Chapter 7: Evaluating Skeletal Trauma

Reading:

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

Barsness KA, Cha ES, Bensard DD, Calkins CM, Partrick DA, Karrer FM, Strain JD The positive predictive value of rib fractures as an indicator of nonaccidental trauma in children. J Trauma. 2003; 54: 1107-10

Clyde Piere M, Bertocci G,Vogeley E, Moreland MS. Evaluating long bone fractures in children: a biomechanical approach with illustrative cases. Child Abuse & Neglect. 2004; 28: 050-524

Clyde Pierce M, et Al. Femur fractures resulting from stair falls among children: and injury plausibility model. Pediatr. 2005; 115: 1712-1722

Merten DF, Radkowski MA, Leonidas JC. The abused child: a radiological reappraisal. *Radiology.* 1983;146c:377-381

Kemp AM, Butler A, Morris S, Mann M, Kemp KW, Rolfe K, Sibert JR, Maguire S. Which radiological investigations should be performed to identify fractures in suspected child abuse?Clin Radiol. 2006; 61: 723-36

Zimmerman S, Makoroff K, Care M, Thomas A, Shapiro R. Utility of follow-up skeletal surveys in suspected child physical abuse evaluations. Child Abuse Negl. 2005;29:1075-83

Kleinman PK, Nimkin K, Spevak MR, Rayder SM, Madansky DL, Shelton YA, Patterson MM. Follow-up skeletal surveys in suspected child abuse. AJR Am J Roentgenol. 1996; 167: 893-6

Day F, Clegg S, McPhillips M, Mok J. A retrospective case series of skeletal surveys in children with suspected non-accidental injury.J Clin Forensic Med. 2006;13: 55-9

Belfer RA, Klein BL, Orr L. Use of the skeletal survey in the evaluation of child maltreatment.Am J Emerg Med. 2001; 19 122-4

Ellerstein NS, Norris KJ. Value of radiologic skeletal survey in assessment of abused children. Pediatrics. 1984; 74: 1075-8

Jaudes PK. Comparison of radiography and radionuclide bone scanning in the detection of child abuse. *Pediatrics.* 1984;73:166-168

Skeletal trauma often reflects severe physical abuse. When discussing fractures, as with much of physical abuse, it is important to pay attention to a child's age and developmental ability. Fractures from the birth process have special significance that must not be missed. Fractures during early infancy, when children are non-ambulatory, are the most concerning for abuse. As the child develops size, motor abilities, and speed, the frequency of non-inflicted fracture increases and the difficulty of discriminating accident from abuse becomes more difficult.

An additional difficulty, is that the CHAMP physician may not care for skeletal trauma in their primary medical practice. Fractures are largely diagnosed by radiologists and treated by emergency departments and orthopedic surgeons. Other physician's experience with fracture may be limited. Much is to be learned, but the CHAMP physician can bring a unique thought process and skill set to the table, which adds greatly to the abilities of the other specialties. It is important not to lose sight of your value in this unfamiliar territory.

A. History:

The injury event history has particular importance when assessing fractures. Because of this we will re-iterate several points made earlier. It is important to determine whether the history provided is a report of a directly witnessed event, a report inferred from indirect evidence, or a second hand report of another person's observations. With this in mind, the actual observations, not the inferences, of the historian must be gathered. If no trauma is reported, a suitable period of time prior to presentation must be reviewed. Give the historian an opportunity to identify overlooked trauma, or to specifically deny that trauma has occurred. A general question about trauma should be used for this. Offering plausible histories to be rejected piecemeal is inappropriate. When a trauma event is reported, it must be reviewed in detail. The position and actions of the child, and other involved person's before the trauma event must be described. The trauma event should include body positions; contact with surfaces, objects and other persons; sounds heard; the child's response; how the child fell, and the final position of the child. At best, the CHAMP physician should have a movie like feel for what transpired during the event. For indirectly observed events, what was heard seen or known prior to the trauma event; any distant or indirect observations, such as sounds heard during the trauma event; and the next direct observation of the child, including emotional response, location, position, verbalizations, symptoms and signs; help create an impression of what might have happened.

