102. Kocher MS, Kasser JR. Orthopaedic aspects of child abuse. J Am Acad Orthop Surg. 2000;8(1):10–20.

103. Augarten A, Laufer J, Szeinberg A, Passwell J. Child abuse, osteogenesis imperfecta and the grey zone between them. J Med. 1993;24(2-3):171–5.

104. Lamptey P, Onwuzurike N, Inoue S. Multiple fractures due to osteogenesis imperfecta mistaken as child abuse. BMJ Case Rep. 2009. doi:10.1136/bcr.07.2008.0589.

105. Laskey AL, Stump TE, Perkins SM, Zimet GD, Sherman SJ, Downs SM. Influence of race and socioeconomic status on the diagnosis of child abuse: a randomized study. J Pediatr. 2012;160(6):1003–8.e1.

106. Kleinman PK, Marks SC, Blackbourne B. The metaphyseal lesion in abused infants: a radiologic-histopathologic study. Am J Roentgenol. 1986;146(5):895–905.

107. Arkader A, Friedman JE, Warner Jr WC, Wells L. Complete distal femoral metaphyseal fractures: a harbinger of child abuse before walking age. J Pediatr Orthop. 2007;27(7):751–3.

108. Gholve P, Arkader A, Gaugler R, Wells L. Femoral neck fracture as an atypical presentation of child abuse. Orthopedics. 2008;31(3):271.

109. Swischuk LE. Irritable infant and left lower extremity pain. Pediatr Emerg Care. 1997;13(2):147–8.

110. Worlock P, Stower M, Barbor P. Patterns of fractures in accidental and non-accidental injury in children: a comparative study. Br Med J (Clin Res Ed). 1986;293(6539):100–2.

111. Kleinman PK, Perez-Rossello JM, Newton AW, Feldman HA, Kleinman PL. Prevalence of the classic metaphyseal lesion in infants at low versus high risk for abuse. Am J Roentgenol. 2011;197(4):1005–8.

112. American Academy of Pediatrics. Section on radiology: diagnostic imaging of child abuse. Pediatrics. 1991;87(2):262–4.

113. Roach J, Hoschl R. Diffuse femoral uptake on bone scan after fracture in an infant. Q J Nucl Med. 1996;40(2):194–6.

114. Conway JJ, Collins M, Tanz RR, Radkowski MA, Anandappa E, Hernandez R, et al. The role of bone scintigraphy in detecting child abuse. Semin Nucl Med. 1993;23(4):321–33.

115. Mandelstam SA, Cook D, Fitzgerald M, Ditchfield MR. Complementary use of radiological skeletal survey and bone scintigraphy in detection of bony injuries in suspected child abuse. Arch Dis Child. 2003;88(5):387–90.

116. Merten DF, Carpenter BL. Radiologic imaging of inflicted injury in the child abuse syndrome. Pediatr Clin North Am. 1990;37(4):815–37.

117. Sugar NF, Taylor JA, Feldman KW. Bruises in infants and toddlers: those who don't cruise rarely bruise. Puget Sound Pediatric Research Network. Arch Pediatr Adolesc Med. 1999;153(4):399–403.

118. Maguire S, Mann MK, Sibert J, Kemp A. Are there patterns of bruising in childhood which are diagnostic or suggestive of abuse? A systematic review. Arch Dis Child. 2005;90(2):182–6.

119. Pierce MC, Kaczor K, Aldridge S, O'Flynn J, Lorenz DJ. Bruising characteristics discriminating physical child abuse from accidental trauma. Pediatrics. 2010;125(1):67–74.

120. Loder RT, Feinberg JR. Orthopaedic injuries in children with nonaccidental trauma: demographics and incidence from the 2000 kids' inpatient database. J Pediatr Orthop. 2007;27(4):421–6.

121. Kleinman PK, Marks Jr SC, Nimkin K, Rayder SM, Kessler SC. Rib fractures in 31 abused infants: post-mortem radiologic-histopathologic study. Radiology. 1996;200(3):807–10.

122. Kleinman PK, Marks Jr SC. Relationship of the sub-periosteal bone collar to metaphyseal lesions in abused infants. J Bone Joint Surg Am. 1995;77(10):1471–6.

123. O'Connor JF, Cohen J. Dating fractures. In: Kleinman PK, editor. Diagnostic imaging of child abuse. Baltimore, MD: William and Wilkins; 1987. p. 6.

124. Kemp AM, Jaspan T, Griffiths J, Stoodley N, Mann MK, Tempest V, et al. Neuroimaging: what neuroradiological features distinguish abusive from non-abusive head trauma? A systematic review. Arch Dis Child. 2011;96(12):1103–12.

125. Touloukian RJ. Abdominal visceral injuries in battered children. Pediatrics. 1968;42(4):642–6.

126. Raissaki M, Veyrac C, Blondiaux E, Hadjigeorgi C. Abdominal imaging in child abuse. Pediatr Radiol. 2011;41(1):4–16. quiz 137–8.