The Skeletal Survey:
Radiographic Evaluation

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Introduction

• The Patient
• Child abuse
• What is a skeletal survey?
• Evaluation of the skeletal survey
  – Multiple types of fractures
    • Long bones
    • Rib fractures
• Bone Scintigraphy
• Differential Diagnosis
The Patient

- 5 wk old infant transferred from OSH for “breathing difficulties”
- PMHx: FT, C/S, no other hx provided
- SH: Lives at home with mother, father (mother’s boyfriend) and 1y/o brother, mother has an older child in DSS custody
- FH: non-contributory
  - At OSH: T:102.3, 86% RA
    - Sepsis workup started
    - CXR unremarkable
    - CT of head found bilateral subarachnoid and R intraparenchymal hemorrhages
      - 51A filed
  - At Children’s:
    - Afebrile, HR:170, BP:121/80, RR:51 O2 sat:100%
    - HEENT: PERRL but sluggish
    - Neuro: CN II-XII grossly intact, DTRs: Knees, Ankles 2+ bilat; downgoing toes
Child Abuse

• Accounts for approximately 1200 deaths/year in U.S.
  – About half occur among children younger than one year of age.
  – Incidence ranges from 15-42 per 1000 children

• Radiographically described by Caffey in 1946
  – Associated subdural hematomas with certain patterns of skeletal injury

• Kempe and Silverman assign skeletal radiological associations to describe the term “battered child syndrome” in 1962

• Currently child abuse constitutes multiple entities
  – Physical abuse
  – Sexual abuse
  – Emotional abuse
  – Child neglect

Skeletal Survey includes...

- AP and lateral views of the skull and chest
- Lateral views of spine
- AP views of pelvis, long bones of extremities and feet
- Posteroanterior oblique views of hands
- Additional views in at least 2 projects if there are any findings

Complete Skeletal Survey
Always do a complete skeletal survey

Not the imaging useful to evaluate and document child abuse

Indications for Skeletal Survey

• Absolute: Mandatory for all children younger that two years of age in whom child abuse is suspected

• Relative:
  – Any child younger than 12 months of age with a fracture
  – Any child with severe or extensive fractures
  – Any child with a history of having one or more fractures
  – A history in the child or family of “soft” or easily broken bones

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<td>Classic metaphyseal lesions (CML)</td>
<td>Multiple fractures, especially bilateral</td>
<td>Subperiosteal new bone formation</td>
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<td>Rib fractures, especially posterior</td>
<td>Fractures of different ages</td>
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Common Inflicted Fractures

• Largest study of inflicted fractures (429 fractures in 189 children) with signs of abuse showed on skeletal survey:
  – 50% had a single fracture
  – 21% two fractures
  – 12% three fractures
  – 17% >3 fractures

• Among single fractures, common location:
  – Femur (35%), humerus (29%), skull (16%)

• Long bone fractures:
  – 48% transverse, 26% spiral, 16% avulsion, 10% oblique

Diaphyseal Fractures

• Most common pattern
  – 60-80% of all femoral shaft fractures

• Two main types
  – Spiral
    • Torsional force on the limb
    • Worry in a child who is too young to walk
  – Transverse
    • Direct perpendicular blow to the shaft, most common type seen in abuse

Metaphyseal Fractures

- 11-18% of all long-bone fractures

- Classic metaphyseal lesion (CML)
  - “corner” or “bucket-handle” fracture
  - Occurs when the extremity is pulled or twisted forcibly or when shaken due to shearing that undercuts fragments of the metaphysis
  - Usually asymptomatic (pain with severe displacement)
  - See disruption as lucency
  - Looks “corner” viewed tangentially, looks “bucket-handle” when angulated

- Consists of a series of microfractures occurring in a planar fashion through immature portion of metaphyseal primary spongiosa (delicate trabeculae/calcified cartilaginous cores).

- Resultant fracture fragment encompasses two adjacent mineralized regions: the distal zone of hypertrophic chondrocytes of the physis and a thin portion of metaphyseal primary spongiosa

- As injury extends to the periphery of the bone, the fracture line passes toward the cortex away from the physis to cut across the subperiostal bone collar

- Radiographically see a transverse radiolucency in the subphyseal region of the metaphysis

Etiology of CML’s

Normal Bone

Metaphyseal fracture

Series of microfractures along metaphyseal spongiosa

Extension to the subperiostal bone collar

Our Patient’s Femur

AP Distal Femur X-ray

Corner Fracture

PACS, Children’s Hospital Boston
Our Patient’s knee

Fracture can look like a bucket handle or corner fracture depending on point of view

PACS, Children’s Hospital Boston
Rib Fractures

- PPV is 95% in age < 3yrs for posterior fractures

- Inflicted rib fractures
  - high risk of mortality
  - Due to degree of force to produce them
  - Produced by direct blows to the chest or during squeezing/shaking
  - Force caused by chest compression (CPR) of infants is not great enough to cause rib fractures

- Multiple sequential ribs (position of abuser’s fingers)

- 36% of rib fractures are visible on skeletal survey

- At times fractures are not apparent. Appear during the stage of callus formation 10-14 days after injury

Mechanism of Rib Injury

Normal rib anatomy

Anterior force pushes down causing thoracic compression

A

1. Costochondral junction
2. Transverse process
3. Rib head
4. Costal facet

A

1. Sternum depression causes fracture force against costochondral junction
2. Lever mechanism causes loading of force against fixed point leading to fracture

Patient’s Chest X-ray

AP Chest X-ray

Costochondral fracture of 7th rib

Multiple Posterior Fractures 4th-7th Ribs

PACS, Children’s Hospital Boston
Skull Fracture

- Direct force applied to the cranium

- Simple fractures could be accidental
  - Single fracture line either straight, jagged or curved

- Complex skull fractures suggestive of inflicted trauma
  - More than one fracture line
  - May have a branching pattern or stellate configuration

- Most common site of skull fractures whether accidental or inflicted is the parietal bone and usually it is a linear fracture

- If there is not a skull fracture, it does not rule out intracranial injury due to abuse. Obtain a CT/MRI to rule out any intracranial injury.

