Chapter 6
Non-accidental Skeletal Trauma

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Abstract Personnel who analyze the biological evidence of fatal child abuse such as forensic anthropologists and pathologists are called upon to assess skeletal trauma and distinguish between injuries stemming from accidental and non-accidental origins. Such analyses assist law enforcement personnel in the identification of individuals and the possible circumstances surrounding death. This chapter offers the reader an essential review of the important literature concerning skeletal evidence of child abuse. It focuses on injuries originating from physically abusive scenarios and also discusses the basic differences between intentional and accidental causes of skeletal trauma.

6.1 Introduction

As part of the multidisciplinary team of personnel investigating child fatalities, forensic anthropologists and pathologists are charged with differentiating injuries stemming from accidental and non-accidental origins. Physicians and dentists may also be called upon to provide their expertise in cases of child abuse in their daily practices and must also be aware of the basic differences between trauma sustained from abuse or accident. Indeed, these practitioners are subject to risk of civil suits and other litigation if abuse is not reported to the appropriate authorities. Most state laws impose criminal penalties, which may include revocation of licenses, for failure to report suspected cases of child abuse. This, along with the expectations of all investigative personnel in the adversarial courtroom setting, presents a daunting challenge [1].

In order to address such clinical and legal demands, this chapter offers the reader an essential review of the important literature concerning skeletal evidence of child abuse that tends to cluster in the infant-to-toddler time span. It focuses on injuries originating from physically abusive scenarios and also discusses the basic differences between intentional and accidental causes of skeletal trauma. Differential diagnoses for trauma sustained in the neonate should consult Heldrich (Chapter 5,

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this volume) for information on birth trauma. Readers interested in soft tissue injuries resulting from abuse are directed to consult the medical pathology literature.

6.2 Factors to Consider When Diagnosing Skeletal Trauma

One must consider the specific type of fracture (spiral, transverse, oblique, etc.), the age and level of motor development of the child, the reported manner of trauma from the caregiver/witness, and, if possible, the child's description of the events. For example, rib fractures and/or spiral fractures of any long bones should be viewed as suspicious for child abuse in non-ambulatory children. This is especially the case when the description of the event would not plausibly produce the presenting trauma (i.e., spiral femoral fracture in an infant that is accidentally dropped).

Socioeconomic variables such as household income and composition are significantly correlated with trauma frequencies and are discussed by Ragan (Chapter 2, this volume).

6.3 Common Features of Non-accidental Trauma

No single fracture or bony reaction is diagnostic for physical abuse, yet there are certain patterns to trauma that may be suggestive of non-accidental scenarios. The most commonly cited are listed in Table 6.1 [2–8].

The most well-known trauma pattern associated with juveniles, especially infants and young toddlers, is shaken baby syndrome. Originally described by Caffey as "whiplash shaken infant syndrome" [9], it is known today as "shaken baby syndrome" and appears as a cluster of specific soft and hard tissue trauma noted in many infants despite the lack of any other external injury or history of trauma from the caregiver. In such cases, the infant is held by the chest and shaken back and forth while the unsupported head and limbs are left to freely swing about. This may result in subdural, subarachnoid, and retinal hemorrhages. If the child is held by the extremities and shaken, traction-type metaphyseal fractures and subperiosteal hemorrhage can result from the traction and shearing forces (Fig. 6.1).

It is important to note that many cases of physical abuse leave no skeletal evidence [10]. Additionally, while multiple fractures are often touted as pathognomonic for child abuse, approximately half of all child abuse victims are found to have only a single fracture [4].

