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Evaluating Young Children With Fractures for Child Abuse: Clinical Report

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abstract

Fractures are common injuries in childhood and can be caused by unintentional injury, medical conditions, and child abuse. Although the consequences of failing to diagnose an abusive injury in a child can be grave, the consequences of incorrectly diagnosing child abuse in a child whose fractures have another etiology are also significant. This report aims to review recent advances in the understanding of fracture specificity, fracture mechanisms, and other medical conditions that predispose infants and children to fracture. This clinical report will aid pediatricians and pediatric care providers in developing an evidence-based differential diagnosis and performing appropriate evaluations when assessing a child with fractures.

INTRODUCTION

Fractures are one of the most common injuries from child physical abuse, second only to bruising.[1–3] However, it can be difficult to determine whether a child's injury is the result of abuse or attributable to another cause, such as an unintentional injury or a medical condition, and whether or not neglect played a role in the child's presentation. Failure to identify an abusive injury and to intervene appropriately may place a child at risk of further abuse, with potentially permanent consequences for the child.[4–6] On the other hand, incorrectly diagnosing physical abuse in a child with a nonabusive injury has serious consequences for the child and family.

An appropriate diagnosis of abuse involves a thorough history and physical examination, including the age and developmental ability of the child; the reported mechanism, location, and type(s) of fracture; and the presence of other injuries.[7] Children whose fractures are the result of abuse commonly present with histories of either no trauma or minor trauma.[6,7] In children younger than 3 years, as many as 20% of fractures caused by abuse may be misdiagnosed initially as unintentional or

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attributed to other causes.[6] In addition, fractures may not be visible on initial radiography if studies are performed early, before bony radiographic changes become obvious.[8] Finally, there is significant concern for racial and ethnic bias in the diagnosis of child abuse.[4,9] Standardized pathways, decision support processes, and even applications for smartphones can help pediatricians and pediatric care providers reduce bias, and it is important for providers to recognize and acknowledge these concerns.[9]

TABLE 1. Features of Fractures That Might Raise Suspicion for Abuse

- No history of injury
- History of injury not plausible—mechanism described not consistent with the type of fracture, the energy load needed to cause the fracture, or the severity of the injury
- Inconsistent histories or changing histories provided by caregiver
- Fracture in a nonambulatory child
- Fracture of high specificity for child abuse (eg, rib fractures)
- Multiple fractures
- Fractures of different ages
- Other injuries suspicious for child abuse
- Delay in seeking care for an injury

MEDICAL EVALUATION

History of Present Illness

It is essential to obtain a detailed history to determine how an injury occurred. When injuries in a child are witnessed or there are witnesses after the fact, details about the child's activity and position prior to an injury and the child's final position and location after the injury occurred are helpful in addressing plausibility.[10] Lack of a history of trauma is also concerning, and caregivers may be able to help narrow the time frame of injury if they are asked when the child was last observed to be well, such as using the affected extremity. In a study of abusive fractures, caregivers commonly provided either no history of an injury or related a low-energy event. By contrast, 29% of caregivers of children with unintentional injuries provided some high-energy explanation, such as a motor vehicle collision or that the child fell from a height.[11] Most low-energy mechanisms provided for injuries involved falls and siblings landing on the injured child during play.[10,11]

The child's response to the event may also provide important clues for the evaluation. Most children with long bone fractures will manifest external signs of injury such as pain, swelling, or decreased use of the extremity.[12,13] However, some children, especially those with nondisplaced fractures, may have less severe responses and/or minimal external signs of injury.[14] The absence of any history of injury; a vague description of the event; delay in seeking care; the absence of an explanation for an injury, particularly in a nonambulatory child; or an inconsistent explanation should increase the medical care provider's concern that an injury was caused by child abuse (see Table 1).[11,15]

Medical History

The medical history of the patient is important and should include details about the child's birth history, including the pregnancy of the delivering parent.[7] Preterm infants, especially those requiring prolonged hospitalization, parenteral nutrition, or diuretic or corticosteroid therapy may have reduced bone mineral content, and therefore, may be more vulnerable to fracture with relatively minor trauma. In addition, bone strength can be affected by chronic diseases, such as renal insufficiency, metabolic acidosis, malabsorption, cerebral palsy or other neuromuscular disorders, other illnesses that limit mobility, and genetic diseases that affect skeletal development. Of note, fractures in children with overt rickets are rare.[16] The child's developmental history is important in differentiating unintentional fractures from abusive fractures. A thorough dietary history and history of medications that can predispose to fractures are important. The pediatrician or pediatric care provider should inquire about previous injuries including bruises.

Family History

A family history of multiple fractures (especially with minor trauma), early-onset hearing loss, abnormally developed dentition, blue sclerae, hypermobility, and short stature may suggest the possibility of osteogenesis imperfecta (OI) or other inherited bone diseases. However, a reported history of a familial bone disease does not preclude the diagnosis of abuse and can be appropriately verified during the evaluation.

Social History

It is important to obtain a complete psychosocial history, including asking who lives in the home and who has provided care for the child.[7] This history includes inquiries about social risk factors such as intimate partner violence, substance use/misuse including drugs and alcohol, mental illness, and previous involvement with child protective services and/ or law enforcement. Social risk factors can aid in safety planning and provision of family support; however, it is important to remember that these risk factors cannot be used to determine whether a fracture is the result of abuse.

