Abusive Fractures in Children

KS CARE Training
September 29, 2022

Kerri Weeks MD, FAAP
Associate Professor, Child Abuse Pediatrics
University of Kansas School of Medicine-Wichita

Objectives

- Identify fractures that are high and low specificity for abuse in the context of a child’s developmental level
- Correlate proposed mechanisms of injury with fracture morphologies
- Identify medical conditions that predispose to easy fracture

Disclosures

- I have nothing to disclose
Fractures in Children: Epidemiology

- Fractures are common (8-12% of all pediatric injuries)
- Second most common injury caused by physical abuse
  - Bruises are most common
- Age and developmental level are important considerations
  - 80% of abusive fractures occur in children <18 months
  - 25%-56% of fx in children < 12 months due to abuse
  - Percent of fractures caused by abuse declines sharply as child begins to walk

What is Different About Children’s Bones?

- Greater plasticity- long bones can bow instead of break
- Metaphysis- site of maximal bone growth & weakest part of the bone
  - CMLs with shear forces
  - Buckle fracture with compression
- Periosteum is less adherent to cortex
  - More easily “stripped” from the cortex- subperiosteal hemorrhage and subsequent SPNB

Fractures in Children: Accidental vs Abusive

- Factors to consider:
  - No fracture is diagnostic of abuse
  - No fracture is diagnostic of accidental injury
  - Some fractures are highly specific for abuse
    - CML, posterior rib fractures
Accidental vs Abusive

- Consider:
  - Location: high or low specificity?
  - History: consistent, detailed, developmental stage fits the mechanism of injury
  - Biomechanics and fracture morphology
  - Severity: comminuted, displaced, angulated…
  - Past history of inflicted or multiple “accidental” injuries
  - Multiple fractures of differing ages
  - Non-osseous injuries
  - Consideration of other medical conditions

Biomechanics: Fracture Morphology and Loading Mechanisms

<table>
<thead>
<tr>
<th>Biomechanical Condition</th>
<th>Fracture Type</th>
</tr>
</thead>
<tbody>
<tr>
<td>Torsional loading:</td>
<td>Spiral/long oblique</td>
</tr>
<tr>
<td>Bending load:</td>
<td>Transverse/short oblique</td>
</tr>
<tr>
<td>Compressive loading:</td>
<td>Buckle/impaction</td>
</tr>
<tr>
<td>Tension and/or shear loading:</td>
<td>CML</td>
</tr>
<tr>
<td>High-energy event:</td>
<td>Open and/or comminuted</td>
</tr>
</tbody>
</table>
Fracture Specificity for Abuse

- High specificity
  - CMLs
  - Rib fractures, especially posteromedial
  - Scapular fractures
  - Spinous process fractures
  - Sternal fractures

Fracture Specificity for Abuse

- Moderate Specificity
  - Multiple fractures, especially bilateral
  - Fractures of different ages
  - Vertebral body fractures and subluxations
  - Digital fractures
  - Complex skull fractures

Fracture Specificity For Abuse

- Low Specificity
  - Subperiosteal new bone formation
  - Clavicular fractures
  - Long-bone shaft fractures
  - Linear skull fractures
High Specificity for Abuse: CML

- Classic Metaphyseal Lesion (CML)
  - Planar fractures through the primary spongiosa of the metaphysis.
  - Caused when torsional and tractional forces are applied across the metaphysis
    - Vigorous pull & twist of an infant’s extremity
    - Associated with AHT (flailing of the extremity)

Classic Metaphyseal Fractures

- Highly specific for abuse in infants
  - Most common in < 6 months old
  - Most common long bone fracture found in infants who die due to abuse
  - Associated with abusive head trauma

Classic Metaphyseal Fractures

- Acute injuries can be difficult to visualize radiographically
- Can appear “corner” or “bucket handle” depending on angle of the x-ray beam
- May require dedicated, coned down views
- May require multiple views and follow up to confirm
Classic Metaphyseal Fractures

- Common anatomic sites:
  - Distal femur, proximal tibia and fibula, proximal humerus, distal tibia and fibula
- Healing
  - Do not heal in same sequence as long bones
  - Sclerotic, widening, irregularity of metaphysis
  - Notoriously difficult to date
  - May resolve without residual x-ray findings in 4-8 weeks

High Specificity for Abuse: Ribs

- Rib Fractures
  - Most abusive rib fractures result from anterior-posterior compression of the chest.
  - Frequently found in infants who are held around the chest, squeezed, and shaken.