6.4 Axial Skeleton

6.4.1 Cranial Vault

Head trauma due to abuse is the leading cause of traumatic infant death from injury [11]. Kleinman et al. [12] found 42% of infants in a retrospective study presented

Table 6.1 Skeletal trauma suggestive of child abuse, assuming child is non-ambulatory

Element	Location	Type/description	Mechanism
Cranium	Parietal, frontal, occipital	Simple linear, wide, complex, depressed, diastatic, growing, and/or multiple fractures that cross suture lines	Direct impact
Vertebra	Spinous process	Avulsion	Hyperflexion, hyperextension
	Centrum	Wedge fracture dislocation/subluxation	Compression, hyperflexion, hyperextension
Sternum	Any portion	Transverse	Direct force
1st ribs	1st ribs, lateral	Transverse	Acute axial load
Other Ribs	Any location, but especially posterior (head, costotransverse process) and axillary	Frequently multiple and bilateral	Shaken baby syndrome and direct impact[a]
Clavicle	Lateral	Transverse	Sudden traction on the arm
Scapula	Blade, acromial process	Transverse	Direct force, severe twisting/shaking
Long bones	Metaphysis	Corner/bucket-handle avulsion fracture	Traction injury from shaken baby syndrome[a]
Humerus	Diaphysis	Any fracture except supracondylar, and periosteal reaction in children under the age of three	Gripping and twisting, direct impact
Hands	Metacarpals, phalanges	Torus	Squeezing, forced hyperextension, trampling
Femur	Diaphysis	Any type (but especially spiral), periosteal reaction in children under the age of three	Gripping and twisting, direct impact
Tibia/fibula	Metaphysis	Any fracture or periosteal reaction in children under 1 year of age	Gripping and twisting, direct impact

[a]High specificity for abuse

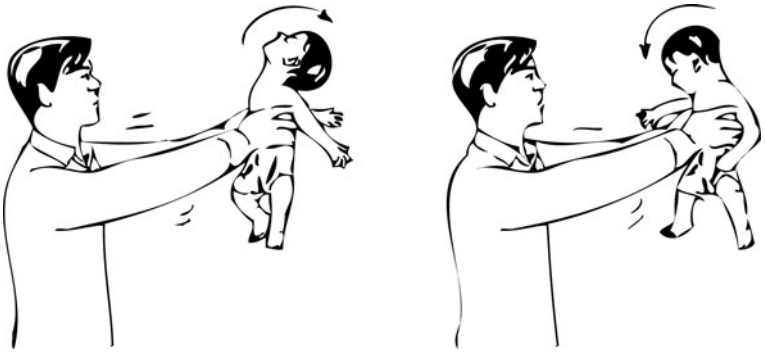

Fig. 6.1 Illustration depicting the movements that result in shaken baby syndrome. (adapted from http://kidsandteensblog.info/shaken-baby-syndrome-sbs-beware)

with skull fractures due to abuse, while Merten et al. [13] report that 50% of all children with complete skeletal surveys under 1 year of age displayed cranial trauma. Hymel et al. [5] report that abusive head trauma accounts for nearly two-thirds of all infant homicides.

The incidence of intentionally inflicted traumatic brain injury is higher in male children, in children aged 1 year and younger, in minority groups, and in those from lower socioeconomic strata [11].

The thin bones that make up the calvarium of young children (especially the parietal bones) lack the more solid adult diploid structure and so may be more vulnerable to fracture. However, the same open-sutured malleability that allows molding of the head during vaginal delivery also results in increased resistance to fractures [14]. In falls of a short distance, young children with open sutures and thin, more malleable crania will generally sustain fractures less often than older children with more tightly closed sutures and a thicker, less malleable crania [15].

The appearance and complexity of cranial fractures is due to different forces and impacts. Types of fractures include simple linear (impact with a large, flat object), concentric (high-energy impact with a solid object), complex (significant violence, multiple blunt force impacts), depressed (impact with an object of small mass and high velocity), diastatic (intrasutural), growing (progressive diastasis of a fracture), and the more rare contracoup (fracture remote from impact site). These fractures occur with widely ranging frequencies based on the age and activity level of the child.

Fatal injury from accidental falls during childhood is very rare. Although possible, it is very unlikely that a short fall in the home will produce complex cranial fractures or retinal/subdural hemorrhage [11]. Indeed, the most common cranial trauma seen in such accidental falls are simple linear fractures, with a very low risk of intracranial sequelae [3].