The complete past medical and family history is taken. The family history must probe for evidence of brittle bone diseases. It is not enough to ask if someone in the family has brittle bones or osteogenesis imperfecta. The CHAMP physician should identify how many fractures each biological parent and sibling has had, and how those fractures were sustained. Dental conditions and hearing loss in the parents should be evaluated. Look at the parents' sclerae, and ask about unusually blue sclerae in their childhood. Evaluate their height relative to population norms and their family trend. Then ask about relatives

suffering unusually short stature, blue sclerae, multiple ill explained fractures, dental fragility, and early adult hearing loss.
Osteogenesis imperfecta is not the only condition causing fragile bones. Premature birth, particularly when accompanied by parenteral nutrition, steroid use, diuretic use, and bronchopulmonary dysplacia, may cause fragile bones. Over-reliance on human milk, when combined with dark skin, limited sun exposure, and lack of vitamin D supplementation can result in rickets. Renal disease, certain immunosuppressive drugs, chronic medical conditions, and prolonged immobility can each contribute to skeletal fragility. These possibilities must be probed in the medical history.

B. Physical Examination:

The physical examination is once again a complete evaluation, not problem focused. Bruising may be sought at the fracture site, but it is far from unusual to see no evidence of overlying cutaneous trauma. Of course other evidence of injury will be sought. Specific observations related to osteogenesis imperfecta are short stature, flat posterior skull with frontal bossing, blue sclerae, and bowed extremities. Unusual skin is also germane both for osteogenesis imperfecta, and for Ehlers Danlos syndrome.

Radiological evaluation of the skeleton is sure to follow, but direct examination, by observation and palpation will clarify if the child demonstrates pain or tenderness, whether swelling, erythema or deformity is apparent, and whether crepitance or other audible evidence of injury is apparent.

C. Imaging and Laboratory Investigation:

Every child under age two will need to be evaluated with a skeletal X-ray survey. Children under five may benefit from a skeletal X-ray survey, when the index injury is itself skeletal, though the return is less. A skeletal X-ray survey is a series of films specifically chosen, aligned and exposed to view all the bones of the body. Twenty one films are recommended in the initial series, as listed below.

AP and lateral skull
Lateral C-spine
AP, lateral and bilateral oblique ribs
Lateral LS-spine
AP abdomen and pelvis
AP humerus right and left
AP radius and ulna right and left
AP femur right and left
AP tibia and fibula right and left
Oblique hands right and left
AP feet right and left

In many institutions it may be necessary to order these films individually, as simply ordering a skeletal X-ray survey will result in a “babygram” with the whole child, or

large segments of the child, exposed on a single plate. A babygram is NOT adequate to rule out possible trauma.

In addition to identifying the presence, and nature of the index and other occult injuries, X-ray provides some evidence of the age of each injury. The absence of visible healing in ribs and long bones suggests that less than a week to ten days has transpired since injury. Beyond that, cues to fracture age exist, but need significant experience to interpret. In general, broad ranges, rather than specific dates should be expected. The presence of fractures in multiple states of healing indicates multiple events; a single episode of non-inlicted trauma is an unlikely cause.

Given the limited ability to precisely age a fracture, it is generally very difficult to pinpoint a narrow window of time. Thus, depending on who had access to the child during that period, the age of each fracture is unlikely to specifically identify an assailant.

