Note: Some images omitted due to file size

Skeletal Injuries in Suspected Abuse

Lori D. Frasier MD
Professor of Pediatrics
Director, Center for the Protection of Children

Disclosure

- I provide medico-legal opinions to both defense and prosecution in child abuse cases.

Objectives

- Review the epidemiology of childhood fractures
- Discuss the types of fractures seen in children
- Describe the mechanism of fractures and the specificity of those fractures for abuse
- Discuss some of the skeletal conditions that may or may not be implicated in the diagnoses of abuse

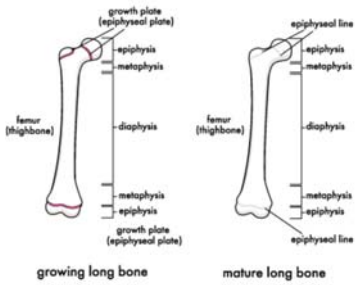
Fractures are a normal part of childhood and common in abuse

- Up to 66% of boys and about 40% of girls will sustain a fracture by their 15th birthday.
- 85% of accidental fractures are seen in children over 5 years.
- Fractures occur in 25% of abused children
- 80% of abusive fractures are seen in children less than 18 months of age.

Infant and children's bones are different than adults

- Bones are more porous (more distance in haversian canals)
- More plastic/more elastic-they permit a greater degree of deformation before they break-
- Thick periosteum-serves to act as restraint to displacement-
  - Periosteum can be injured
- Angular deformation may cause fracture without displacement ie greenstick fracture

Anatomy



Patterns of skeletal injuries in child abuse: A systematic review-Kemp et al (BMJ 2008)

- Most commonly due to abuse
  - Infants < 1 year, toddlers 1-3 y
  - Multiple fractures
  - Rib fractures (once major trauma excluded)
- Less likely to be abuse
  - Supracondylar fractures (humerus)
  - Linear parietal skull fractures
- Femur fractures-development is an important discriminator

Kemp et al

- No fracture, on its own, can distinguish an abusive from a non-abusive cause. During the assessment of individual fractures, the site, fracture type, and developmental stage of the child can help to determine the likelihood of abuse.

Child abuse fractures

- Any bone can be fractured as a result of abuse.
- Many abusive fractures in infants are not clinically obvious (rib and metaphyseal especially)
- Associated bruising is rarely present over abusive fractures.
- The highest incidence of abusive fractures are under 5 months of age.

Bones: Abusive Fractures

- Type of fracture is important
- Age and development of child
- History is important and is often incompatible with history trauma
- There may be evidence of abuse, other fractures

Distribution of Abusive Fractures
Kleinman, et al 1995

- 165 inflicted fractures in 31 fatalities
  - 51% involved the rib cage
  - 44% long bone fractures
    - 89% Classic Metaphyseal Lesions (CMLs)
  - 5% long bone shaft fractures

Myths about fractures

- Spiral fractures are nearly always abusive
  - Fact: Spiral fractures can be accidental if a twisting mechanism is implicated.
- Babies bones break easily
  - Young infants have flexible bones that bend before they break
- There should be bruises over inflicted fractures
  - Bruises over inflicted fractures are rare

Specificity **of Skeletal Injury*-Kleinman**

- Common, but low specificity
  - **Subperiosteal new bone formation**
  - **Clavicular fractures**
  - **Long bone fractures except in non mobile infants**
  - **Linear skull fractures,may be abuse if history doesn't fit**
  - *Any fracture in an infant has high specificity
    - Kleinman: Diagnostic Imaging of Child Abuse, 2nd Edition

Patterns of Skeletal Injury

- Moderate Specificity
  - Multiple fractures
  - Fractures of different ages
  - Epiphyseal separations
  - Vertebral body fractures
  - Digital fractures
  - Complex skull fractures

- Kleinman: Diagnostic Imaging of Child Abuse, 2nd Edition

Patterns of Skeletal Injury

- High Specificity
  - Classic metaphyseal fractures
  - Rib fractures
  - Scapular fractures
  - Spinous process fractures
  - Sternal fractures