There are no specific features of skull fractures that are diagnostic of child abuse. Fractures resulting from abuse can be simple linear, complex, bilateral, multiple, or depressed [3]. Multiple or bilateral fractures, or those that crossed suture lines,

however, are significantly associated with child abuse [6]. Knight [16] describes bilateral horizontal fractures extending posteriorly from the coronal suture as a common finding in child abuse. These injuries may originate from direct blows to the top of the head or dropping a child on the head.

6.4.2 Facial Elements, Mandible, and Teeth

Galloway [17] notes that, in the mind of the perpetrator, a victim's identity is psychologically linked to the head and face. This may make these areas a focal point of intentional injury. In a study of children less than 2 years of age who were the victims of abuse, Naidoo [18] found the soft tissues of the face to be the most frequently injured (41%) part of the body, with the cheek being the most common site for the injury. Fractures to the midface in the pediatric age group, however, may be a relatively rare occurrence because the mandible and cranium provide protection and absorb most of the traumatic impact to the elastic bones. Blunt force trauma to the eye may result in a blowout fracture of the delicate orbital floor as well as the medial side of the maxilla and neighboring zygomatic bone, but these tend to be rare in children under the age of 8 years [19]. Mandibular fractures are rare in infants and young children and are more likely to originate from high-impact accidental scenarios [20].

Dental trauma is common in children and may result from sports, accidents, and abuse. It is very difficult, however, to distinguish between accidental and non-accidental origins. Fractured, avulsed, and discolored teeth (pulpal necrosis from previous trauma), caries, and/or periodontal disease may or may not indicate some level of child abuse or neglect [21–23]. In these cases it will be important to take into consideration the child's access to preventive dental care as well as the appropriateness of the caregiver's history of how any dental injuries occurred.

6.4.3 Vertebrae

Vertebral trauma is rare in children. However, vertebral trauma may be asymptomatic and therefore may go unrecognized. They are often found incidentally on a skeletal survey without obvious clinical findings [4]. When present, they tend to result from high-energy incidents such as motor vehicle accidents, falls from heights, and sports-related injuries [15]. Such trauma is mostly seen in older children. The most common injuries are compression fractures of the body of the vertebrae, fractures to spinous processes, dislocations, and subluxations.

"Hangman's fractures," or traumatic spondylolisthesis of the second cervical vertebra, were observed historically in case of judicial hangings, where the drop of the body was far enough to generate adequate weight to forcibly produce bilateral fractures separating the neural arch after the sudden stop. In more contemporary times, such fractures occur mainly in sports or motor vehicle accidents and result from

hyperextension of the head in relation to the cervical spine. “Hangman’s fractures” are rarely observed in suicidal hangings because the orchestrated drop is usually too short to produce the necessary force to generate the fracture [15]. Fatalities from such hangings are usually due to asphyxia more so than traumatic vertebral dislocations.

Avulsion fractures of the spinous processes seen in the lower cervical and upper thoracic spine may be caused by non-accidental hyperflexion. Spinal fracture resulting from severe hyperflexion, however, is rare in the thoracolumbar region [24] and is less frequent in cases of child abuse [25]. In a study of vertebral trauma stemming from known abuse, Cullen [26] found various compression fractures, dislocations, subluxations, and reduced heights of the vertebral bodies throughout the thoracic vertebrae and superior lumbar vertebrae. The mechanism by which the vertebrae were injured is not discussed.

Carty [3] notes that flexion and extension injuries may result from direct trauma or from impaction injuries as the child is forcibly thumped down on the buttocks. Galloway [17] adds that vertebral wedge fractures in the lower thoracic and upper lumbar region may also be found in cases where the child was shaken.

6.4.4 Sternum

Fractures of the sternum in children are uncommon. Along with ribs, they are very rarely fractured even during resuscitative maneuvers. When present, an abusive origin should be considered [27]. Hechter et al. [28], however, found that sternal fractures are not specific for child abuse. In 12 children who presented with such fractures, the mechanism of injury was suspicious for child abuse in only two. Both victims were 2 years old and younger. Other reported mechanisms for injury included forced accidental episodes such as falling from swings/monkey bars and jumping on the bed.