Rib Fractures

- Positive predictive value of rib fractures for child abuse in children younger than 3 years was 95% in one retrospective study.
- <1% of accidental fractures (rare even in MVAs)
- Other much less common causes include
  - Birth trauma
  - Maybe CPR (two-handed technique)
  - Minor trauma in infants who have increased bone fragility
- Always require an abuse evaluation!
Rib Fractures

- Often multiple: 5.9 rib fractures/child one series of abused children
- Often with other associated manifestations of abuse
- Often associated with AHT
- Presentation scenarios:
  - Occult incidental finding
  - Irritable with paradoxical crying (cries more with "rocking or bouncing to soothe")
  - Feel "pop" "crunch" in chest
  - Respiratory distress
  - Seldom overlying bruising

Rib Fracture Biomechanics

- Compression/Squeezing
  - Violent excessive force often associated with shaking
  - Anterior to posterior squeezing
    - Levering ribs on vertebral body and transverse process
    - Fractures located posterior-medial, posterior-lateral
- Direct Impact
  - Usually anterior, anterior to mid clavicular line
  - Rarely if ever due to CPR
    - Review of 770 children who received CPR—3 had rib fx, located in anterior mid-clavicular line

Other High Specificity Fractures

- Scapula
  - Rare from abuse or accidental injury
  - In abuse, associated with rib, spine, & clavicle fx + lung injury
  - If accidental, there will be a major verifiable traumatic event
- Spinous Process
- Sternum
  - 63% with other injuries ribs, pulmonary, cardiac
  - Abuse: direct high energy impact to mid chest with fist or object
  - Accidental: MVA, long falls
Fractures with Moderate Specificity for Abuse

- Vertebral
  - Uncommon in abuse or accidental except in a major trauma
  - Axial loading when forced into a sitting position
  - Forceful hyperflexion
  - Direct impact to spine
  - Most fractures at thoracolumbar junction then c-spine
- Hand and Foot Fractures
  - Infant or young child raises suspicion for abuse
  - In older child most commonly sports related

Low Specificity for Abuse

- Clavicle Fractures
  - Abuse:
    - Thrown or pushed falling onto lateral shoulder
    - Compression (thumbs during shaking)
    - In a study <12 months, 28.1% due to abuse
  - Accidental:
    - Birth trauma
    - Mobile child from direct fall laterally on shoulder
    - Indirect force by falling on outstretched arm
      - parachute reflex > 5 months

- Femur Fractures
  - <1 year old 60-70% are abusive
  - 28-35% of abused children with femur fx have other injuries (don’t forget to look)
  - Bruising associated with femur fx: 8%
Femur Fracture Presentation

- Infant (nonmobile)
  - Not moving, positioning leg
  - Cries with passive movement of leg
  - Thigh swollen
  - No mechanism of injury offered

- Child (mobile)
  - Refuses to bear weight
  - Accidental injury often includes a detail-rich history

Femur Fracture Biomechanics

- Abuse
  - Infant: torsion, twisting, bending-compression, levering
  - Spiral fracture not always diagnostic of abuse
    - High level of concern for abuse in nonmobile infants

- Accidental
  - Fall down steps
  - Fall from height with impact to knee (buckle fracture distal femur)
  - Run & trip/slip on a planted foot (spiral)

Low specificity: Humerus Fracture

- Accidental:
  - Older, mobile children (average 6.2 years)
  - Fall from play equipment (monkey bars, slides)
    - Fx upper extremity 90% of the time
    - 40% supracondylar fx of distal humerus