Physical Examination

It is important to perform a comprehensive physical examination, including careful review of the growth parameters.[7] Growth parameters outside of expected may indicate neglect or may suggest genetic (eg, OI), endocrine, or metabolic disorders. It is important to document any signs or symptoms of fractures, such as swelling, limitation of motion, and point tenderness. A complete skin examination is important to look for bruises or other injures as well as an inspection of the oral cavity to look for signs of trauma and abnormal dentition.[17,18] The majority of children with fractures do not have bruising associated with the fracture; the presence or absence of bruising does not help to determine which fractures are caused by child abuse.[19,20] Bruising in a child who is not yet cruising or bruising in unusual locations, such as the ears, neck, or trunk, raises concern for child abuse and may prompt further evaluation.[17,21] In addition to looking for other injuries, a physical examination can help elucidate signs of other medical conditions such as those associated with bone fragility. For example, blue sclerae can be a marker in certain types of OI; dentinogenesis imperfecta is occasionally identified in older children with OI; and sparse, kinky hair is associated with Menkes disease.

IMAGING APPROACH

Radiological imaging can be guided with the assistance of a pediatric radiologist and/or a child abuse pediatrician. In cases of suspected abuse, it may be most prudent to consult local specialists or even transfer a child to a higher level of care.

It is recommended that children younger than 24 months who present with fracture(s) with increased concern for child abuse have a radiographic skeletal survey to look for other bone injuries or osseous abnormalities.[22,23] Additional fractures are identified in approximately 10% of skeletal surveys, with infants having the highest yields of additional fractures, up to 13% to 26%.[24–26] Skeletal surveys may be appropriate in some children 24 to 60 months of age, depending on the clinical suspicion of abuse. If specific clinical findings indicate an injury at a particular site, imaging of that area can be obtained regardless of the child's age.

The American College of Radiology has developed specific practice guidelines for skeletal surveys in children including the need for an appropriately skilled facility and radiology team.[27] A total of 21 images are obtained: frontal images of the appendicular skeleton, frontal and lateral views of the axial skeleton, and oblique views of the chest. Oblique views of the chest have been shown to increase the sensitivity, specificity, and accuracy of the identification of rib fractures.[28] Some institutions add lateral views of the long bones to improve detection of metaphyseal fractures.[29,30] A full 4 skull series is also obtained if there are concerns of head injury. Computed tomography (CT) 3-dimensional models may replace the skull series if performed with thin cuts and bone algorithm.[31–34] Fractures may be missed if the guidelines are not followed or if the images are of poor quality.[35] It is also recommended that a follow-up skeletal survey be performed approximately 2 weeks after the initial skeletal when the initial study is positive or has equivocal findings or when the initial study is negative and there is still strong clinical suspicion of abuse.[22,36] The follow-up examination may identify fractures not seen on the initial skeletal survey, clarify uncertain findings identified by the initial skeletal survey, and improve both sensitivity and specificity of the skeletal survey.[36,37] A large multicenter study found the follow-up study added new information in 21.5% of the patients with concern for nonaccidental trauma.[38] The number of images on the follow-up examination may be limited to 15 views by omitting the views of the skull, pelvis, and lateral spine.[39,40]

Radiography may assist in assessing the approximate time when an injury occurred, because, in an otherwise healthy child, long bone fractures heal following a particular sequence.[41–43] If the healing pattern of the injury is not consistent with the history provided, the concern for child abuse is increased.

Head imaging (CT and/or magnetic resonance imaging [MRI]) is indicated in children younger than 6 months and can be considered for any child younger than 1 year with a fracture suspicious for abuse.[44]

Bone scintigraphy may be used to complement the skeletal survey but cannot be the sole method of identifying fractures in infants. Although it has high overall sensitivity, it lacks specificity for fracture detection and may fail to identify classic metaphyseal lesions (CMLs) and skull fractures.[22,41,45] In addition, the radiation exposure is high, and in young children, sedation may be required. Scintigraphy does have high sensitivity for identifying rib fractures, which can be difficult to detect prior to healing. In toddlers and older children, bone scintigraphy or skeletal survey is only useful in cases where there are concerns for developmental delay as older children are able to express pain and/or loss of function.[22]

Chest CT can identify rib fractures that are not visualized on chest radiographs.[46–48] CT is particularly useful in detecting anterior rib fractures and rib fractures at all stages of healing. Although CT may be more sensitive in identifying these injuries, a routine chest CT exposes the child to significantly more radiation than chest radiography; modified CT parameters can help identify rib fractures at lower radiation doses.[49] It is important to minimize children's exposure to radiation while at the same time considering the risk to the child if abuse is not identified.[50] Therefore, selective application of this technique in certain clinical settings is appropriate.

Other modalities may become available in the future that provide more accurate identification of skeletal injuries. Whole-body short Tau inverse recovery (STIR) imaging, an MRI technique, may identify rib fractures not recognized on the radiographic skeletal survey.[51] In a study of 21 infants with suspected abuse, whole-body MRI at 1.5 Tesla was insensitive in the detection of CMLs and rib fractures.[52] Whole-body MRI can identify soft tissue injuries, such as muscle and subcutaneous edema, ligamentous injuries, and joint effusions, that can lead to the identification of skeletal injuries with additional radiographs.[52,53]

Bone scintigraphy with 18F-sodium fluoride positron emission tomography (18F-NaF PET) bone scan, although not widely available, may be useful in cases of equivocal or negative skeletal surveys when there is high clinical suspicion of abuse. If available, 18F-NaF PET bone scan has better contrast and spatial resolution than technetium 99m-labeled methylene diphosphonate.[45] The radiation dose is similar to bone scintigraphy with technetium 99m-labeled methylene diphosphonate but much higher than a skeletal survey; therefore, the use of bone scintigraphy is recommended only for cases when the findings of the study would significantly change the outcome of the case, for example when the findings are urgently needed to determine child safety or placement.

