Fractures – When to Suspect Abuse

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Objectives

- Be able to describe the biomechanics of common abusive fractures
- Understand the importance of medical mimics of child abuse fractures
- Be familiar with typical histories (stories) in abuse and unintentional injury (accident) scenarios
- Understand the role of medical screening for occult injury in infants and young children suspected of being abused

Key Points

- Cause of fractures by type
  - Some fractures because of their very nature are highly correlated with abuse – ANY fracture can be from abuse
  - The only fracture expected in a short fall such as from a bed or sofa is a skull fracture, but skull fractures can be from abuse, as well
- Symptoms- Not all fractures are severely symptomatic
- Evaluation
  - Protocol-based screening is essential in suspected abuse cases
  - Only about 25% of all fractures are associated with bruises even if the injuries are from abuse
  - Siblings and household contacts of a child suspected to be abused should also be evaluated
- It is not possible to date fractures accurately by radiographs alone

Abusive Fractures (broken bones)

- Incidence
  - Frequency of fractures associated with abuse – 12% of all <36 mo hospitalized children with fractures (Leventhal 2008 *Pediatrics*)
- Age:
  - Most important risk factor
  - 55% to 70% of abusive fractures occur in children under 1 year of age
  - Incidence of abusive fractures is 1/2000; Medicaid is a major risk factor (Leventhal 2010 *Pediatrics*)

Presentation-Variable

- Swelling to extremity
- Pain to extremity
- Usually no bruising
- Decreased movement
- General fussiness
- No symptoms

Symptoms

- 2011 Farrell et. al- Interviews of parents of 206 children < 6 y/o with accidental extremity fractures. Mean age 3.7 years
  - No child with accidental fracture was asymptomatic
  - Parent noticed external sign of injury in 85%
  - 21% seen >8 hours after injury (median time was 1 hour)
- Flawed by
  - Recall/reporting bias- those who delayed in seeking care had a vested interest in underreporting/minimizing symptoms
  - Did not survey both parents
  - Few infants and toddlers- only 20% were <2 y/o.

What about bruises?

- Bruising does not differentiate between inflicted and unintentional
- About 25% of all fractures have associated bruises
- How can this be?
  - Skin compliance of young children
  - Bruises can be difficult to see in darkly pigmented children
  - Bruises can evolve over time, be covered by cast/splint, and heal quickly

Abusive Fractures

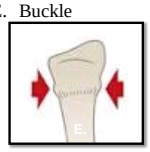
- Age of the child:
  - Most important risk factor
  - 55% to 70% of abusive fractures occur in children under 1 year of age
- Fractures are classified by
  - location (which bone and what part of the bone),
  - type (what is the direction of the break),
  - whether it is healing or not (healing vs. acute) and
  - angulation/displacement

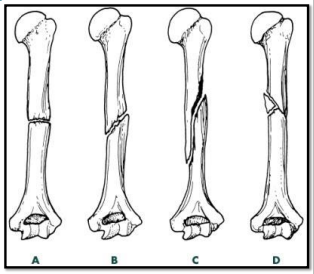
Location

- What bone?
  - Long bones of the arm- humerus, radius, ulna
  - Bones of the hands- metacarpals and phalanges (finger bones)
  - Bones of the leg- femur, tibia, fibula
  - Bones of the feet- metatarsals and phalanges (toe bones)
- Where on the bone?
  - Long bones:
    - Closer to the trunk=proximal
    - Farther from the trunk=distal
  - Ribs, skull
    - Anterior- toward the front of the body
    - Posterior- toward the back of the body
- What part of the bone?
  - Shaft- diaphysis
  - Growing part of the end- metaphysis
  - Growing cartilage- physis
  - Growth plate- epiphysis

Types - Diaphyseal Fractures

A. Transverse
B. Oblique
C. Spiral
D. Comminuted
E. Buckle





Biomechanics

- Transverse:
  - Fracture line perpendicular to long axis
  - Tensile or bending load
  - Direct or indirect force

Biomechanics

- Spiral/Oblique:
  - Torsional force
  - Twisting about the longitudinal axis
- Accidental or abusive
  - Toddler's fracture
  - Exersaucer injury (see 2001 Grant in *Pediatrics*)

Biomechanics

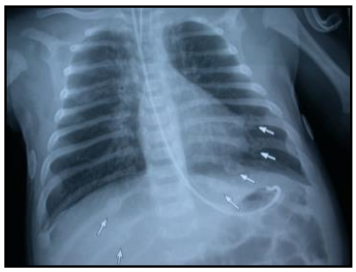
- Buckle/Torus:
  - Compression (axial loading) or bending force
  - FOOSH fractures