- Kleinman: Diagnostic Imaging of Child Abuse, 2nd Edition

Rib Fractures

- Unusual in children, except in cases of abuse
  - May see in some metabolic disorders, premature infants, skeletal dysplasias, motor vehicle collisions
  - Rarely caused by CPR
  - Rarely caused by birth
  - Rarely caused by surgery
- Locations
  - Typically posterior
  - Also lateral and anterior

Anterior rib

Rib Fractures

- Clinical presentation
  - Rib fractures may be found as an incidental finding on chest radiographs
  - Usually children are asymptomatic
  - Often no bruising or swelling

Rib Fractures-Mechanism

- Posterior rib fractures
  - from levering over transverse process of spinal vertebra

Skeletal Injuries-Rib fractures

- Rare from CPR (Maguire et al 2006)
  - Mostly anterior may be multiple
  - Some reported increase since the 2 hand method of CPR
  - *rare* from birth

Comparison of computed tomography and chest radiography in the detection of rib fractures in abused infants. Wooten-Georges et al Child Abuse Negl 2008

- 3D reformatted CT

Suggests CT improves detection of rib fractures in abused children

3D Recon of Chest CT

Controversy? Rib fractures without intrathoracic trauma?

- Frequency of intrathoracic injuries in children younger than 3 years with rib fractures Darling et al (Pediatr Rad 2014)
  - Abused infants have fewer intrathoracic injuries but more rib fractures
  - Likely due to the inherent mechanism of the abuse (longer duration, manual squeezing or crush, rather than high velocity) rather than bone fragility

Metaphyseal Fractures
(Classic Metaphyseal Lesion-CML

- Series of microfractures oriented horizontally across the metaphysis (perpendicular to the long axis of the bone)
- To-and-fro manipulation of the bone.
- 39-50% of abused children
  - Distal femur
  - Proximal tibia
  - Distal tibia
  - Proximal Humerus

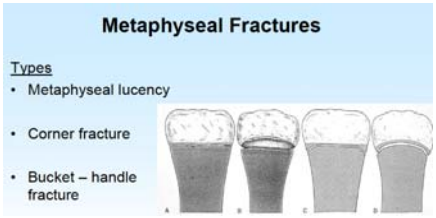
Classic Metaphyseal Lesions

- CML requires shearing forces **not** produced in accidental trauma
- Consider forceful twisting or traction
- Possibly produced during shaking where limbs flail about

Skeletal Injuries

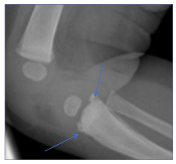
- Metaphyseal Fractures
  - require "non- accidental" forces
    - **Grabbing, twisting, shaking produce shear strains**
    - **Common in fatal abuse**
    - **Common in AHT**

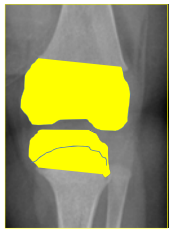
How the CML looks on xray depends on the plane of the xray



Metaphyseal Fractures

- "Bucket handle" or "corner fractures"





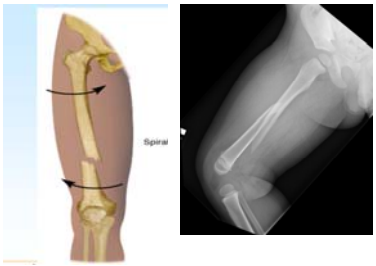
Fractures of the Diaphysis (midshaft)

- Less specific for abuse and metaphyseal fractures
- Occur 4X more often in abused children

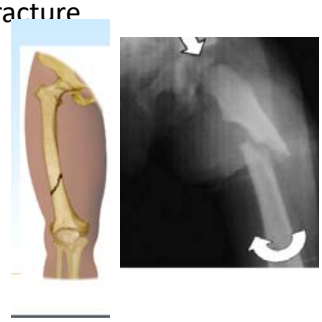
Types of long bone fractures

- Spiral: requires a rotational or twisting force
- Oblique: Combines loading a compressive forces with rotation (can look similar to spiral on xray)
- Transverse Fracture: Bending or direct force
  - Displaced transverse fracture due to high energy blow
- Greenstick (incomplete)
- Torus (Buckle) Axial loading

Spiral fracture



Oblique fracture



Transverse Fractures

Bending or direct force

More energy than a spiral fracture

Transverse fracture with displacement

Greenstick or incomplete

- Flexible bones in infants often break this way.

