Metaphyseal and Rib Fractures in Child Abuse

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In real life, no one tells you that the topic of the patient presentation is child abuse.
Presentation of patient:

• 5 month old female presented to Children’s hospital with decreased mobility of her right lower extremity.

• The baby was visiting her father when she rolled off a bed.

• After she was returned to her mother, her aunt noticed that she was not using her leg and suggested bringing her to her doctor.

• Her mother called for an appointment several days later.
Plain films of right leg included the following:

- Fibula
- Tibia
- Talus
- Calcaneus
- Navicular

Case courtesy of Paul Kleinman, Children’s Hospital Boston
Look again:
Note the transverse radiolucencies running through the subphyseal regions of the metaphyses.
Skeletal survey also included the following:
Look again: Abnormal

Rib thickening due to callus pushing in pleural surface

Rib thickening due to callus accentuated by bronchus below
Osteosclerosis and sub-periosteal new bone formation are also signs of fracture healing.
Callus formation

Subperiosteal bone formation

Osteosclerosis

- All signs of fracture healing...
- Not consistent with new fractures
Conclusion based on Radiology Findings:

• Classic metaphyseal lesions NOT consistent with story of patient falling off bed

• Healing of old fractures NOT consistent with story of patient falling off bed

• Both quality and long-standing nature of fractures gave radiologists a high suspicion of child abuse in case of this 5 month old girl.
Child Abuse

Each Year

• 3 million reports to DSS
• 1 million substantiated
• 600,000 seriously harmed
• 2,000 die
Child Abuse

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• Psychological morbidity unmeasurable

Courtesy of Paul Kleinman
Why focus on skeletal injuries?

- Skeletal injuries not usually life threatening and usually heal well
- High diagnostic value
- Common findings in abused babies
- Skeletal survey is highly sensitive test for abuse

Skeletal injuries

Distribution of 165 inflicted fractures in 31 fatally abused children

• 64 Classic Metaphyseal Lesions

• 84 rib lesions
Highly specific bone findings

- Classic metaphyseal lesions*
- Rib fractures, especially posterior*
- Scapular fractures
- Spinous process fractures
- Sternal fractures

*also highly common, occur in almost all abused children

Classic metaphyseal lesions

Also know as “corner fractures” and “bucket-handle fractures”
Metaphyseal lesion that looks like a corner of the bone is fractured.

Metaphyseal lesion that looks like a bucket handle.

Now, remove from your vocabulary:

“corner fractures” and “bucket-handle fractures”
The appearance of a corner fracture or a bucket handle fracture depends on the angle of radiograph projection. But these are part of the same fragment which is in the shape of a disc or frisbee. We will therefore refer to this fracture as a Classic Metaphyseal Lesion.
Physis: Chondrocytes grow in zones of proliferation and hypertrophy and then calcify matrices between their columns in zone of provisional calcification.

(growth plate or epiphyseal plate)

Metaphysis: vascular channels invaded chondrocytes but intercolumnar calcification persists, eventually becoming mineralized osteoid.

(distal metaphysis = primary spongiosa)

Normal COJ

Subphyseal Metaphysis

COJ

Physis
hypertrophied chondrocytes

Physis Physiology

1. Chondrocytes proliferate and then enlarge in a columnar organization with a terminal chondrocyte at edge of physis.

2. Metaphyseal vasculature sends a signal to terminal chondrocyte which causes it to undergo a morphological change: cell begins to apoptose or somehow to be released.

3. Metaphyseal vasculature invades the lacuna of the changing chondrocyte.

Why the physis doesn’t disappear:

- Vascular invasion of chondrocyte lacunae is BALANCED by chondrocyte proliferation deep in the physis plate, distal to the COJ.

- Metaphyseal vasculature allows for extension of metaphysis into physis

- Epiphyseal vasculature allows for proliferation of chondrocytes from mother cell
Why the classic metaphyseal lesion forms in the distal metaphysis:

- The most vulnerable part of the bone in an infant is the distal metaphysis (aka primary spongiosa).
- Having no chondrocytes makes it weaker than physis.
- Fewer organized cells and less calcification makes it weaker than the more proximal parts of metaphysis or the rest of the bone.