Although bone densitometry by dual energy x-ray absorptiometry (DXA) is useful to predict bone fragility and fracture risk in older adults, interpretation of bone densitometry in children and adolescents is often more problematic.[54] Peak bone mass is not achieved until early adulthood. In children, Z-scores are used to interpret bone density. The Z-score express the child's bone mineral density as a function of SDs above or below the average for an age- and sex-matched norm control population. [55] In addition, because bone size influences DXA, Z-scores can be adjusted for height Z-scores,[56] and for children with early or late puberty, interpreted in the context of pubertal status and/or bone age assessment. The International Society for Clinical Densitometry recommends that the diagnosis of osteoporosis in childhood not be made on the basis of low bone mass alone but, in the absence of vertebral fractures, also include a clinically significant history of low impact fracture.[57] A clinically significant fracture history is defined as two or more long bone fractures prior to the age of 10 or three or more long bone fractures before age 19. The recommendations currently apply to children 5 years and older, although reference data are available for children as young as 3 years.[58,59] Unfortunately, there are very limited reference data for infants and toddlers who are most at risk of suffering fractures caused by child abuse. Proper positioning for interpretable measurements in very young children is also often difficult.

LABORATORY EVALUATION

The clinical evaluation guides the laboratory evaluation. In children with fractures suspicious for abuse, serum calcium, phosphorus, and alkaline phosphatase are important, noting that alkaline phosphatase may be elevated because of bone remodeling associated with healing fractures. Other helpful laboratory tests include serum concentrations of parathyroid hormone (with a serum creatinine) and 25-hydroxyvitamin D, especially if there is clinical evidence of rickets or radiographic evidence of osteopenia or metabolic bone disease. Screening for abdominal trauma with liver enzymes as well as amylase and lipase concentration is important when severe or multiple injuries are identified. A urinalysis will screen for occult blood and any injuries to the renal system. Serum copper, ceruloplasmin concentrations, and vitamin C levels may be considered if the child has a dietary history that suggests copper deficiency or scurvy and has radiographic findings that include metaphyseal abnormalities.

If OI is suspected clinically or radiographically, *COL1A1* and *COL1A2* genes are sequenced first, because autosomal dominant mutations in these genes are associated with 80% to 85% of cases of OI.[60,61] If there is suspicion of OI and *COL1A1/COL1A2* sequencing is unremarkable, then testing of other genes associated with less common autosomal recessive or x-linked inherited forms of OI can be performed, because this testing is more sensitive than biochemical tests of type I collagen and may identify variants to guide testing of other family members.[62] Molecular testing is preferred over skin biopsy if there is clinical suspicion for OI. It is important to consult with a pediatric geneticist or genetic counselor in deciding which children to test and the preferred testing to order.[63] A child with OI can still be at risk for child abuse; hence, it is important to perform a comprehensive evaluation if there is a suspicion for child abuse.

DIAGNOSIS

When evaluating a child with a fracture, it is important that providers take a careful history of any injury event and then determine whether the mechanism described and the severity and timing are likely consistent with the injury identified (see Table 1).[64] The child's specific gross motor developmental abilities are important to assess if an offered injury mechanism is plausible. In addition, it is important to consider other nonabusive explanations for the injuries, including medical conditions or unintentional injury. A careful evaluation for other injuries is important, because the presence of additional injuries that are associated with child abuse increases the likelihood that a particular fracture was the result of abuse.[11,65] It is important to remember that even if a child has an underlying disorder or disability that could increase the likelihood of a fracture, the child may also have been abused, as children with disabilities and other special health care needs are at increased risk of child abuse.[66,67] If a provider is uncertain about how to evaluate an injury or if there is suspicion for abuse, a child abuse pediatrician or multidisciplinary child abuse team can assist in the evaluation.[68] In certain circumstances, the provider may need to consult an orthopedic surgeon, endocrinologist, radiologist, geneticist, or other subspecialist(s). In circumstances in which these specialists are not available in a timely fashion, a discussion with investigators on options to ensure child safety may be necessary.

All US states, commonwealths, and territories have mandatory reporting requirements for physicians and other health care providers. These requirements vary by state and it is important that providers are aware of and comply with the reporting requirements of their state. Typically, the standard for making a report is when the reporter "has reason to believe" that a child has been abused or neglected. This belief typically is a higher level of concern than that needed for a workup for suspected abuse. Sometimes, determining whether that "reasonable belief" or "reasonable suspicion" standard has been met can be nuanced and complex. Incontrovertible proof of abuse or neglect is not required for a child abuse report by state statutes, and on the other hand, one can initiate a workup for possible abuse but then not have enough concern to warrant a report. The assistance of a hospital child protection team and/or child abuse pediatrician can help with decision making.

It is important that providers recognize the existing bias that occurs in child abuse evaluations related to historically marginalized racial and ethnic populations.[9] Some processes that can assist in mitigating bias include education for medical and child welfare professionals, electronic medical record screening tools, and standardized pathways.[9,69]

Child's Age and Development

Approximately 80% of all fractures caused by child abuse occur in children younger than 18 months,[70] and approximately one quarter of fractures in children younger than 1 year are caused by child abuse.[3,15,71–73] Physical abuse is more likely to be the cause of femoral and humeral fractures in children who are not yet walking, compared with children who are ambulatory,[11,73–75] and the percentage of fractures caused by abuse declines sharply after the child begins to walk.[3,76,77]

Fracture Specificity for Abuse

There are no specific fractures that are pathognomonic for child abuse. However, fractures have differing levels of specificity for child abuse (see Table 2).[78] Knowing whether a specific fracture corresponds to high-, mid-, or low-specificity for child abuse can be helpful in work-up and diagnosis.