Fracture Patterns

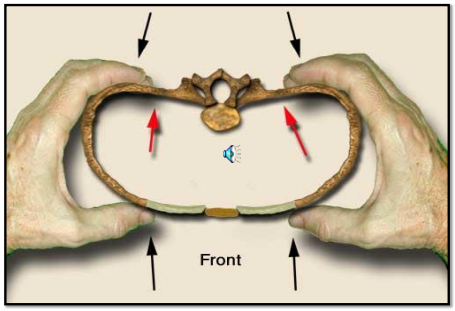
- High Specificity:
  - Classic Metaphyseal Lesion (CML)- commonly called bucket handle or corner fractures
  - Rib- especially posterior
  - Scapula
  - Spinous process
  - Sternum
- Moderate Specificity:
  - Multiple, bilateral
  - Different ages
  - Vertebral body
  - Digits
  - Complex skull fx
- Low Specificity:
  - Clavicle
  - Long bone shaft
  - Linear skull fx
  - Supracondylar fx humerus

Rib Fractures

- Most common fracture in child abuse (5-30%)
- Often diagnosed during healing phase (occult)



Rib Fracture--Mechanism



Classic Metaphyseal Lesions (CML)

- Also called "bucket handle", "corner", or Classic Metaphyseal Lesions (CML)
- Highly correlated with abusive injury
- Mechanisms
  - Twisting or pulling of affected limb
  - Shearing of metaphysis from shaking
- Difficult to date
- Usually clinically silent (or quiet once the immediate pain has subsided)
- Most commonly in tibia, femur

Skull Fractures

- Simple:
  - Linear
  - Parietal
  - Accidental or abusive
  - Most are due to short falls (Leventhal 2008 and 2010)

Skull Fractures

- Complex:
  - Depressed
  - Diastatic
  - Comminuted
  - Stellate or branching
  - Multiple
- Occipital and frontal fx require more force than parietal fxs. Unusual in short falls

Jaw fractures

- Sublingual hematoma should raise this concern
- Often multiple fractures
- Mechanism – direct impact, often in the context of AHT

Medical Evaluation of Fractures

- History-Particularly developmental age/stage and details of the injury event and subsequent symptoms
- Physical Exam- Only about 25% of abusive or accidental fractures have associated bruises. Bruising is not helpful in assessment. (Valvano 2009, Peters & Starling 2008)
- Laboratory Analysis- Bone labs (Ca, PO_4, Mg, Alkaline Phosphatase, intact PTH, Vit D-25). Only <25% of kids with overt rickets have fractures. Better to evaluate bone health and address issues related to possible metabolic bone disease in court.
- Imaging

Red Flags

- No history
- History inconsistent with developmental abilities
- Mechanism inconsistent with injury
- Other signs of abuse/neglect:
  - Bruises, scars, other fractures, old fractures
- Prior injuries
- Delay in seeking care
- Social risk factors:
  - DV, poverty (Medicaid), drug use

Imaging

- Skeletal survey in children under 2 y/o and repeat in 2 weeks. Second SS should omit skull, coned down views and oblique ribs unless specific interest
- Value of repeat SS- approximately 46% when selective; likely lower in universal screening
- Consider bone scan when safety is at risk. Even when bone scan is performed, repeat SS should be performed.

Skeletal surveys

- What are they?
  - Series of plain films (X-rays) of all of the major bones of the body:
- Why are there 2 parts?
  - To detect subtle fractures
  - To show healing of known fractures

COMPLETE SKELETAL SURVEY TABLE

APPENDICULAR SKELETON
Humeri (AP)
Forearms (AP)
Hands (PA)
Femurs (AP)
Lower legs (AP)
Feet (AP)

AXIAL SKELETON
Thorax (AP, lateral, right and left obliques), to include ribs, thoracic and upper lumbar spine
Pelvis (AP), to include the mid lumbar spine
Lumbosacral spine (lateral)
Cervical spine (lateral)
Skull (frontal and lateral)

2011 ACR Practice Guidelines: http://www.acr.org/~/media/ACR/Documents/PGTS/guidelines/Skeletal_Surveys.pdf

Plain films vs. Bone Scan

- X-Ray may miss new fractures
- Bone Scan can identify "missed" fractures
  - Sty and Starshak—Radiology 1983; 146:369-375
    - 261 suspected abuse cases
    - 12 patients with 1 or more rib fractures identified by bone scan but not by X-ray
  - Limited sensitivity for metaphyseal fractures due to normal uptake of tracer in growth plate
  - Lacks sensitivity for skull fractures