Our patient had a normal skull X-ray, so a head CT was done to rule out any hemorrhage.
Occipital fracture was found.
CT of Patient’s Head

Axial Head CT

Subarachnoid Hemorrhage
To further characterize the bleeding and to look for other signs of injury, a head MRI was performed.
MRI of Patient’s Head

Subdural hemorrhage

Subarachnoid hemorrhage

Intraventricular collection

PACS, Children’s Hospital Boston
Other Fractures

• Sternum, Scapula, and Pelvis fractures are suspicious for child abuse if they occur in the absence of a plausible history of high-energy injury

• Spinal
  – Most common is asymptomatic compression fracture due to forceful sitting
  – Hyperflexion or hyperextension during violent shaking produce a variety of fractures

Bone Scintigraphy

• Alternative to skeletal survey for the initial evaluation of possible fractures

• Advantages
  – More sensitive than plain radiography (25-50% more)
  – Can detect rib and costovertebral fractures
  – Recent non-displaced fractures
  – Early periosteal elevation

• Disadvantages
  – Less specific than plain films, with more false positives
  – Cannot detect skull fractures
  – Symmetrically located bilateral fractures may be overlooked
  – Cannot estimate age of fractures
  – Injuries near physis difficult to assess
  – Difficult to obtain on an emergency basis
  – Cost is about 300% higher
  – Requires sedation

• Currently used as an adjunct to the skeletal survey

Repeat Skeletal Survey

- Repeat skeletal survey two weeks after initial evaluation
  - Increases the diagnostic yield
  - Recommended in highly suspicious cases.
  - Detects additional fractures
  - Differentiates fractures from normal developmental variants
  - Date injuries
Repeat Skeletal Survey two weeks later

Fractures of 4th-7th rib still evident, Show signs of healing
Fracture age

I. Soft tissue changes (obliteration of the normal fat planes and muscle boundaries) secondary to hemorrhage or inflammation last for few days

II. Periosoteal new bone formation detectable on plain film radiographs only after it becomes calcified (usually 7-14 days)

III. Necrotic bone is reabsorbed, margins of the fractures lines become blurred and the fracture gap widens at 2-3 weeks after injury and is the only means of dating metaphyseal fractures

IV. Soft callus from production and calcification of osteoid follows

V. Hard callus (lamellar bone that bridges the fracture site, filling the fracture line) appears approximately 1 week after soft callus, completes at 3-6 wks after injury

Fractures in children

- Osteogenesis Imperfecta
- Congenital indifference to pain
- Myelodysplasia
- Osteomyelitis
- Congenital syphilis
- Rickets
- Scurvy
- Vitamin A intoxication
- Caffey’s disease
- Leukemia

- Prostaglandin E1 therapy
- Methotrexate Therapy
- Menkes’ syndrome
- Copper deficiency
- Metaphyseal and spondylometaphyseal dysplasia
- Accidental injury
- Obstetric injury
Osteogenesis Imperfecta (OI)

- Generalized disorder of connective tissue involving bone, skin, ligaments, fascia, sclera, and the auditory system

- Large phenotypic range
  - Four different subtypes

- Consider OI if skeletal survey or physical exam show the following
  - Significant or equivocal osteoporosis
  - Wormian bones
  - Blue sclerae
  - Abnormal skin texture
  - Hearing loss
  - Dentinogenesis imperfecta
  - Joint laxity

- Difficult to ascertain if abuse is also involved
  - Look for nonskeletal findings, CMLs, or multiphasic rib fractures to rule in abuse
Accidental Trauma

• Radiologically difficult to rule out
  – Necessary for a detailed description of events surrounding fracture
• Fall is usually the most common event offered to explain fracture
  – Fractures from crib/bed falls are unusual
    • Except for clavicle/skull fractures
• Certain fractures are noted to be accidents
  – Toddler’s fracture
    • Spiral fracture of tibia usually associated with the toddler “cruising” or walking
  – Midshaft humeral fracture
    • Rolling of infant from prone to supine by placing had under axilla leads to contralateral midshaft humeral fracture. Hear loud “snap”
Conclusions

• Skeletal survey is currently the diagnostic modality for documenting child abuse and should be done if there is a high clinical suspicion

• Certain fractures are hallmarks for abuse (CMLs, posterior rib fractures)

• Bone scintigraphy is currently adjunct radiographic image that can find fractures before evident on skeletal survey

• Other radiological modalities (CT/MRI) add more information especially for head and visceral trauma

• Differential diagnosis for fractures in children is extensive; history and physical exam are useful tools for initial evaluation
Our Patient

- The patient had multiple subdural, subarachnoid hemorrhages, and intrathecal bleeds and developed seizures which were controlled with phenobarbital.

- Found to have a duodenal hematoma w/ pancreatitis.

- Developed central diabetes insipidus.

- Father admitted to abuse of the child. Child was placed into DSS custody. At time of discharge, mother was considering giving up child for adoption.
References

• Caffey J. Multiple fractures in the long bones of infants suffering from chronic subdural hematoma. *American Journal of Roentgenology* 1946; 56:163-173
• Kempe et al. The battered-child syndrome. *Journal of American Medical Association* 1962; 181:105-112
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Questions?