Torus or “buckle” fracture

- Axial loading-longitudinal compression
- Any long bone
- Immature bones often fracture this way

Femur-Torus fracture

Bones fractured-femur

- Femur: most common in abused and non abused children
  - Abusive femur fractures occur most often in children not yet walking

Tibia and fibula

- Abusive fractures most common in non ambulatory infants
- Toddler's fracture: a stress fracture, usually accidental in children 9mo- 3y.

Toddler's fracture

Humerus

- Supracondylar: majority are accidental due to a fall
- Spiral or oblique: in less than 5 years, commonly abusive, if no history

- Acromion fracture-

- Spiral or possibly oblique humeral diaphyseal fracture

Radius/Ulna

- 10-20% are from abuse
- Mid diaphysis usually from abuse
- Distal buckle fractures in mobile children usually accidental (FOOSH)

Mid shaft radius/ulna

Clavicle

- Common birth injury
- Common accidental injury in mobile children
- Abusive fractures are often midshaft
- Acute clavicle fractures in non mobile infants have a high specificity for abuse if there is no history

Hands and Feet

- Feet fractures are uncommon and specific for abuse in young children
- Likely due to direct trauma
- Difficult to see radiology, may require multiple high resolution if suspected

Digital fractures can be subtle

3D CT to define unusual fractures

Skull Fractures

- Linear, parietal bone fractures
  - Most common type and location in both accidental and abusive head injury
- Fractures caused by abuse constitute a minority of all pediatric skull fractures
- Wegmann 2016, Injury: 248 infants mean age 7 months, 2% (6) were victims of child abuse and had additional fractures (10). Most were falls from changing tables, arms of caregivers and off beds.
- Fracture which may be more suggestive of abuse
  - Multiple, bilateral and fractures that cross suture lines
    - Hobbs and Meservy

Click to edit Master title style

- Linear parietal skull fracture with overlying swelling

PennState Health Children's Hospital

Skull Fractures

- May or may not have associated intracranial injury
  - Schutzman, 2001: the presence of a skull fracture is a positive predictor of intracranial injury
- Most childhood fractures occur from short distance falls and are neurologically benign

Skull Fractures

- Unlike skeletal injuries, skull fractures do not heal with the typical periosteal reaction and cannot reliably be dated
- May or may not see overlying swelling
  - In some cases swelling is seen only at autopsy
  - This may be related to the hemodynamic compromise present in many of these children that have sustained massive head injuries

Imaging in skull fractures

- Conventional radiographs
- Should not be the primary imaging choice in children with suspected head injury
  - Often performed as part of the skeletal survey to demonstrate and document fractures
  - AP and lateral images are standard
  - Skull radiographs should be obtained in addition to bone scans which are relatively insensitive to detecting skull fractures
- CT with 3D reformatting are the standard in evaluating most skull fractures.

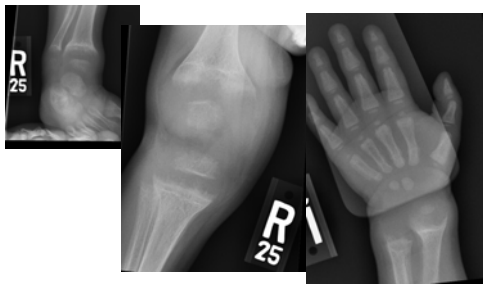
Complex Skull Fracture

Differential Diagnosis of fractures

- Most difficult to distinguish from non-accidental trauma
  - Skeletal injuries:
    - Accidental injury
    - Metabolic bone disease (rickets/scurvy/other diseases)
    - Osteogenesis imperfecta
    - Menkes' Syndrome
    - Leukemia/Lymphoma
    - Caffey's disease
    - Congenital syphilis

21 month old FTT-

Radiologic rickets



Rickets and fractures, not a new question-Proceedings of the Royal Society of Medicine-1916

Section for the Study of Disease in Children.