Protocol for when to image

- All children less than 2 y/o if concerned about abuse
- Ages 2 y/o – 5 y/o abused children, consider a skeletal survey in some circumstances
  - History of musculoskeletal symptom
  - Siblings of severe physical abuse
  - Other
- Developmentally delayed children – consider regardless of age in some cases

Dating of fractures – inexact*

- Not possible in skull fractures or CMLs
- Skull fractures usually heal by 6 months but without callus
- CMLs usually heal by 4-6 weeks
- Long bone and rib fracture dating assumes there is no re-injury
- Little research basis- can sometimes put a minimum age but an outside range is very difficult.

2006 Prosser I et al How Old Is This Fracture? Radiologic Dating of Fractures in Children: A Systematic Review. *AJR* 2005;184:1282
2015 Pickett Review: The challenges of accurately estimating time of long bone injury in children. J Forens Leg Med 2015;33:105-110

Can We Date Fractures? (Kleinman)

- Induction
  - Inflammation, removal of damaged tissue
  - 3-7 days
- Soft Callus
  - New bone formation
  - 5-14 days in children, earlier in infants
- Hard Callus
  - Union of fracture
  - 14-21 days (loss of fracture line definition)
- Remodeling
  - Smoothing of callus to original configuration
  - 3 months-1 year (longer in older children)

Radiation Exposure in Diagnostic Imaging

TABLE 1 Estimated Medical Radiation Doses for a 5-Year-Old Child

Imaging Area	Effective Dose, mSv	Equivalent No. of CXRs
3-view ankle	0.0015	1/14th
2-view chest	0.02	1
Anteroposterior and lateral abdomen	0.05	2½
Tc-99m[2] radionuclide cystogram	0.18	9
Tc-99m radionuclide bone scan	6.2	310
FDG PET[3] scan	15.3	765
Fluoroscopic cystogram	0.33	16
Head CT	4	200
Chest CT	3	150
Abdomen CT	5	250

CXR indicates chest radiograph; Tc-99m, technetium 99m; FDG PET, fluorodeoxyglucose positron emission tomography.
Data were provided by R. Reiman, MD (Duke Office of Radiation Safety [www.safety.duke.edu/RadSafety], written communication, 2006).

Brody AS et al. *Pediatrics* 2007;120;677-682

Skeletal Survey- 0.716 per survey= 1.4 mSv when study is repeated (Ahmed BA *Pediatrics* 2010;126;e851-e858)

Background exposure from natural sources is 3.0 mSv per year. Frush DP *Pediatrics* 2003;112;951-957

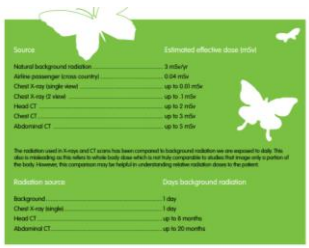
1 mSv= 1000 microSv

Lifetime cancer risk with diagnostic imaging

- Cancer risk <u>may</u> increase with early exposure to as little as 10-50 mSv and is widely thought to increase a small, but significant amount with 50-100 mSv
- "Background" radiation is the largest exposure and CTs account for the second largest exposure
  - Sea level background radiation is about 1.8 -3 mSv/year
  - 8 hours of flying at 36,000 feet is the same as 9 days of ground exposure

For more information:

- Generally, pediatric health care institutions are going to use Image Gently principles
- Image Gently: What Parents Should Know about Medical Radiation Safety
- http://pedrad.org/Portals/6/Procedures/Image_Gently_8.5x11_Brochure.pdf



Who Did It?

- Who first noticed any symptoms?
- Would symptoms be expected? Corner fractures, skull fractures and rib fractures often have minimal symptoms after the initial trauma event
- Who last saw the child well?
- Who has had access to the child?
- Who might be a witness, especially siblings?

What happened?

- Detailed description of events during the prior 48 hours
  - What were the symptoms?
  - In what order did the symptoms develop?
  - What was the child's position before and after?
  - If a fall occurred, what was the height of the fall and the surface?
  - What was the caretaker response?
- Was there a delay in seeking care? If so, why?
- Delay in seeking care is very common with skull fractures!

Where did it happen?

- Where did the child become symptomatic?
- Where was the child found?
- Did any emergency phone calls take place?
- Where did these calls take place?
- How did the child get to the hospital?