6.4.5 Ribs

The thoracic cage of infants and toddlers is very pliable and is therefore less prone to fracture than the more stable adult thorax. Normal daily interaction and child care such as bathing/dressing/picking up a baby or changing diapers will not produce rib fractures unless there is an underlying health condition that results in decreased bone mineral density [15]. Rib fractures are unlikely to occur during birth, even in traumatic vaginal deliveries. It is very rare for the ribs of young children to fracture in cardiopulmonary resuscitation efforts [29].

Rib fractures are, however, the most common fracture resulting from physical violence and are considered to be the most diagnostic of all abuse-related fractures [6, 8, 30]. Fracture frequencies per child will range depending on age category. Kogutt et al. [27] found that 15% of 52 abused children between 6 weeks and 2

years old displayed rib fractures. Kleinman et al. [12] found a fracture frequency of 35% of all infants in their study. Merten et al. [13] observed that 21% of all infants with skeletal surveys had rib fractures and that 61% of all rib fractures occurred in abused children less than 1 year old. Of all rib fractures sustained in child abuse, 90% were found in children less 2 years of age.

Rib fractures from abuse may occur anywhere on the rib, but they tend to be found more often at the anatomical head, neck, and costotransverse process [30]. Fractures are also found in the posterior, lateral, and anterior arcs [3, 12]. Anterior costochondral separations can also occur in abuse, where the end of the rib appears widened and clubbed [27]. Fractures resulting from abuse are frequently multiple, involving several contiguous ribs.

The most common action in which ribs are fractured is by shaking an infant held by the chest. Such excessive anteroposterior compression levers the rib head and rib neck against the transverse process of the vertebra, leading to fracture [3] (Fig. 6.2). This anterior–posterior compression also stresses the lateral aspects of the ribs, which can result in lateral rib fractures. Strouse and Owings [31] report on possible mechanisms for fractures found in the first ribs of abuse victims. Axial loads are produced when the child is shaken or slammed down. Additional forces result when the relatively heavy head moves violently forward and backward when the child is shaken. All these forces travel indirectly to first ribs via the muscles of the neck and may result in fracture. Direct trauma of sufficient force will also lead to rib fracture.

Trauma to the thorax may be just one component of a suite of injuries that make up the "shaken baby syndrome." As the infant is held and squeezed by the thorax, it is violently shaken. The head is thrown back and forth in a whiplash movement and the limbs swing without restraint. These actions result in often lethal brain injury as well as skeletal trauma that can be observed in the chest and limbs.

Fig. 6.2 Frontal radiograph illustrating multiple posterior rib fractures from excessive squeezing forces. Reprinted with permission from LearningRadiology.com

Rib fractures are often asymptomatic; it is estimated that approximately 80% of fractures do not lead to complaint [13]. They are rarely accompanied by external evidence of trauma [29] and are also difficult to visualize on radiographs. Fractures of the rib head and the costochondral junction are particularly difficult to observe, even with callus formation [12]. Therefore, rib fractures are in all likelihood underdiagnosed in the clinical setting. Anthropologists are in a much better environment to macroscopically visualize rib fractures (or any other skeletal trauma) as the elements can be manually freed from obscuring soft tissue.

Rib fractures may be the only skeletal evidence of child abuse. Barsness et al. [30] found that rib fractures were the only skeletal trauma as a result of child abuse in 29% of their study population. When such fractures are found, it may be in an accidental finding in a child that is examined for other reasons, or a finding within the scope of a full radiological examination upon suspicion of abuse.

As rib fractures carry such diagnostic weight in child abuse investigations, it is important to consider differential diagnoses. Rib fractures have been associated with violent coughing [32], chest physiotherapy [33–35], and prematurity [36].