TABLE 2. Specificity of Radiologic Findings in Infants and Toddlers[78]

High specificity[a]	• Classic metaphyseal lesions (CMLs) • Rib fractures, especially posteromedial • Scapular fractures • Spinous process fractures • Sternal fractures
Moderate specificity	• Multiple fractures, especially bilateral • Fractures of different ages • Epiphyseal separations • Vertebral body fractures and subluxations • Digital fractures • Complex skull fractures
Common, but low specificity	• Subperiosteal new bone formation • Clavicular fractures • Long-bone shaft fractures • Linear skull fractures

[a] Highest specificity applies in infants.

Fractures With High Specificity for Abuse

Rib fractures have a high probability of being caused by abuse.[73,74,79] The positive predictive value of rib fractures for child abuse in children younger than 3 years was 95% in 1 retrospective study.[80] A systematic review of 10 studies that included infant data found a prevalence of abuse in 91% of children with rib fractures if motor vehicle collisions and metabolic bone diseases were excluded.[81] Rib fractures encountered in abuse may be the result of anterior to posterior compression of the chest, as when the perpetrator squeezes the chest, or a direct impact.[82] Historically, posterior rib fractures were thought to be most indicative of abuse, with a classic pattern described as fractures of 3 or 4 consecutive ribs, corresponding to the placement of the hand of the perpetrator while he or she squeezed or shook the child. In contrast, Kemp's meta-analysis from 2008 included 2 studies in which anterior rib fractures were found to be more common in abuse, and overall, rib fracture location did not correlate to the likelihood of abuse.[83] However, more recent studies with better imaging techniques confirm that posterior rib fractures are more commonly found in abuse.[49,84–86] Other less common causes of rib fractures in infants include motor vehicle collisions, minor trauma in infants who have increased bone fragility and, very rarely, trauma sustained during childbirth.[87–90]

Cardiopulmonary resuscitation (CPR) has been proposed as a cause of rib fractures, but conventional CPR with 2 fingers of 1 hand rarely causes fractures in children.[91–93] Since 2005, it has been recommended that in infants CPR be performed with both thumbs using 2 hands encircling the rib cage. There is evidence that this technique might cause increased incidence of rib fractures compared with the former technique. An analysis of infants who were discovered during autopsy to have rib fractures and had received 2-handed chest compressions antemortem suggested that 2-handed CPR is associated with anterior-lateral rib fractures of the third to sixth ribs.[94] In this small study, no posterior rib fractures were observed. The fractures in these infants were always multiple, uniformly involved the fourth rib, and were sometimes bilateral. An autopsy study that compared a cohort from 1997–2005 with one from 2006–2008 found a statistically significant increase in rib fractures in the later cohort in whom CPR was performed with the 2-hand technique, however there were no identified posterior rib fractures.[95] Although rib fractures have been reported with the 2-thumb technique, there have been no reports of posterior rib fractures.[96]

Classic metaphyseal lesions (CMLs) have high specificity for child abuse in infants.[79,97] CMLs are the most common long bone fracture found in infants who die with evidence of abusive injury.[98] CMLs are planar fractures through the primary spongiosa of the metaphysis. These fractures are thought to be caused when torsional and tractional shearing strains are applied across the metaphysis, as may occur with vigorous pulling or twisting of the infant's extremity, or from varus and valgus bending, as when there is an inversion or eversion strain to the joint.[99–102] Fractures resembling CMLs radiographically have been reported following difficult deliveries[103] and as a result of treatment for clubfoot.[104]

Depending on the projection of the radiograph, CMLs can have a corner, partial bucket handle, or bucket handle appearance.[101] CMLs frequently heal without subperiosteal new bone formation, because the tightly adherent periosteum in the metaphysis does not generate subperiosteal hemorrhage.[29] These fractures can heal quickly and be undetectable on plain radiographs 4 to 8 weeks after the injury.[99]

Fractures of the sternum, scapula, and pelvis are typically the result of high-energy trauma, such as a motor vehicle collision, pedestrian-struck, or a fall from a height. They are rare in children and should trigger concern for abuse in the absence of a plausible, verifiable incident.[85,105–108]

Long bone fractures in nonambulatory children are highly suspicious for abuse. The femur, humerus, and tibia are the most common long bones to be injured in child abuse.[71,109] A fracture of the humeral shaft in a child younger than 18 months has a high likelihood of having been caused by abuse.[83,110,111] Up to 54% of humerus fractures in children younger than 3 years are attributable to abuse, with a statistically significantly higher prevalence in those younger than 15 months.[83,111,112] Hymel and Jenny described a plausible unintentional mechanism resulting in a spiral-oblique fracture of the humerus in an infant.[113] When a young infant is rolled from the prone position to the supine while the child's arm is extended, the torsion and stress placed on the extended arm appeared to cause a spiral-oblique fracture of the midshaft of the humerus. Similarly, a cohort study of lower extremity injuries in children younger than 18 months found that nearly 75% were the result of abuse.[114] Although there are reports of isolated transverse femur fractures resulting from unintentional injury, these fractures still need a complete evaluation.[115,116] An isolated long-bone fracture in an ambulatory child without a plausible history presents a diagnostic challenge to clinicians. Although not as suspicious as the case of a long-bone fracture in a nonambulatory child, this situation should prompt a consideration for abuse. One multicenter study proposed initiating a child-abuse workup for a child younger than 12 months with any fracture, younger than 18 months with a femur fracture, and younger than 2 years with a humerus fracture.[117] However, in the absence of other corroborative injuries or skeletal survey findings, a definitive determination may not be possible in these cases.