Additional imaging is often necessary. Nuclear medicine bone scans have been recommended as more sensitive to rib fracture. Unfortunately this enhanced sensitivity comes with limited ability to detect skull fracture and difficulties in evaluating metaphyses of long bones. Combining a nuclear medicine scan with a skeletal X-ray survey will increase sensitivity, and is one way to evaluate a child more thoroughly when time is of the essence. If two weeks is available for evaluation, however, an alternative has some benefits. Repeating a limited skeletal X-ray survey in two weeks adds significantly to the sensitivity and specificity of the evaluation. The skull films may be eliminated, and sometimes the series can be limited to four views of the ribs, and single views of the shoulders, elbows, wrists, hips, knees and ankles, evaluating the metaphyses of the long bones. Any questionable areas from the first survey should be re-examined.

Routine laboratory tests are not generally recommended to evaluate skeletal fragility. Where renal, hepatic, or endocrine function, or nutritional sufficiency are questioned, they may be evaluated. BUN, creatinine, calcium, phosphorus, parathyroid hormone, 25 and 1-25 hydroxy vitamin D levels, may each contribute to the evaluation. The skeletal X-ray survey may also contribute to evaluating for fragile bones. Poor apparent mineral density, thin cortices, and the presence of excess wormian bones of the skull, may contribute to concerns. The absence of concerns on skeletal survey, however, does not eliminate the possibility of skeletal fragility. Unfortunately DEXA and other radiological bone mineral studies are not yet highly reliable in the evaluation of infants.

Where the only basis for abuse concerns is fracture under questionable circumstances, there is some new evidence to suggest that laboratory testing for osteogenesis imperfecta will detect some OI misdiagnosed as abuse, even when there is limited clinical suspicion. This is a new concept, and not universally practiced. It seems as if skin biopsy and phenotypic testing of collagen secreting cells is the best first test, though some opt for gene sequence testing since it may be performed on a blood sample. These tests are expensive, and take significant time, so last minute testing before a court appearance must be avoided. Finally, a negative test does not perfectly exclude OI, though it is able to detect about 90% of cases.

D. Assessment and Diagnosis:

Evaluating fractures requires specific knowledge of the epidemiology of fractures, a biomechanical understanding of how they occur, a consideration of the history, and of course knowledge of other injuries that may be present in the child. As with other abuse injuries, the crux of the matter involves evaluating whether the history reasonably explains the physical findings. The presence of multiple unexplained injuries in a child, for example, raises significant concern for child abuse. But even this relatively strong case has been challenged as an example of osteogenesis imperfecta, or more mysterious "temporary brittle bone disease." The most common, and most difficult case to evaluate is that of a child with a single fracture of a long bone, and a minor trauma history. If such a situation can be mastered, other circumstances will be easily overcome by the same methods.

Epidemiology, as we will use the term here, includes both statistical observations formulated from the observation of large populations, and individual observations that are instructive. An epidemiological consideration of a fracture may offer a probabilistic answer, rather than a firm conclusion. For instance, femur fractures in infants have been the subject of significant research. Frequencies of abuse have varied widely, from 30% to 80% but are all high. If the group is defined by independent ambulation, rather than age, it appears as close to 50% of femur fractures in non-walking children, are due to abuse. Knowing nothing else, if you are approached with a seven month old suffering femur fracture, you would then opine that there is a significant likelihood of abuse, approaching the preponderance of the evidence. A small case series of femur fractures sustained when non-ambulatory infants were playing too vigorously in exersaucers has been published. The fractures were buckle or impacted transverse fractures of the distal-posterio-medial metaphysis. Similar fractures have been described following short falls off of a bed, but this fracture has also occurred in cases of abuse. With this in mind, if the case before you now had an accompanying X-ray, showing this form of fracture, your assessment would have to change. You would need to reflect that while all femur fractures taken together have a strong association with abuse, this particular fracture has a history of occurring following relatively minor trauma, some of which might not appear traumatic at all to an adult observer. Let's say you now had the opportunity to take a history from the parents, and they absolutely denied any trauma. They insist that they put their baby to bed well on the prior day, and found the baby upset, and unable to bear weight the next morning. The absence of explanatory history, and development of symptoms in a protected environment again raises the question of abuse, because it suggests that the parents are hiding something. On the other hand, our experience with this fracture morphology indicates that what they are hiding may not be serious injury. Might they have taken a crying baby from an exersaucer and put him to bed in frustration. Might someone have dropped the baby and be afraid to admit it to the other parent or a system that could judge them. Or are they hiding a willful violent act that injured their baby? A well considered opinion would need to consider all possibilities.