President—Dr. Robert Hutchison.

(*March* 24, 1916.)

Rickets; Multiple Fractures.

By Hugh Thursfield, M.D.

The patient, a girl, aged 2½ years, has old fractures of both clavicles, both femora, and both humeri, and recent fractures of the right humerus and the left fibula and tibia. She has marked rickety deformity of the thorax.

I am twitted with having implied that the multiple fractures are due to the rickets: that is not my meaning. I think the child has rickets and also has multiple fractures. From time to time one comes across cases of children with rickets, at various ages, who, for some reason, have an undue fragility of their bones, with the result that multiple fractures occur. I think this condition cannot be of the same class as that properly called fragilitas ossium, a disease which usually exhibits multiple fractures, either during fœtal life or immediately after birth. I brought this child in order to obtain the opinions of those who have seen more of such cases than I have as to whether the condition can be definitely related to rickets.

Does low 25(OH) vitamin D cause bone fragility without radiologic evidence of rickets?

Vitamin D and skeletal health in infancy and childhood: *Osteoporos Int*. 2014 December ; 25(12): 2673–2684. doi:10.1007/s00198-014-2783-5.

- **Moon, RJ et al (all authors are Rheumatologists or endocrinologists)**
- **Review article that is heavily referenced.**

"We conclude that there is insufficient evidence to support the suggestion that low serum 25-hydroxyvitamin D [25(OH)D] increases childhood fracture risk."

REVIEW

The etiology and significance of fractures in infants and young children: a critical multidisciplinary review

Sabah Servaes[1] · Stephen D. Brown[2] · Arabinda K. Choudhary[3] · Cindy W. Christian[4] · Stephen L. Done[5] · Laura L. Hayes[6] · Michael A. Levine[7] · Joelle A. Moreno[1] · Vincent J. Palusci[8] · Richard M. Shore[9] · Thomas L. Slovis[10]

Received: 21 December 2015 / Accepted: 13 January 2016 / Published online: 17 February 2016
© Springer-Verlag Berlin Heidelberg 2016

Abstract This paper addresses significant misconceptions regarding the etiology of fractures in infants and young children in cases of suspected child abuse. This consensus statement, supported by the Child Abuse Committee and endorsed by the Board of Directors of the Society for Pediatric Radiology, synthesizes the relevant scientific data distinguishing clinical, radiologic and laboratory findings of metabolic disease from findings in abusive injury. This paper discusses medically established epidemiology and etiologies of childhood fractures in infants and young children. The authors also review the body of evidence on the role of vitamin D in bone health and the relationship between vitamin D and fractures. Finally, the authors discuss how courts should properly assess, use, and limit medical evidence and medical opinion testimony in criminal and civil child abuse cases to accomplish optimal care and protection of the children in these cases.

Keywords Child abuse · Children · Fractures · Infants · Metabolic bone disease · Non-accidental trauma · Radiography · Rickets · Vitamin D

This review was endorsed by the Society for Pediatric Radiology Board of Directors on Nov. 29, 2015.

Sabah Servaes, Stephen D. Brown, Arabinda K. Choudhary, Laura L. Hayes, and Joelle A. Moreno are members of the Child Abuse Committee of the Society for Pediatric Radiology.

Summary

- (1) Vitamin D levels do not denote bone disease.
- (2) Rickets is a metabolic bone disease that must be diagnosed by objective historical, laboratory and radiologic findings.
- (3) Fetal and neonatal bone health is not correlated with maternal vitamin D levels.
- (4) Congenital rickets is a rare phenomenon and has only been seen in newborns born to severely impaired mothers (e.g., renal failure, placental insufficiency). In such cases, there are always radiographic changes in the newborn indicative of poor bone health.