Fractures With Moderate Specificity for Abuse

The presence of multiple fractures, fractures of different ages and/or stages of healing, and complex skull fractures have moderate specificity for physical abuse.[83,118] The likelihood of abuse for infants with 3 or more fractures is four- to sixfold when compared with infants with only 1 fracture.[3] In this study, 85.4% of cases (n = 298 infants) involving more than 3 fractures were determined to be child abuse versus 18.5% of cases (n = 5076 infants) involving a single fracture. In children in whom abuse is diagnosed, 50% overall and 80% of those younger than 1 year will have more than 1 fracture diagnosed.[106,119,120] Children in whom abusive head trauma is diagnosed can have bilateral acute symmetrical fractures from being shaken.[121–123]

Displaced physeal fractures or "epiphyseal separations" can be the result of abuse, particularly in the distal humerus. This fracture, also known as a transphyseal humerus fracture, is 13 times more likely to be abusive compared with displaced supracondylar humerus fractures in children.[124] The typical pattern is a displaced Salter-Harris 1 fracture in a child younger than 1 year. In these very young children, the distal humerus is still nonossified, which makes visualization on plain radiography challenging. Ultrasonography, MRI, or arthrography can aid in visualization, but these fractures are often diagnosed late, after healing has begun to occur and periosteal new bone formation is visible. One study found the diagnosis was missed on 56% of plain radiography but confirmed by ultrasonography in 100% of cases, with 38% of cases (all in children younger than 1 month old) secondary to birth trauma and 40% the result of abuse.[125] Skeletal survey is necessary not only in infants with distal humerus fracture with epiphyseal separation but also in children 12 through 23 months of age when the mechanism of injury provided is a short fall.[25]

Spine fractures are rare in children and account for 1% to 3% of both unintentional and abusive pediatric fractures.[126] Similarly to pelvic, scapular, and sternal fractures, spine fractures are typically the result of a high-energy injury and are, therefore, concerning in the absence of a verifiable incident, although not as specifically as those listed above. Spine fractures are frequently asymptomatic and can be the only finding on skeletal survey.[127] Flexion-extension injuries can cause a variety of fracture patterns in the posterior vertebral elements and are more likely to be symptomatic and associated with neurologic deficit.[128,129]

Fractures of the hands and feet, although common unintentional injuries in older children, are rare in nonambulatory children, with a prevalence ranging from 1% to 5%.[130,131] In skeletal surveys for suspected abuse, the prevalence of digital fractures increases to 20% in children with more than one fracture.[130]

Common Fractures With Low Specificity for Child Abuse

Clavicle fractures have been reported in 3% to 10% of cases of child abuse.[109,132] Clavicle fractures are a common birth-related injury. These fractures will demonstrate callus within the first 7 to 10 days of life; therefore, an acute clavicle (or humeral) fracture with no signs of healing in an infant older than 10 days is unlikely to be a birth injury. Although mid-shaft clavicular fractures can occur from short falls, distal and proximal clavicle fractures are uncommon in children younger than 3 years and likewise would prompt an evaluation for abuse.

Supracondylar humerus fractures are usually unintentional, and a history of a fall from playground equipment or a trampoline is typical.[111,112,133] One study of 388 supracondylar humerus fractures found that only 0.5% were the result of abuse.[133] However, younger children are more at risk for abuse, as another study reported 30% of supracondylar humerus fractures in children younger than 3 years to be the result of abuse.[111]

Distal radius and ulna buckle fractures are common compressive injuries caused by a fall on an outstretched arm or by running into a barrier with an outstretched arm. They are almost always unintentional in ambulatory children.

Femoral fractures in the nonambulatory child are more likely caused by child abuse, whereas these fractures in ambulatory children are most commonly unintentional.[11,65,134–136] In fact, ambulatory status is the single most important predictive factor for abuse in children with a femur fracture.[83,134,137] Several studies have demonstrated that a short fall to the knee may produce a torus or impacted transverse fracture of the distal femoral metadiaphysis.[10,138] Oblique distal femur metaphyseal fractures have been reported in children playing in a stationary activity center.[139] Although transverse distal femur fractures in nonambulatory children can result from abuse, this pattern can also result from an adult falling onto the child's femur while holding a child on their hip.[115,116] In both ambulatory and nonambulatory children, under some circumstances, falls on a stairway can cause a spiral femoral fracture. For example, a fall down several steps and landing with one leg folded or twisted underneath a child can lead to excessive torsional loading of the femur and a spiral fracture.[10] In ambulatory children, unintentional femoral fractures have been described in children who fell while running or who fell and landed in a split-leg position.[65]

"Toddler's fracture" refers to an isolated, nondisplaced, spiral fracture of the distal tibial metaphysis or diaphysis often most clearly visualized on an internal oblique radiograph. These fractures occur in children who have recently become ambulatory, often during seemingly trivial incidents such as a misstep off a stair or a trip over a toy or a playground fall.[140] A well-documented etiology is getting a foot caught on the edge of a slide while riding down on the lap of an adult or older child.[140] Similarly, a nondisplaced transverse or torus fracture of the proximal tibia is a common trampoline injury, caused by compression from "double-bounce"—the recoil of the mat as one child jumps and the other lands.[141]

Skull fractures are also common in both the unintentional and abusive settings. A simple, linear parietal fracture is the most common pattern in both unintentional and abusive trauma and in lower risk skull fractures, some researchers have recommended eliminating a skeletal survey.[15,142–144] Complex fractures such as stellate, depressed, diastatic, multiple, bilateral, or fractures crossing suture lines are more specific for abuse than simple fractures.[15,145,146] Therefore, corroborative history is especially important in evaluating skull fractures, and an implausible or inconsistent history is cause for concern. Household falls of fewer than 3 feet are associated with a low incidence of complex skull fracture.[147,148]