6.5 Shoulder and Pelvic Girdles

6.5.1 Clavicle

The clavicle is the most commonly fractured bone in children, due mainly to its superficial location and its function as part of the supportive girdle for the upper limb in an active child. However, only 2–7% of all fractures due to child abuse are found in the clavicle [13, 27]. Midshaft fractures are not specific and should be considered significant only when associated with other injuries that may suggest child abuse. Fractures of the lateral end of the clavicle, however, are much less common and not usually encountered except as part of birth trauma or in child abuse, where they result from violent shaking or twisting [27].

It is nearly impossible to differentiate between clavicular fractures caused by birth trauma, by accident, or by abuse. Dating the fracture may help determine whether a fracture was caused by birth trauma. Generally, any fracture found 10 days to 2 weeks postdelivery that does not show radiographic evidence of soft callus formation was not the result of delivery.

Once birth injuries are excluded, clavicular fractures are rare as a result of accidents under the age of 2 years [3]. Fractures to the clavicle found in children this age and younger are the result of sudden traction to the arms by violent shaking. In children of preschool age, clavicle fractures become more common. They are caused by falls with the arm held against the side of the body. Falls from a short distance are unlikely to produce serious injury. In a study of 207 children under the age of 6 years who reportedly fell out of bed/crib, Lyons and Oates [37] found only one clavicle fracture. In older children a clavicle fracture tends to be more the result of an accident. Generally, it will be midshaft and mostly due to a fall on the shoulder.

6.5.2 Scapula

Fractures of the scapula are generally associated with high-energy impacts such as motor vehicle accidents and direct, sports-related blows [15]. Such accidental fractures are extremely rare, especially in children under 2 years of age. Fracture of the acromial process may occur, however, from severe twisting or shaking [27]. Fractures in the glenoid fossa are usually the result of a fall on the upper arm. Concomitant trauma/dislocation/avulsion of the acromio-clavicular joint may also be seen.

6.5.3 Innominates

Fractures to the innominates are rare; most are due to significant impact injury such as motor vehicle accidents [15], and trauma to this region is not usually included among those considered specific for child abuse. Johnson et al. [38], however, report on the occurrence of disruption or fracture to the pubic rami and sacroiliac joint that were associated with sexual assault.

Starling et al. [39] note that pelvic fractures are unlikely to occur in isolation, and patients who present with fractures to any part of the pelvic ring may also have concomitant trauma to other bony elements.

Any fracture to the innominates that occurs outside of a documented high-energy scenario, such as a motor vehicle accident, is suspicious for child abuse.

6.6 Extremities

6.6.1 Diaphyseal Trauma

Diaphyseal fractures in abused children are relatively more common than fractures found in other regions, such as the metaphyses. Various studies report a wide range in relative frequencies of the shaft fractures to the long bones, spanning from 33% to almost 100% [40–42].

When fractures to the long bones are observed, the investigator must consider the context of the clinical history and make a judgment whether the history, the clinical presentation, and the fracture type are all compatible. Transverse diaphyseal fractures of child abuse may be the result of direct trauma such as a blow. Spiral diaphyseal fractures may occur when an infant is grabbed by a limb; the weight of the suspended child, who may struggle against the fixed adult hand, applies twisting forces to the shaft of the bone.

Accidental transverse, oblique, greenstick, and spiral fractures in children under 2 years of age certainly do occur, but they are relatively rare in comparison with older children [3]. The 2-year mark is an important age at which trauma is critically judged regarding abuse, as children this age and younger are smaller and less able to protect themselves against attack.

6.6.2 Growth Plate Injuries

True Salter-Harris injuries to the growth plates are more often the result of accidental trauma. Indeed, they account for up to 30% of all accidental trauma-related fractures in mobile children and are therefore not primarily suspicious for abuse [43]. They may occur from non-accidental episodes, but they are relatively rare sequelae from child abuse [2].

Physeal fractures with separation of the epiphysis result from traction or rotation forces and shaking. Such fractures are uncommon in abused children [4]. A buckle fracture at the juncture of the femoral diaphysis and metaphysis, however, may result from forcibly thumping a young child on his leg on a hard surface [2].