Summary

- (5) Rickets is not associated with retinal hemorrhages or subdural hematomas, which occur with abuse.
- (6) The fractures with high specificity for child abuse — classic metaphyseal lesions and posterior rib fractures — are not sequelae of rickets.
- (7) Death is extremely rare in childhood rickets and is usually caused by superimposed infection in a malnourished child.
- (8) Classic metaphyseal lesions (corner fractures) are not controversial fractures; they have validated medical literature support.

Radiology 2015 vol 275 (3)

Absence of Rickets in Infants with Fatal Abusive Head Trauma and Classic Metaphyseal Lesions[1]

Summary

- Children with fatal AHT-determined to be homicide
  - 72 fractures
  - All infants had CMLs and head trauma
  - 6/9 had skull fractures
  - 5/9 had rib fractures
  - NO RADIOGRAPHIC EVIDENCE of RICKETS in any patient
  - 17 Resected femoral metaphyses-No rickets histologically
  - CML is the result of trauma, not rickets

Osteogenesis Imperfecta

Rare, inherited disorder of connective tissue resulting from abnormal quantity or quality of type I collagen.

- Type I: 80% of cases, AD inheritance, milder form, blue sclerae, short stature, positive family history
- Type II: < 10% of cases, perinatally lethal
- Type III: rare and severe, AD or new mutation, fractures at birth in 2/3
- Type IV: rare, sporadically occurs in 1 in 3 million births, AD inheritance, normal sclerae, may have normal looking bones, most likely to be confused with child abuse
- Types V-VII more newly identified

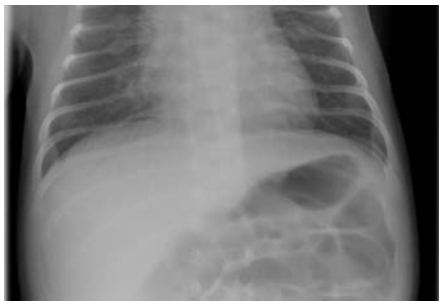
Pereira, Am J Med Genetics 2015

TABLE I. Radiological Signs More Common in Either OI or NAI

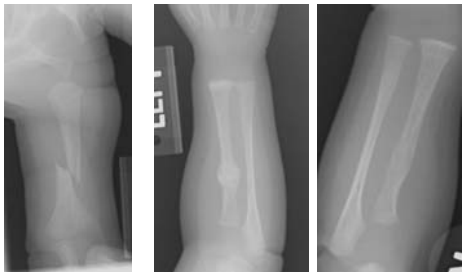
Radiographic signs	Seen more commonly in OI	Seen more commonly in NAI
Apophyseal avulsion fracture	X	
Classic metaphyseal lesions		X
Complex skull fracture		X
Long bone deformities	X	
Multiple wormian bones	X	
Osteopenia	X	
"Popcorn" calcification	X (type III)	
Posterior rib fracture		X
Skull deformities	X	
Spinous process fracture		X

Table I modified from Renaud et al., 2013 article.

Gracile or ribbon-like ribs seen in osteogenesis imperfecta with rib fractures



Osteogenesis Imperfecta



Pepin and Byers, Am J of Medical Genetics 2015

- Testing for OI
  - Sequence COL1A1, COL1A2, and IFITM5 simultaneously
    - No causative variant identified-no significant clinical phenotype- NO additional testing
      - Recessive form of OI usually present with prenatal or neonatal onset of fractures and moderate to severe bony phenotype
      - If a variant of uncertain significance is identified-get help!
  - Clinical evaluation includes a full workup for non accidental trauma including testing for occult injury

Ehlers-Danlos syndrome

- Heritable, soft connective tissue disorder with generalized joint hypermobility, abnormalities of skin texture and fragility of internal organs and vessels.
- Increased numbers in ”diagnosed” EDS may be due to a clinical identity between EDS hypermobility syndrome and the more common joint hypermobility syndrome.(JHS)

Ehlers-Danlos and child abuse

- Misdiagnosis of child abuse in patients with EDS has been described (6 cases). All involved increased fragility of soft non-ossified (skin) rather than ossified connective tissue (bone).
- EDS with generalized joint hypermobility may lead to increased fractures in adults especially pre-menopausal women.