Several fractures have been noted to be associated with abuse. As mentioned before, femur fracture has been frequently studied. In non-ambulatory children it had been found to be abusive about 50% of the time. Humeral fractures are also fairly well studied. Supracondylar fractures are a fairly common accidental injury in the broader age ranges these studies included, but in children under 18 months, non-supracondylar humeral fractures were significantly associated with abuse. All humeral fractures, taken together, are found to be abusive about one third of the time. A videotaped exception occurred when a three year old rolled her infant sibling from a prone position, with the arms in a forward prop, over to the infant's back. This motion resulted in a spiral fracture of the humeral mid shaft. Several studies of infant rib fractures have yielded a convergent result, 80% association with abuse. The remaining 20% sustained their fracture during a motor vehicle crash, when an adult fell while holding the infant, during an uncommon birthing injury, or due to an underlying bone disorder. The classic metaphyseal lesion (CML) is the proper name for a fracture of the metaphyseal-physeal junction giving the corner chip or bucket handle appearance. This is the radiological finding most suggestive of abuse. Despite this there are no epidemiological studies. There are a few published exceptions. Children have sustained similar appearing lesions during cephalic version for breech presentation, and during serial casting for club-foot deformity. One study reported similar lesions in children with osteogenesis imperfecta, but only when their disease was advanced and radiologically obvious. An important caveat is that a child can both have an underlying medical condition and be abused.

Fracture	Population	Abuse Likelihood	Published Exceptions
Femur	Non-ambulatory infants	50%	Exersaucer and short fall fracture of the distal metaphysis
Humerus (not supracondylar)	Children under 18 months	30%	Child rolled over from prone by someone
Rib	Infants under 12 months	80%	Motor vehicle crash Osteogenesis imperfecta Fall in the arms of a falling parent Birth fracture
Classic Metaphyseal Lesion	Infants under 12 months ? others ?	Near pathognomonic	Serial casting for club-foot External version for breech Radiologically apparent OI

Additional fractures that have been reported as associated with abuse have not been studied much but should be known. Sternal fractures, scapular fractures, and fractures of the spinous process of the vertebra are believed to be strong indicators of abuse. Fractures of the small bones of the hands and feet in infants, and fractures of the distal or medial clavicle, rather than the common mid-clavicular fracture, are felt to be concerning for abuse as well.

Biomechanics may be useful in assessing a given history, though this must be done with care and humility. Transverse and some oblique fractures absorb the most energy. Energy absorption increases as fractures go from simple plastic deformity, to greenstick, to complete, to displaced, to comminuted. As such, a completely displaced transverse fracture is a very high energy fracture, whereas an incomplete, non-displaced spiral fracture may occur with a lower energy event. This has been shown in the lab, and through clinical correlation. Clinically this means that "high energy" fractures call for a history where the child fell further, or was moving faster, prior to any impact. Unfortunately, there are no numerical energy thresholds that are clinically useful, so it remains speculative to determine which events possess enough energy to cause which fractures. Still, the general concept will help point out where the CHAMP physician should raise suspicion, and where caution is advised. Transverse and shallow oblique fractures occur from blows and bending, while long oblique and particularly spiral fractures indicate torsion or twisting of the bone. It is not always possible to identify the presence or absence of twisting or bending in a history, but apparently inconsistent mechanics will form a basis to increase suspicion. Impacted fractures, such as buckling, indicate forces directed axially up or down the bone. Again the possible presence of such forces must be identified in the given history and correlated with the clinical fracture.