6.6.3 Metaphyseal Lesions

Metaphyseal fractures are much less common than diaphyseal or epiphyseal fractures [8], but are much more specific for child abuse [6, 44]. Percentages of all long bone fractures that involve the metaphysis have been reported at 1–44% [40–42, 45] and even reached 50% in one study [8].

These lesions occur very close to the growth plate, unlike accidental metaphyseal fractures (usually of the torus variety), which occur at the junction of the diaphysis and metaphysis. Metaphyseal injuries are also called “bucket-handle” or corner fractures due to slight angulations in radiographic projection (Fig. 6.3).

Fractures to the metaphysis are most often caused by a shaking injury which can also inflict life threatening brain damage [2]. Hymel and Spivak [46] maintain that violent shaking of a child may lead to simultaneous avulsion fractures of the distal femur and the proximal and distal tibia accompanied by fractures of the posterior ribs and inflicted skull/brain injuries. This is the ‘whiplash shaken infant syndrome’, or ‘shaken baby syndrome’, originally described by Caffey [9].

In addition to rib fractures, metaphyseal fractures are the most specific injury for child abuse, especially when no reasonable explanation is offered for how the injury occurred. However, metaphyseal injuries are rarely the reason that a child is brought in for medical attention. They are often very difficult to detect and will usually not be verified unless they are specifically sought in high-detail skeletal surveys [12].

Metaphyseal fractures are the result of horizontal movement through the metaphysis, which is not present in a fall or blunt trauma. Indeed, the biomechanical forces necessary to produce fractures in this area are unlikely to be generated from falls or other accidents [4]. However, such forces are produced when a child is shaken while holding on to the hands or feet, or when the child is held around the chest with the extremities swinging back and forth [47]. Metaphyseal fractures occur most often from these acceleration and deceleration forces indirectly applied during shaking, but they may also occur when either twisting or shearing forces are applied when a child is taken by the arm or leg [3]. Symmetrical fractures are usually caused by indirect, violent shaking whereas single lesions and are more likely to occur by direct force [2].

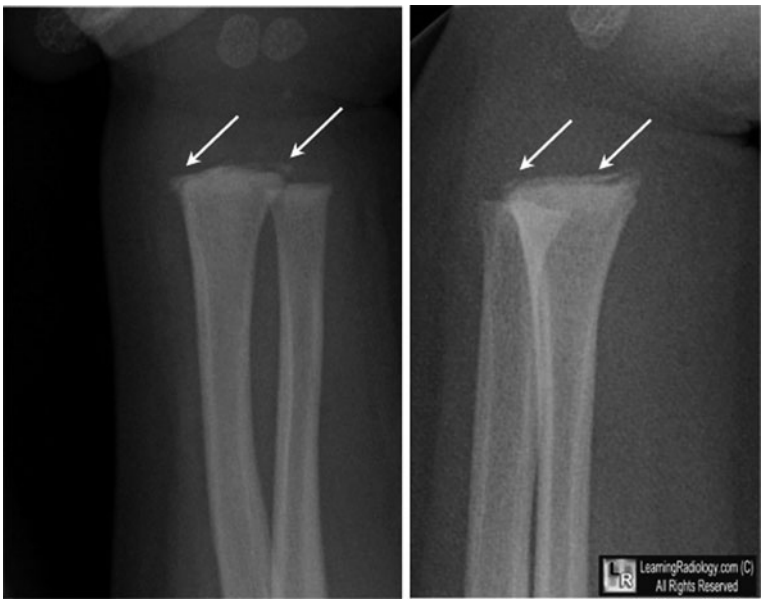

Fig. 6.3 Metaphyseal fractures of the distal radius. Both of these images are of the same element. The injuries appear as corner fractures in the frontal view (*left*) and bucket-handle fractures in the oblique view (*right*). Reprinted with permission from LearningRadiology.com

Metaphyseal fractures are most frequently found in the distal femur, the proximal and distal tibia, and the proximal humerus [15]. The tibial metaphysis is the most prevalent location for avulsion fractures [48]. Between 39 and 50% of children under the age of 18 months suspected of being physically abused will have one or more of these fractures. They are most often seen in children less than 2 years of age.