- Abuse:
  - <12 months humerus fractures: 43.1% due to abuse
  - 12-23 months: 6.9% due to abuse
  - 24-36 months: 1.6% due to abuse
Humerus Fracture Biomechanics

- Accidental falls
  - On flexed elbow or extended arm = supracondylar fracture
- Abuse
  - Yanking, whiplash of arm results in proximal CML
  - Bending/compression results in transverse fracture
  - Twisting/torsion of arm results in spiral fracture

Low specificity: Radius and Ulnar Fractures

- Abuse
  - Not from normal activity of nonmobile infant
  - Trauma by forceful levering, yanking, bending arm
  - Direct impact in “defense”, transverse fracture (older child)
- Accidental
  - Common in childhood, rare in infants that lack parachute reflex
  - Axial loading from fall on outstretched arm in child
  - Trauma event may be unobserved in a mobile child

Low specificity: Tibia and Fibula

- Abuse
  - Proximal and distal tibia common site for CMLs in infants
    - Torsion, jerking of extremity
  - Spiral or oblique non-displaced tibia fracture in non-ambulatory child
    - Violent twisting of lower extremity
Low specificity: Tibia and Fibula

Toddler’s Fracture
- Non-displaced spiral/oblique fracture
- Involves fall with a twist, often a trivial mechanism
- Trauma event seldom observed
- Presents unexplained limp or refusal to bear weight
- If not toddling, not a toddler’s fracture

Physiologic Periosteal Reaction
- Normal variant
- Mimic of SPNBF
- Bilaterally symmetrical
- Long bones
- Age 1-6 months
- On one side of shaft

Question:
- Which fracture is least likely to be abuse related? (choose one)
  - A. Proximal “corner fracture” of tibia in 10 month old
  - B. Subtle nondisplaced spiral fracture of distal tibia in an 18 month old
  - C. Femoral fracture in 7 month old
  - D. Posterior rib fracture in 4 month old
Question:

- Which fracture is least likely to be abuse related? (choose one)
  - A. Proximal “corner fracture” of tibia in 10 month old
  - B. Subtle nondisplaced spiral fracture of distal tibia in an 18 month old
  - C. Femoral fracture in 7 month old
  - D. Posterior rib fracture in 4 month old

Fractures: Imaging

- Skeletal Survey (SS)
  - Initial 15-21 views depending on size of child
  - Cone down and additional views PRN
  - Identify occult acute and healing fractures
  - Dating of skeletal injuries
  - May reveal signs of bone disease

  Reminder: DON’T FORGET the rest of the NAT workup!

Skeletal Survey (ACR recommendations)

- Skull (AP & lateral) 4 views if suspected skull fracture
- AP radii/ulnae
- C spine (AP & lateral)
- PA hands
- Lumbar spine (lateral)
- AP femurs
- Thorax (AP, lat, right and left oblique) including thorax and upper lumbar spine
- AP tibia/fibulae
- Pelvis, abdomen (AP) to include mid lumbar-sacral spine
- AP or PA feet
- AP humeri
Skeletal Survey Indications

- <2 years of age suspected/concern for abuse
  - Including abusive burns and siblings of abused kids
- 2-5 years of age case-by-case decision
  - Acute serious non-osseous injury
  - Special needs, nonverbal
  - 1+ known fracture suspected of being inflicted
- >5 years of age SS rarely indicated, selected views

- Review the films with the radiologist to look for osteopenia, misshapen bones, wormian bones, and other signs of disease. Discuss timing and healing process.

Follow-Up Limited Skeletal Survey

- Perform 2-3 weeks after initial skeletal survey
- Detect fractures not apparent on initial SS
- Clarify "possible/probably" fractures on initial SS
- Detect acute fractures occurring after initial SS
- More closely approximate age/dating of fracture(s)
- Views same as initial skeletal survey without skull, spine, abdomen, pelvis
- Reason for "limited" skeletal survey
  - Decrease radiation exposure
  - Low yield for finding "new fractures" in these areas

Laboratory Workup for Bone Health

- Calcium
- Phosphorus
- Alkaline phosphatase
- 25-hydroxy Vit D
- PTH

Normal lab does not exclude metabolic bone disease
AND
Abnormal lab does not always provide a reason for fracture
Differential Diagnosis Tips

- Most of these can be excluded by a good history and physical exam.
- You can have a condition that affects bone health AND be abused.
- If you come across a case with interesting complexities, contact your mentor. We can all learn from unusual cases.