DIFFERENTIAL DIAGNOSIS OF FRACTURES

Trauma: Child Abuse Versus Unintentional Injuries

Fractures are a common childhood injury and account for between 8% and 12% of all pediatric injuries.[149–151] In infants and toddlers, physical abuse is the cause of 12% to 20% of fractures.[3] Although unintentional fractures are much more common than fractures caused by child abuse, the clinician should remain aware of the possibility of abusive injury. Although some fracture types are highly suggestive of physical abuse, no pattern can exclude child abuse.[134,152] Specifically, it is important to recognize that any fracture, even fractures that are commonly unintentional injuries, can be caused by child abuse. Certain details that can help the clinician determine whether a fracture was caused by abuse rather than unintentional injury include the history, the child's age and developmental stage, the type and location of the fracture, the age of the fracture, and an understanding of the mechanism that causes the fracture type. The presence of multiple fractures, fractures of different ages or stages of healing, delay in obtaining medical treatment, and the presence of other injuries suspicious for abuse (eg, coexisting injuries to the skin, internal organs, or central nervous system) raises the likelihood of abuse.

An understanding of the extent and type of load that is necessary to cause a particular long bone fracture can help to determine whether a specific fracture is consistent with the injury described by the caregiver.[153,154] Transverse fractures of the long bones are caused by the application of a bending load in a direction that is perpendicular to the bone, while spiral fractures are caused by torsion or twisting of a long bone along its long axis. Oblique fractures are caused by a combination of bending and torsion loads.[155] Torus or buckle fractures are the result of compression from axial loading along the length of the bone. Although earlier studies had suggested that spiral fractures should always raise suspicion for child abuse,[70] more recent studies do not show that any particular fracture pattern can distinguish between abuse and nonabuse with certainty.[11,156]

Falls are common in childhood.[157] Short falls can cause fractures, but they rarely result in additional significant injury (eg, neurologic injury).[152,158–160] In a retrospective study of short falls, parents reported that 40% of the children before 2 years of age had suffered at least one fall from a height of between 6 inches and 4 feet. Approximately one quarter of these children suffered an injury; bruises were the most common injury observed.[65]

Syndromes, Metabolic Disorders, Systemic Disease

Preexisting medical conditions and bone disease may increase the bone vulnerability to fracture. Some of these conditions may manifest with skeletal changes, such as metaphyseal irregularity and subperiosteal new bone formation. These entities are considered in the differential diagnosis of childhood fractures.

Osteogenesis Imperfecta

OI is a group of inherited connective tissue disorders with remarkable clinical and genetic heterogeneity. The hallmark feature is bone fragility with susceptibility to fractures from minimal trauma and low bone mineral density or osteopenia.[161] Other secondary features include growth failure, macrocephaly, Wormian bones of the skull, blue sclera, dentinogenesis imperfecta (weak, discolored, or translucent teeth), hearing loss, scoliosis, limb deformities, hyperextensible joints, bruising, and cardiopulmonary complications. Sometimes OI symptoms resolve or lessen after puberty. [60,162] When OI is suspected, multidisciplinary clinical management and genetic analysis are needed.

Approximately 80% to 85% of cases are autosomal dominantly inherited and present with a full spectrum of OI severity because of heterozygous mutations of the *COL1A1* and *COL1A2* genes, which encode type I collagen that forms the structural framework of bone.[60,162] This includes perinatal lethal OI (previously OI type II), classic nondeforming OI with blue sclera (previously OI type I), progressively deforming OI (previously OI type III), and common variable OI with normal sclera (previously OI type IV). Rare autosomal recessive forms of OI are caused by variants in genes whose protein products interact with collagen for post-translational modification or folding.[60]

TABLE 3. Characteristics of Osteogenesis Imperfecta

Fragile, bones with few, some, or many of the following findings:	• Poor linear growth • Macrocephaly • Triangular-shaped face • Blue sclerae • Hearing impairment as a result of otosclerosis (usually manifests in adulthood) • Hypoplastic, translucent, carious, late-erupting, or discolored teeth • Easy bruisability • Inguinal and/or umbilical hernias • Limb deformities • Hyperextensible joints • Scoliosis and/or kyphosis • Wormian bones of the skull • Undermineralized bones

Although OI is a genetic disorder, many children have de novo mutations or autosomal recessive disease and, therefore, have no family history of bone fragility. In addition, the disease presentation within affected members of the same family can be quite variable. Phenotypic disease expression depends on the nature of the variant and its expression in target tissues.[163]

The diagnosis of OI is often suggested by features outlined in Table 3. The types of fractures can help determine whether the diagnosis is likely. For example, transverse and diaphyseal humerus and olecranon fractures are most likely to indicate OI compared with physeal and supracondylar humerus fractures that were least likely to indicate OI.[164,165] It is unusual to have multiple long bone fractures or rib fractures, particularly in infancy, without other clinical and radiographic evidence of OI. [166,167]

OI can be misdiagnosed as child abuse.[168] On the other hand, OI is sometimes also suggested as the cause of fractures in children who have been abused. When fractures continue to occur when a child is placed in a protective environment, a more thorough evaluation for an underlying bone disease is needed. Child abuse is more common than OI, and children with OI and other metabolic or genetic conditions may also be abused.[169–171]

Preterm Birth

Preterm infants have decreased bone mineralization at birth, but after the first year of life, bone density normalizes. Metabolic bone disease of prematurity (MBDP), defined as preterm infant skeletal undermineralization arising from inadequate prenatal and postnatal calcium and phosphate accretion, has been well described as a complication in low birth weight infants.[172,173] Infants born at less than 28 weeks' gestation or who weigh less than 1500 g at birth are particularly vulnerable. This condition is defined as reduced bone mineral content with characteristic biochemical and/or radiographic changes.[174,175] MBDP is estimated to occur in 16% to 40% of infants with very low birth weight (<1500 g) and extremely low birth weight (<1000 g). MBDP is multifactorial. Infants are at higher risk if they receive prolonged (for 4 or more weeks) total parenteral nutrition, have bronchopulmonary dysplasia, and/or received a prolonged course of diuretics, antacids, or steroids.[176] MBDP can be ameliorated and even avoided if infants are monitored closely and adequate nutritional and mineral supplementation is initiated in the neonatal intensive care unit.