Therefore, Classic Metaphyseal Lesions:

- Are planar fractures, not corners or rings
- Occur in the metaphysis, not the physis
- Are “virtually pathognomonic” for abuse
- Result from repeated torsional and shearing forces

Shearing and torsional forces which lead to CML’s:

The shape of the calcified segment below the CML

- Frisbee or disk-like
- Centrally the calcified segment is thin
- Peripherally the calcified segment is thicker

Why?
Why the CML is shaped like a frisbee:

- Thick subperiosteal bone collar surrounds the thin cartilage network of the distal metaphysis and the hypertrophied chondrocytes of the adjacent physis.
- Fractures therefore tend to cut under the bone collar.
- This produces the corner fracture appearance from a perspective tangential to the bone.


Normal COJ and CML shape

Bone Collar

Acute CML Changes

Subperiosteal bone collar

Calcified disc fragment: thin layer of primary spongiosa of metaphysis + zone of hypertrophic chondrocytes within the zone of provisional calcification + bone collar

The calcified portion of fractured segment:

1. Thin portion of metaphyseal primary spongiosa
2. Zone of provisional calcification with the hypertrophic chondrocytes of physis
3. Bone collar at the periphery of fragment

Courtesy of Paul Kleinman lecture
Radiographic alterations: acutely

- If no displacement of the fragment occurs, or if the angle of projection is oblique to the fracture, the radiographic image may look normal.

- If some degree of displacement occurs in the plane of the projection, transverse lucency is seen in the subphyseal region of metaphysis.

- Fracture line may be apparent in one projection and invisible in another.

Chronically, what happens?

- Metaphyseal vessels damaged
  - loss of signal that normally leads to morphologic death/differentiation of terminal chondrocyte.
- PERSISTENCE rather than DEMISE of terminal chondrocyte = osseous growth arrest
- Epiphyseal vessels undamaged = chondrocyte proliferation continues
- Abnormal survival of cells causes net increase in cell number present within cartilage column.
- Metaphysis does not invade physis column


Healing of Focal Metaphyseal Injury

1. Terminal chondrocytes persist ONLY in focally damaged columns where transformation into bone is blocked.

2. Damaged columns blocked from calcification

3. Uncalcified region extends into calcified region

Histologic view: Extension of metaphysis into normal hypertrophic chondrocytes

 Radiographic view: Focal Metaphyseal Radiolucencies (inconspicuous fx)

Healing of extensive metaphyseal injury

- Chondrocytes accumulate at COJ, resulting in increased thickness in zone of provisional calcification
- Fragment appears to thicken on radiograph
- Cessation of endochondral bone growth
- Diffuse widening of physis

Recall our patient:

Healing of an extensive metaphyseal injury led to diffuse widening of the calcified zone of the physis.

Courtesy of Paul Kleinman at Boston Children’s Hospital
The second major finding in our patient’s radiographs:

Hints of:

Rib Fractures
Why Get Images of Ribs in a Case involving a leg?

- Suspicion of abuse
- Central to radiologic diagnosis of abuse
- Usually rib fractures NOT suspected clinically
- 51% of fxs in fatally abused children involve ribs
- Posterior rib fractures are highly specific for child abuse (especially after ruling out metabolic disorders, skeletal dysplasias, and MVA’s)
- Therefore a skeletal survey of ribs is both sensitive and specific for child abuse

Let’s Review Anatomy:

- **Costo-chondral junction**
- **Rib Head**
- **Costo-transverse process articulation**
- **Rib Tubercle**
- **Transverse Process facet**

Rib Head Apophysis

Transverse Process Apophysis

Which parts of the ribs fracture most often in cases of abuse?