Since most cases of metaphyseal fractures do not cause severe pain, these lesions may not be obviously diagnosed in a clinical setting [2]. Often, the only evidence that may exist is radiological, and films must be of superior quality to observe these often very subtle lesions. This subtlety is because subperiosteal new bone formation does not occur because the periosteum in this area is tightly adherent and is not disrupted, therefore the usual marker of periosteal reaction for fracture will be either very subtle or not present at all [4].

6.6.4 Humerus

In determining the origin of humeral fractures, differential diagnoses are dependent upon general age groups. In neonates, humeral fractures result mostly from birth trauma, where delivery is difficult and/or the infant is macrosomal. In children less than 3 years of age, fractures to the humerus, especially spiral and oblique

fractures, are going to result more often from abuse. Children in the toddler years are small and light enough to be handled in such a way that produces fracture, and they are unable to fight off an assault as an older child might do. The presence of any underlying medical condition that includes some degree of osteological involvement, and thus possible bone weakness, will naturally need to be considered as well.

Fractures to the midshaft of the humerus should be carefully assessed to exclude child abuse in children under 15 months [6]. While never an absolute indicator of child abuse, midshaft spiral fractures are caused by twisting forces, and unless a plausible scenario is provided, they should always raise suspicion for non-accidental trauma. Spiral midshaft fractures of the humerus may, however, result from accidental twisting that mimics fractures from abuse. Hymel and Jenny [49] report on documented cases where children were simply rolled over onto their backs from a prone position. The caregiver pulled them over by one arm, which allowed the opposite arm to be twisted behind the back, resulting in spiral fractures.

Fractures of the medial condyle of the humerus are another frequent fracture found in child abuse. These can be produced by violent torsion on the arm and involve both the trochlear groove and the growth plate [50]. They are rare in accidental trauma. With the exception of supracondylar fractures, all fractures of the humerus in children under the age of 3 years are generally suggestive of abuse [2].

In children 10 years of age and older, humeral fractures are more often the result of direct (impact against the shoulder or a fall on the posterolateral part of the shoulder) or indirect trauma (a fall backward on the extended arm) from contact sports, play, or motor vehicle accidents. Supracondylar fractures are nearly always the result of an accident and result when the child falls on the extended arm or elbow. Fractures to the lateral condyle are commonly seen after falls experienced during an active childhood.

6.6.5 Radius/Ulna

Of all bone trauma due to child abuse, 10–20% are fractures of the radius and ulna [51]. In general, fractures of the forearm in children less than 1 year old are highly suspect for abuse. Transverse fractures may occur when the older toddler holds up the arm to ward off a blow [3].

In the general population of mobile children, fractures of the forearm are usually the result of accidental trauma. These fractures tend to be sustained from falls, with indirect forces applied to the lower arm as the child tries to break the fall by outstretching the arm and hand. The majority of the force is transferred and applied to the radius. In younger children, this type of accident generally produces greenstick or torus fractures [15]. When an older child is held by the arms and swung, the triceps muscle is stronger than the cartilaginous insertion point on the olecranon process, and the centrifugal forces applied to this specific area can result in tearing off at the olecranon process [17].

6.6.6 Femur

Spiral fractures to the diaphysis are caused by torque (rotation along the longitudinal axis of the bone). Torque may occur in child abuse, such as when the leg is grabbed and twisted. In non-ambulatory children, child abuse should be considered when no plausible reason for the injury is given. Torque, however, can produce spiral fractures of a purely accidental nature, especially in mobile children, and can occur from actions as simple as slipping and falling while running [3].

Transverse and oblique fractures of the femoral diaphysis and are due to compression, tension, shearing, and bowing forces, and can result from accidental and non-accidental situations and from direct and indirect forces.