Ehlers-Danlos and infant fractures

- Castori, Am J. Medical Genetics 2015
- While EDS may easily predispose to trauma of the soft tissues (e.g., skin lacerations, extensive bruising, dislocations), the likelihood of non-accidental fracture as a presenting symptom in non-mobile infants has not been reported in the literature, and the differential should include disorders known to be associated with bone fragility, such as osteogenesis imperfecta.

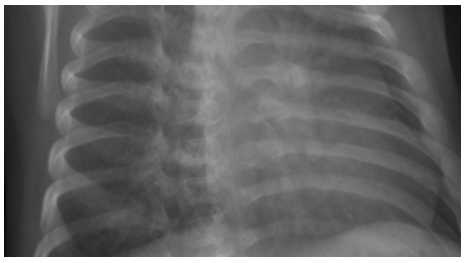
Skeletal Survey

- Performed in all infants and young children with suspected abuse less than 2 years.
- Children greater than 5 years rarely have skeletal injuries related to abuse.
- Children in the 2-5 year range are imaged on a case-to-case basis.
- "The 'body gram' (a study that encompasses the entire infant or young child on 1 or 2 radiographic exposures) or abbreviated skeletal surveys have no role in the imaging of these subtle but highly specific bony abnormality"
  - American Academy of Pediatrics statement on diagnostic imaging of child abuse (Pediatrics Vol.105 No.6 June 2000)

American College of Radiology

- ACR Standards suggest a minimum of 19 images to include a separate exposure of each anatomic location
  - AP and lateral views of the axial skeleton
  - Frontal views of the extremities
  - Additional views may be necessary to confirm or document suspicious sites of injury- radiologist must review before child leaves the suite
  - Most centers have added two views R and L obliques of the chest

Oblique



Babygram

Dating Fractures

- Radiological-
  - less than a few days may not be visible
  - Subperiosteal new bone is apparent on xray at about 7-10 days
  - Callous can be visible for several months
- Histologically--autopsy may be more precise in dating
- Clinical--Use of arm, bearing wt, irritability may help define when the injury occurred

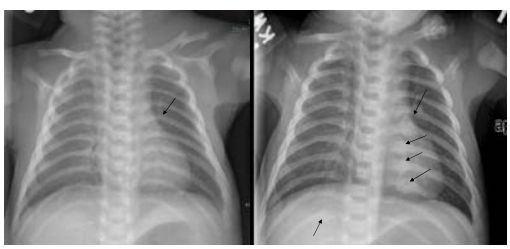
Fracture Healing

- Periosteal new bone
  - 10-14 days
- Visible callus
  - 2-4 weeks
- Incomplete bridging
  - 3 weeks
- Complete bridging
  - 10 weeks

Infants heal more rapidly but good data is not available.

Follow-up Skeletal Surveys

- Follow-up skeletal survey in 10-14 days to look for additional sites of injury that may not be seen on initial study
  - Skull films are not repeated
  - Nuclear Bone scan can also be considered but has some limitations. (ie skull and metaphyses especially)
  - May be especially helpful in ribs and CMLs



Nuclear Medicine Bone Scans

- May be used to clarify fractures
  - Ribs
  - Long bones
- Not useful for:
  - Skull
  - Metaphyseal fractures
- Requires sedation
- Maybe more radiation that a well-done skeletal survey

Rib Fractures- NM bone scan can be helpful

Siblings

- Twins or multiples must have skeletal surveys if sibling has suspicious injuries
- Siblings less than two in same environment skeletal survey is recommended
- Older siblings not recommended

Recommended non radiology work up

- Comprehensive metabolic panel to include Calcium, phosphorus, alkaline phosphatase
- 25-0H Vitamin D
- Possibly PTH if signs of bone turnover or high alkaline phosphatase
- Referral to genetics if concern regarding OI
- DEXA scans (bone density, speed of sound) have no role in the evaluation of infant fractures

Thank you!

- lfrasier@hmc.psu.edu