Osteopenia commonly manifests biochemically between 6 and 12 weeks of life. Fractures associated with MBDP usually occur in the first year of life.[17,177] Rib fractures are typically encountered incidentally, whereas long bone fractures commonly present with extremity swelling. MBDP can be associated with rickets, and in such cases, metaphyseal irregularities, like fraying and cupping of the metaphyses, may be present.[178]

Vitamin D Deficiency Rickets

Vitamin D insufficiency in otherwise healthy infants and toddlers is common. Approximately 40% of infants and toddlers ages 8 to 24 months in an urban clinic had laboratory evidence of suboptimal vitamin D (serum 25-hydroxyvitamin D concentrations of ≤30 ng/mL).[179] Fewer had vitamin D insufficiency or deficiency, generally defined as ≤20 ng/mL for insufficiency and <12 ng/mL for deficiency.[180] Maternal vitamin D deficiency and prolonged breastfeeding without vitamin D supplementation is a common feature placing infants at risk of low circulating vitamin D, although increased skin pigmentation and/or lack of sunlight exposure can contribute. Prolonged vitamin D deficiency may leads to rickets, characterized by bone changes including demineralization, loss of the zone of provisional calcification, widening and irregularity of the physis, and fraying and cupping of the metaphysis.[181] Of note, despite the high prevalence of suboptimal serum vitamin D levels in infants and toddlers, rickets is uncommon.[182]

Low vitamin D concentrations and rickets have been proposed as causes of infant fracture.[183] However, no evidence supports that vitamin D deficiency or insufficiency predisposes a child to fracture. Radiographs of children with rickets and osteomalacia will sometimes demonstrate "looser zones;" these areas likely represent insufficiency/stress fractures and are not associated with bony angulation, discontinuity, or displacement.[16] A systematic clinical, laboratory, and radiologic assessment along with history will exclude that vitamin D insufficiency or deficiency is the cause of fracture(s).[184–186] Schilling et al found no difference in serum concentrations of 25-hydroxyvitamin D in young children with fractures suspicious for abuse and noninflicted fractures.[187] Vitamin D insufficiency was not associated with multiple fractures, in particular rib fractures or CMLs.

In a study of 45 young children with radiographic evidence of rickets, investigators found that fractures occurred only in those infants and toddlers who were mobile.[174] Fractures were seen in 17.5% of the children, and these children were 8 to 19 months of age. The fractures involved long bones, anterior and anterior-lateral ribs, and metatarsal and metaphyseal regions. The metaphyseal fractures occurred closer to the diaphysis in the background of florid metaphyseal rachitic changes and did not resemble the juxtaphyseal corner or bucket handle appearance of the CML.[174] In a series of infant fatalities with head trauma, CMLs, and other skeletal injuries, radiographic or histologic rachitic changes were not present.[188]

Fractures Secondary to Demineralization From Disuse

Any child with a severe disability that limits or prevents ambulation can be at risk of fractures secondary to disuse demineralization, even with normal handling, physical therapy and range of motion exercises.[189,190] They may also be less able to report symptoms (because of cognitive or communication impairments) or less likely to display signs.[191] These fractures, however, are usually diaphyseal rather than CMLs. Often, these fractures occur during physical therapy and range-of-motion exercises. It can be difficult to distinguish between abusive and unintentional fractures occurring in these children. At the same time, children with disabilities are at an increased risk of maltreatment.[192–194]

Scurvy

Scurvy is caused by insufficient intake of vitamin C, which is important for the synthesis of collagen. Although extremely rare today because formula, human milk, fruits, and vegetables contain vitamin C, scurvy may develop in older infants and children exclusively given cow milk without vitamin supplementation and in children who eat foods containing no vitamin C.[195,196] Although scurvy can result in metaphyseal irregularity, other osseous changes, including osteopenia, increased sclerosis of the zones of provisional calcification, dense epiphyseal rings, and extensive calcification of subperiosteal and soft tissue hemorrhages, will point to the diagnosis of scurvy.

Copper Deficiency

Copper plays a role in cartilage formation. Preterm infants are born with lower stores of copper than term infants, because copper is accumulated at a faster rate during the last trimester.[197] Copper insufficiency may be observed in children with severe nutritional disorders, for example, liver failure or short gut syndrome.[198] This deficiency is not likely to be observed in full-term children younger than 6 months or preterm infants younger than 2.5 months of age, because fetal copper stores are sufficient for this length of time. In addition, human milk and formula contain sufficient copper to prevent deficiency. Psychomotor retardation, hypotonia, hypopigmentation, pallor, and a sideroblastic anemia are some of the characteristic findings of copper deficiency in infants. Radiologic changes that may increase suspicion for possible deficiency include cupping and fraying of the metaphyses, sickle-shaped metaphyseal spurs, significant demineralization, and subperiosteal new bone formation.[197] Copper deficiency is a rare condition that may result in metaphyseal fragmentation; however, these will be accompanied by other clinical and biochemical findings of copper deficiency.