The age and associated level of motor development of the child who presents with a femoral fracture will provide clues regarding the true circumstances in which the injury incurred. Approximately 60% of diaphyseal fractures of the femur in children under 1 year of age are due to abuse [52, 53]. In children above 5 years, a shaft fracture is more likely due to high-energy impact, such as a motor vehicle accident. Johnson et al. [38] present a few rare cases of femoral fractures due to sexual abuse.

Kempe et al. [6] find the most common location of femoral fracture in both abused and nonabused children to be the midshaft of the diaphysis. Additionally, these authors found no significant difference in the frequency of transverse, spiral, or oblique fractures between abused and nonabused children.

6.6.7 Tibia/Fibula

In young, non-ambulatory children, fractures of the tibial shaft should be highly suspicious for child abuse. Spiral fractures can result from grabbing the lower leg and twisting but may also be the result of accidents [2], especially in mobile children 3–4+ years of age [54]. For example, “toddler’s fractures” (non-displaced spiral tibial shaft fractures) are common and tend to be the result of accidental trauma [4]. These fractures can occur in youngsters who fall while running and should not be mistaken for abuse [3]. Similar to the femur, transverse and oblique fractures of the tibia may occur from direct force applied to the diaphysis.

Simultaneous fractures to the tibia and fibula are more often the result of accidents, such as spoke injuries. Such fractures can occur when a child is seated in a child’s seat on the back of an adult’s bicycle and their foot gets caught and becomes twisted between the frame and the spokes of the wheel [55, 56].

Isolated fibular fractures are rarely seen in child abuse. When they occur, they tend to be the result of direct-impact force to the shaft.

6.6.8 Hands/Feet

Fractures of the hands and feet are unusual, for any scenario. When present, they should be suspect for abuse in any age.

Trauma resulting from abuse tends to present as torus fractures to the metacarpals, metatarsals, and/or the proximal phalanges of the hands [15]. It often concerns multiple fingers and/or toes, perhaps in multiple stages of healing [57]. They result from direct impact, hyperflexion and hyperextension [15], or by squeezing the extremity or trampling on them [3]. In 11 abused infants with fractures of the feet, Nimkin et al. [58] found that 4 of 6 metatarsal fractures involved the first digit. In older children, fractures to the hands and feet are more often the result of accidents.

6.7 Subperiosteal Hemorrhage

Subperiosteal reaction resulting from trauma needs to be distinguished from normal physiological periosteal reaction. Physiological periostitis is commonly observed on the femoral, humeral, and tibial diaphyses of infants aged 6 weeks to 6 months. There is occasional extension to the metaphysis. It is idiopathic in nature and is usually symmetrically distributed [59]. Such physiological new bone is smooth and lamellar and observed mostly on the medial aspect of the diaphysis [3].

Traumatic periosteal reaction may also be bilateral, but there is usually other evidence of trauma, such as fracture or hematoma [59]. Caffey [60], however, previously suggested that periosteal reaction may also occur without a fracture, where rough gripping leads to periosteal damage and subsequent reaction. It has now been shown that the lesions can result from simply shaking, where the unsupported limbs are affected by acceleration and deceleration forces [1]. In child abuse, the periosteal reaction often extends to the metaphysis. Note that in periosteal reactions due to infection, new bone will not affect multiple bones symmetrically [59].

6.8 Harris Lines

Skeletal indicators such as Harris lines may be used as a proxy to determine generalities concerning overall physical health and environmental stress. Indeed, trauma resulting from child abuse is often accompanied by Harris lines. These lines (best observed radiographically) are formed in the metaphyses and are evidence of disturbances in longitudinal growth. They occur during the course of any illness involving metabolic stress (for example, malnutrition), but they are also encountered in cases involving failure to thrive and lack of bonding [15].

Harris lines are formed after an initial slowing or cessation of growth, followed by a period of resumed growth. Since the child must live through whatever nonspecific stress was encountered in order to form the Harris line, the lines represent periods of stress that have since passed. Harris lines may be multiple and represent more than one period of delayed growth followed by a period of resumed growth [61]. The lines will remain visible until puberty, at which point they will begin to shorten and eventually disappear.

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