- Mostly rib head and rib neck
- In a study of 63 abused children, 87% of rib fractures were either at the head or the neck
- Fractures of rib head and neck are very rarely from any cause other than abuse or a severe motor vehicle accident


Rib head and neck fractures

• No fx visible on frontal projection

• Disruption of Ventral bone cortex at rib head (short arrows) and rib neck (long arrows) often difficult to visualize (>50%)

Mechanism of Rib Fracture

Thoracic compression with free posterior motion:

Mechanism of fracture

- Excessive leverage of rib over transverse process consistent with fracture features
- Classic type 1 lever:
  - Force on ventral portion of rib
  - Fulcrum at articulation between transverse process and rib
  - Loading (pull) on costovertebral articulation
- Costovertebral ligaments stronger than rib, so mechanical failure over point of fulcrum

• Front to back force with free posterior rib motion

• Excessive leverage over costo-transverse process fulcrum

• Fractures at maximal points of strain (ventral portion of rib at neck and head, dorsal portion elsewhere)

• Studies with rabbits support compression mech.
Rib Head fractures

- Extend from ventral cortex of rib into costo-osseous junction
- Conforms to growth plate fractures described by Salter and Harris
- Often not visible on frontal image if no displacement and fx oblique to plane of x-ray
- If visible, subtle verticle lucency at extreme medial aspect of rib
- Heal with fibrosis and increased osteoblastic activity, visible radiographically after several weeks

Right posterior ribs, third through eighth, show widening on frontal radiograph.

Right posterior rib, sixth, shows fracture callus at rib head.

Rib Neck Fractures

- Ventral surface fracture (location of maximal strain)
- Line through medullary cavity
- Reaches dorsal cortex

- In tact rib head cartilage (*)
- In tact rib tubercle cartilage (diamond)

Rib Neck Fracture Healing

Callus formation over rib neck

Rib Neck Fracture Healing

- Acute posterior rib neck fractures: right 4th, 5th, and 6th possible

- Callus indicating healing of rib fractures: right 4th, 5th, and 6th rib. (Also callus at inferior margins of left 6th and 7th)

Thoracic compression:

- Gripping is most common cause of compression
- Similar force vector and rib motion if infant slammed on face or hurled face forward at an immobile object, as rib arcs free to move posteriorly, causing excessive leverage

Review: Highly specific bone fractures

- Classic metaphyseal lesions
- Rib fractures, especially posteriorly at head and neck
- Scapular fractures
- Spinous process fractures
- Sternal fractures

Moderate specificity fractures

- Multiple fractures of different ages
- Epiphyseal separations (Salter fx of elbow where radial line does not intersect capitabulum)
- Vertebral body fractures (C2 pedicle fx of “Hangman’s”)
- Digital fractures (buckling of cortical bone)
- Skull fractures (occipital region fx, often ass. w/ soft tissue injury)

Common fractures with LOW specificity for child abuse

- Subperiosteal new bone formation
- Clavicular fractures
- Long bone shaft fractures (transverse or oblique/spiral—poor correlation shown between pattern of shaft fx and inflicted vs. accidental injury, although direct forces cause transverse fx and torsional forces cause oblique fx)
- Linear skull fractures

Protocol

- **Problem:** acutely most fx's very difficult to see on plain film
- **Solutions:**
  - Full skeletal surveys vs. specific bone film
  - Follow up surveys needed to see callus formation
  - Bone scans (nuclear medicine scintigraphy) needed to see fractures acutely
- **Rule out metabolic abnormalities and other causes**

Exact protocol depends on age of child and findings. Protocol decisions will not be addressed here.
Let’s now return to our patient

- Classic metaphyseal lesions consistent with repetitive torsional forces more than 1 week prior to exam

- Rib fractures consistent with compressional force more than 1 week prior to exam
What was the outcome for this 5 month old little baby?

- Social worker met with her mother.
- Child protection team consulted and reviewed her films.
- Department of social services met with her mother.
- Her mother disclosed a 2\textsuperscript{nd} fall from a bed a few weeks previously.
- DSS not satisfied with new explanation
- Child protection team ultimately went to court on the baby girl’s behalf.

Courtesy of Paul Kleinman, Boston Children’s Hospital
References

- Caffey J. Multiple factures in the long bones of infants suffering from chronic subdural hematoma. AJR 1946, 56:163-173.

*Reading maketh a full man, conference maketh a ready man, and writing an exact man.* -Bacon
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