Menkes Disease

Menkes disease, formerly known as Menkes kinky hair syndrome, is a very rare congenital defect of copper metabolism.[199] Menkes disease is an X-linked recessive condition that occurs only in the male sex; it is attributable to pathogenic variants in the *ATP7A* gene, that encodes a copper-transporting ATPase. Although it has many of the features of dietary copper deficiency, anemia is not associated with Menkes disease. Classic Menkes disease typically presents after 6 to 12 weeks of normal health and pregnancy, usually initially presenting with feeding difficulties and/or seizure. Metaphyseal fragmentation and subperiosteal new bone formation may be observed on radiographs, and the findings may be difficult to distinguish from fractures caused by abuse.[200] Other signs of Menkes disease include sparse, kinky hair, Wormian bones, anterior rib flaring, failure to thrive, and developmental delay. A characteristic finding is tortuous cerebral vessels. Intracranial hemorrhage can occur in Menkes disease but has not been reported in infants with nutritional copper deficiency.[199]

Systemic Disease

Chronic renal disease affects bone metabolism, because it interferes with vitamin D metabolism. Chronic renal disease can cause renal osteodystrophy, resulting in the same radiographic changes as nutritional rickets.[201] Chronic liver disease (eg, biliary atresia) can interfere with vitamin D metabolism; children with chronic liver disease are at an increased risk of rickets, low bone mineral density, and fractures.[202] Fanconi syndrome, hypophosphatasia, hypophosphatemic (vitamin D-resistant) rickets, hyperparathyroidism, and renal tubular acidosis also cause clinical variants of rickets with bone changes associated with alterations in calcium, phosphate, alkaline phosphatase, parathyroid hormone, and/or vitamin D metabolites.

EVALUATION OF SIBLINGS

Siblings, especially twins, and other young household contacts of children who have been physically abused are at high risk of also being abused, and it is recommended that they also be evaluated for possible abuse.[203] In a study of 795 siblings in 400 households of a child who had been abused or neglected, all siblings in 37% of households and some siblings in 20% of households had suffered some form of maltreatment.[204] In this study, which included all manifestations of maltreatment, siblings were found to be more at risk of maltreatment if the index child suffered moderate or severe maltreatment. In addition to a careful evaluation, imaging should be considered for any siblings younger than 2 years, especially if there are signs of abuse.

LEGAL CHALLENGES

Alternative, nonevidence-based explanations for child abuse have been proffered by a few vocal physicians both in the medical literature and in legal civil and criminal proceedings. These explanations have been used in court to assert that the evidence supporting the diagnosis of abuse is suspect. A false, fabricated condition is “temporary brittle bone disease” (TBBD).[205] TBBD has been invoked for cases in which infants younger than 6 months are said to experience multiple initial (often painless) fractures in a home environment that cease when the child is removed from the home. TBBD is described as a self-limited bone demineralization attributable to antacid use by the mother during pregnancy, transient copper deficiency, or limited prenatal movement. Experts from many subspecialties have exposed TBBD as an unproven, dishonest sham.[206] Another flawed explanation for fractures during infancy is an undiagnosed genetic disease like hypermobile Ehlers-Danlos syndrome (EDS).[207] Again, this represents a false explanation for multiple infant fractures without evidence, particularly for syndromes such as hypermobile EDS in which long bone and rib fractures are not components of the clinical disease presentation or diagnostic criteria for the hypermobile EDS.[208,209] Other “experts” maintain that CMLs and posterior rib fractures nearly pathognomonic of child abuse are often instead rachitic changes.[210] Yet, data suggest that these findings are distinct and distinguishable radiographically.[188,211,212] These false explanations and irresponsible legal testimony put forth by these denialists undoubtedly have resulted, at times, in children being returned to life-threatening home environments.

CONCLUSION

Optimal assessment of the child with fractures and suspected child abuse requires careful review of the clinical history, a thorough physical examination, rigorous imaging evaluation, and correlation with bone health laboratory studies. A multidisciplinary evaluation with consultation as indicated to a child abuse pediatrician, orthopaedic surgeon, radiologist, endocrinologist, and/or geneticist can help ensure a correct diagnosis of unintentional injury, abuse, or disease process.

KEY POINTS AND RECOMMENDATIONS

1. Fractures that are more concerning for abuse include fractures in a nonambulatory child, fractures that are not consistent with the history provided or for which no history of injury is given, and fractures that have a high or moderate specificity for abuse.
2. In children in whom abuse is suspected, the following is recommended:
   a. On physical examination, a close evaluation of all areas of the skin to look for other injuries is important, as well as closely looking for indications of a medical condition, such as OI.
   b. Medical history and family history are important to evaluate for prior injuries, fractures, or medical conditions that would predispose a child to fracture more easily.
   c. A head CT is recommended in children up to 6 months of age to rule out a head injury; a skeletal survey is recommended up to 2 years of age to evaluate for occult fractures, although the survey may be performed up to 5 years of age in certain situations. All children with significant concern for abuse will also need a follow up skeletal survey 2 weeks after the initial evaluation to assess for occult fractures.
   d. The laboratory evaluation is important, to include serum calcium, phosphorus, and alkaline phosphatase. Also helpful are serum parathyroid hormone and 25-hydroxyvitamin D. In severe trauma, liver enzymes, lipase, amylase, and a urinalysis are helpful to evaluate for abdominal trauma. Finally, more detailed evaluation for metabolic bone disease, such as OI, can be conducted on the basis of clinical suspicion.
3. Reporting suspected abusive fractures to authorities is based on reasonable concern/suspicion for abuse and subject to individual state statutes.
4. Bias is known to exist in child abuse diagnosis and reporting. It is important to be aware of that bias and attempt to limit its effects.

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ABBREVIATIONS

CML: classic metaphyseal lesion
CT: computed tomography
CPR: cardiopulmonary resuscitation
DXA: dual energy x-ray absorptiometry
EDS: Ehlers Danlos syndrome
MRI: magnetic resonance imaging
MBDP: metabolic bone disease of prematurity
OI: osteogenesis imperfecta
TBBD: temporary brittle bone disease

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