Precipitating events – "Why?"

- Crying
- Child ill
- Culmination of stress
- Single explosive episode
- Feeding problems
- Toilet training
- Domestic violence/Drug abuse
- Torture

Fractures

Differential Diagnosis or "What else could this be?"

Differential Diagnosis

- Accidental Injury
  - Short Falls
    - 3 studies of falls from hospital beds
    - 367 subjects
    - **3 linear parietal skull fractures (1/100 short falls involving infants), 1 clavicle fracture, no neurological complications**
  - Stair Falls
    - CHOP study of 363 patients (Joffe Pediatrics 1988;82:457)
    - Initial mild to moderate impact followed by series of low-energy non-injurious falls
    - 6% fractures (humerus, tibia, radius/ulna), 1 concussion, no intracranial hemorrhage; no visceral injury
    - **Vast majority sustained only minor soft tissue injuries**
    - **Multiple, truncal or proximal extremity injuries are suspicious**

Differential Diagnosis

- Obstetrical Injury
  - Clavicle and humerus fractures most common
  - Rib fxs rare but can occur in LGA infants
  - LGA infants
  - shoulder dystocia
  - vacuum- or forceps-assisted delivery

Differential Diagnosis

- Conditions/diseases that predispose to fracture:
  - Osteopenia of prematurity (<1500 gm, cholestatic jaundice, TPN>3wks, Lasix>2wks, immobilization, Cu and Calcium deficiency)
  - Nutritional: scurvy, rickets
  - Infection: osteomyelitis, syphilis
  - Neuromuscular disorders
  - Kidney disease: calcium wasting
  - Drugs: Vitamin A, methotrexate, prolonged glucocorticoid use, anti-epileptic meds and others
  - Leukemia
  - Other- normal variants, hyper/hypothyroidism, Menke's, etc.

Normal Variants

- Many normal variants exist
- Mendosal suture with an Inca bone
- Many other examples!

Osteogenesis Imperfecta

- Heritable collagen disorder with variable phenotypic expression
  - Type I: Mild; decreased production of Type 1 collagen* 71% of OI
  - Type II: lethal in perinatal period; 9% of OI
  - Type III: severe, progressive, usually apparent at birth; 15% of OI
  - Type IV: Moderate; production of defective collagen* 5% of OI
  - Other
- *Can be confused with NAT

Features of OI

- Type I
  - Blue sclera (60-70%)
  - Hearing loss (50%); presents in 2nd decade
  - Wormian bones
  - Osteopenia
  - Dentinogenesis Imperfecta
- Type IV
  - Normal sclerae
  - Short stature
  - Hearing loss
  - Wormian bones
  - Dentinogenesis Imperfecta

Diagnosis of OI

- Family History
  - Frequent fractures, hearing loss in teen or young adult, joint laxity, abnormal teeth
  - Spontaneous mutations are common so family history may be negative
- Physical Exam
- Osteopenia on plain films; decreased lamina dura (surrounding tooth socket)
- Skin biopsy to culture fibroblasts or blood for DNA sequencing
  - Each with 85% sensitivity
  - Several months for results
- Genetics consult

Does CPR Cause Rib Fractures?

- Pre-2005:
  - Feldman and Brewer (1984)
    - 113 children
    - Mostly civilian CPR
    - No fractures
  - Spevak and colleagues (1994)
    - 91 infants
    - Various CPR training
    - No fractures
  - Of over 900 children in the literature, only 3 had rib fractures; never posteriorly

2-handed CPR

- Since 2005, 2 handed CPR has become AHA standard- No published case of posterior rib fractures related to this
- *2010 Matshes and Lew (*Am J Forensic Med Pathol* 2010;31: 303-307) reported 5 cases of infant death with possible multiple acute anterolateral rib fx from 2 handed CPR.
- Literature analysis by Maguire et al, concluded that if they occur, they are anterior (see 2010 Matshes and 2009 Weber [Weber et al Forensic Science International 2009;189(1-3):75-81]) and not posterior.

2014 Franke,I et al

- 2-thumbs approach to CPR since 2000 in Germany
- German study of 3 children's hospitals
- All < 12 months with professional CPR over 10 yrs who had CXR
- Excluded infants with osteopenia, bone disease, abuse
- Independent review of CXRs – 80 infants; 39 had a f/u CXR after at least 10 days
- No rib fracture on any CXRs
- Conclusion – rib fractures should raise significant concerns about child abuse

Key references

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