While we are evaluating the history, some studies have looked at histories more in depth. The absence of a history of any trauma is always a concern for abuse, when a child is very young. As the child becomes more independent and mobile, historical absence begins to lose its specificity for abuse, though neglect remains as something to be considered. Some authors have looked at the completeness of a reported observed event. The child's initial condition, the nature of a fall, and their landing posture were requested. As historians were less able to provide all three components, the likelihood of abuse increased.

Differential diagnosis must be carefully considered in these cases.
1. The occurrence of brittle bones from any cause, but particularly from osteogenesis imperfecta, must be excluded. Until recently, it was recommended that a good clinical assessment, with an open mind, was enough to exclude osteogenesis imperfecta in a child abuse case. Recently this recommendation was revised. Some authors are recommending that when an abuse case rests exclusively on fracture following limited trauma, screening tests for OI will identify a very small number of cases in which OI is mistaken for child abuse. While rickets, prematurity, and chronic medical illnesses have not received as much scrutiny, clinical assessment, accompanied by a low threshold for progressing to laboratory assessment, remains the standard.

2. Another cause for confusion is radiological variants. Variations of the acromion process, pelvis, and metaphyses of the long bones have been mistaken for fractures. These concerns can be evaluated by comparing a repeat skeletal x-ray survey to acute films for evidence of healing. Perhaps the most common source of confusion is physiologic sub-periosteal new bone formation. This variant looks like a healing response to skeletal injury, though no fracture is seen. It is common in infants under six

months of age. It is usually symmetrical, but may be asymmetric. Pediatric radiologists are very familiar with this entity, though general radiologists may not be.

A high energy fracture or a fracture with high prevalence of abuse, such as rib or CML, and an absent or clearly inconsistent history is adequate basis to diagnose abuse, so long as additional non-skeletal injuries are present, or OI had been clinically excluded. When a fracture is a lower energy type and less epidemiologically associated with abuse, trauma is reported, but its consistency is uncertain, abuse may be suspected but not ultimately diagnosed. Still the CHAMP physician may be able to lay out the likelihood of abuse, and describe what abusive or accidental acts would be expected.

E. Diagnostic and Treatment Plan:

We have talked about making a diagnosis of abuse at an evaluation. Often, however, we must offer an opinion on the likelihood of abuse, while further evaluation is still pending. This is a particularly common situation in suspicious fractures. If the history is inconsistent, the epidemiology suggests likely abuse, and there are no clinical signs of osteogenesis imperfecta, the CHAMP physician will likely make a preliminary diagnosis of abuse, though a genetics consult or skin biopsy study is pending. This should be explained clearly to consulting agencies. All medical diagnoses are subject to revision. In two weeks a repeat skeletal survey may remove all doubt about abuse, or identify a suspected fracture as a normal variant. An osteogenesis imperfecta evaluation may take weeks to arrange, and more than 6 months to return. When these tests are complete, the diagnosis may change, but until that time the child should be treated as if abuse is the case, not as if the answer is unknown. In many instances where abuse is probable albeit not definite, the need to protect the child should be seriously considered. If future evidence changes the initial evaluation findings, the intervention should be modified.

Treatment of the fracture will require working with an orthopedic surgeon. Cultivating this relationship may be particularly important. Orthopedists are quite often dismissive of abuse concerns. They forget their referral bias, and see injuries as common, when in fact they are not. Because of their great experience with skeletal injury, their opinion may seem to have greater weight than that of the CHAMP physician. Working in partnership is the best resolution of this situation. Competing for influence over the child protection system may be necessary in some cases, but is a poor substitute for true partnership.

F. Conclusion:

The consideration of fractures is often complex. As injuries occur within the body, they become less intuitively obvious to both physicians and the protection systems that we must enlist in treating our patients. This chapter has only scratched the surface. Further and continued study of the literature, and personal experience will reward the CHAMP physician with a greater sense of certainty.