Differential Diagnosis

Birth Trauma
- Large Baby 4 kg or more
- Difficult delivery
  - Shoulder dystocia, forceps, vacuum extraction, breech
- Most common sites:
  - Clavicle, long bone (humerus, maybe femur), rarely ribs, rarely skull. Possible CML from breech delivery

Osteopenia of Prematurity
- Born at less than 28 weeks or <1500 g
- >4 weeks TPN, BPD and/or prolonged course of steroids
- Osteopenia commonly presents between 6-12 weeks of life
- May have rib, long bone fractures
- Bone density normalizes after first year
- Preterm infants are also at a higher risk of abuse
Rickets

- Different than Vitamin D deficiency or insufficiency
- True rickets is uncommon
  - Characterized by demineralization, widening and irregularity of the physis, and fraying and cupping of metaphysis
  - Fractures occur in mobile children
- No difference in Vitamin D levels in young children with fractures suspicious for abuse vs accidental. Vitamin D insufficiency was not associated with multiple fractures or suspicious fractures.

Differential Diagnosis

- Osteomyelitis
  - In infants can present as multiple metaphyseal irregularities which can potentially resemble CML’s
  - Other signs of infection are present
- Disuse Osteopenia
  - Severe disability that limits or prevents ambulation can cause risk for fractures secondary to disuse demineralization, even with normal handling.
  - Usually diaphyseal fractures
  - Children with disabilities also at risk of being maltreated!

Differential Diagnosis: Rare

- Scurvy
  - Older infants and children who eat no foods containing Vitamin C
  - Can result in metaphyseal changes as well as other characteristic bony changes
- Copper deficiency
  - Severe nutritional deficiencies such as short gut syndrome
  - Bony changes as well as psychomotor retardation, hypotonia, hypopigmentation, pallor, anemia
Differential Diagnosis

- Menke's Disease
  - Rare congenital defect of copper metabolism
  - X-linked recessive, occurs only in boys
  - Metaphyseal fragmentation, sparse, kinky hair, wormian bones, failure to thrive, developmental delay

- Osteogenesis Imperfecta (OI)
  - Genetic disorder, has a lot of variability
  - Fractures are most commonly transverse in shafts of long bones.
  - Unusual to have rib fractures/CML’s

Characteristics of OI

- May have the following findings:
  - Poor linear growth
  - Macrocephaly
  - Triangular-shaped face
  - Blue sclerae
  - Hearing impairment as a result of otosclerosis
  - Hypoplastic, translucent, carious, late-erupting, or discolored teeth
  - Easy bruising
  - Inguinal and/or umbilical hernias
  - Limb deformities
  - Hyperextensible joints
  - Scoliosis and/or kyphosis
  - Wormian bones of the skull
  - Demineralized bones

Question:

Which of these children needs a skeletal survey?

- A. 20 month old with unexplained burn to feet
- B. 3 year old with bruising to face
- C. 4 year old with radius and ulna fractures from a fall
- D. 12 year old with multiple fractures from MVA
Question:

- Which of these children needs a skeletal survey?
  
- A. 20 month old with unexplained burn to feet
- B. 3 year old with bruising to face
- C. 4 year old with radius and ulna fractures from a fall
- D. 12 year old with multiple fractures from MVA

Key Points

- No fracture is diagnostic of abuse. History and mechanism are important.
- Nonmobile infants are at the highest risk
- Think about possible medical contributors to fracture
- Skeletal survey for children < 2yrs with concerns of physical abuse
- Don’t forget the remainder of the NAT workup
- If you have questions, call your mentor for help

References

- Anderst, J. Kellogg N. “Mechanisms of Injury in Childhood” 3D Modeling and Animation (Medical Version)