Scope of the problem\textsuperscript{1,2}
U.S. Data since 2012

- According to US Department of Health and Human Services, 686,000 were maltreated in 2012
- 2014 study found that annual rate of confirmed cases of maltreatment dramatically understates the cumulative number of confirmed cases
- Birth to 1 year of age had highest rate of victimization and highest risk of fatality
- 1593 fatalities in the US in 2012

Common Imaging Findings

- Long bone fx - shaft & metaphyseal
- Rib fx
- Skull fx
- Subdural & subarachnoid hemorrhage
- Cerebral edema
- Visceral injury
Scintigraphy

• More sensitive than plain films for rib fractures
• Probably slightly more sensitive for detection of some other fractures
• Can detect fractures missed on plain radiographs
Scintigraphy - Limitations

- Higher radiation dose than skeletal survey
- Insensitive for skull fractures
Scintigraphy - Limitations

- Can’t help determine age or type of fracture
- More technically & professionally demanding
Scintigraphy – New Advances

- $^{18}$F-NaF PET – comparable dose but superior contrast and spatial resolution\(^1\)

The skeletal survey
(all: bone technique)

• AP thorax
• AP humeri
• AP forearms
• oblique hands
• AP feet
• AP femora
• AP tibiae
• AP & LAT skull
• AP pelvis

• LAT C-spine
• LAT thorax
• LAT L-spine

Skeletal Survey

- At least 2 views of any abnormality
- Do all of above even if post-mortem
Highly Specific Bone Injuries

- Classic metaphyseal lesion
- Posterior rib fractures
- Spinous process fx
- Sternal fractures
- Scapular fractures
Moderately Specific Bone Injuries

• Multiple fractures, especially if bilateral
• Fractures of different ages
• Vertebral body compression fractures
• Digital fractures
• Stellate skull fx
Common But Low Specificity

- Clavicular fracture – common birth injury
- Long bone shaft fracture
- Linear skull fracture
Classic Metaphyseal Lesion\(^1\)

- High specificity for abuse
- Also known as “corner” and “bucket-handle” fractures
- Most common around knee and ankle

\(^1\)Kleinman PK, Marks, SC, et al. AJR 1986; 146:895-905
CML

- Microfracture through the most immature bone - primary spongiosa – metaphysis
- Thicker collar of metaphyseal bone at periphery
Shaking Mechanism

- Child may be held around chest and shaken violently
- Due to rapid, forceful acceleration/deceleration
- Shearing forces - oriented perpendicular to long axis of bone
CML

- “Corner” fracture and “bucket-handle” fracture are different projections of the same fracture
• Look for lucent line that extends through the cortex
Healing of Metaphyseal Fractures

• Callus unusual - difficult to date
• Heal quickly (10 days to several weeks)
  – prompt radiography is ESSENTIAL
• The younger the infant, the quicker the healing
Rib Fracture

• Posterior fractures have high specificity for abuse
• All rib fractures are very suspicious
• Occur with chest compression, typically during violent shaking
• 35-60% of abused infants (<18 months)\textsuperscript{1,2}

\textsuperscript{1}Kleinman PK, Marks SC, et al. AJR 1995;165:647-650
• Lateral rib fracture – AP compression folds ribs, apex lateral
• Posterior rib fracture - posterior compression levers rib end over transverse process
  - Fx most pronounced at ventral cortex
  - Compression from posterior/impact necessary for fracture to occur
Rib Fractures

- AP chest relatively insensitive in acute setting\(^1\)
- Callus production (best at 7-14 days) aids visualization

\(^1\)Kleinman PK, Marks SC, et al. AJR 1988; 150:635-638
Rib Fractures

• To increase detection
  – Skeletal technique for chest film
  – Bone scintigraphy
  – Chest CT
  – Oblique chest films (bone technique)
    • consider as part of skeletal survey
  – Follow-up films in ≥ 7 days
Callus development aids visualization
Rib Fracture & CPR

• Posterior compression NOT a feature of CPR
• Experimental studies fail to reproduce posterior fractures with CPR or report their occurrence ¹-⁴

¹Kleinman PK, Schlesinger AE. Pediatr Radiol 1997; 27:87-91
²Feldman KW, Brewer DK. Pediatrics 1984; 73(3): 339-342
Rib Fractures

- Rib fractures (anterior and lateral) rarely seen after CPR in normally mineralized bones of infants & young children\(^1,2\)

Spine Injury

• Hyperflexion $\rightarrow$ anterior compression and superior endplate fractures at thoracolumbar junction$^1$

$^1$Kleinman PK & Marks SC, Invest Radiol 1992; 27: 715-722
Spine Injury

• Hyperflexion $\rightarrow$ distraction avulsion injury to interspinous ligament and spinous process cartilage$^1$
  
  $^1$Swischuk LE. Radiology 1969; 92:733-738

• Rarely spinous process fracture
  – high specificity
  – unusual
Spine Injury

- Spine fractures found in 0-3% of skeletal surveys for suspected abuse, but in 9.7% of positive skeletal surveys\(^1\)
- There is a correlation between spine injuries and intracranial injuries (10/14) \(^1\)

Long Bone Shaft Fracture

- MOST common fracture in abuse when all ages considered
  - Infants - metaphyseal, rib, & skull more common\(^1,2\)
- Not specific for abuse but suspicious in nonambulatory infants without convincing hx

\(^1\)Kleinman PK, Marks SC, et al. AJR 1995;165:647-650
Developmental Milestones

- 4 mos
- 5-6 mos
- 8-9 mos
- 15 mos
- 18 mos
- 24 mos
- 36 mos
- raises head 90°
- rolls over
- sits alone
- walks alone
- climbs stairs
- runs well
- alternates feet up stairs
Spiral fractures in nonambulatory infants

- Indicative of torsional force
- Most common sites: femur, humerus
Healing of Fractures

• No callus          fx < 14 days old  
• Callus              fx >  7 days old    
• These are general estimates and should not be thought of as fixed time frames, as healing & callus formation are a continuum 
• The younger the child, the faster the healing

Cranial Injury

- Leading cause morbidity & mortality
  - mortality peaks at 6 months
- Mechanisms – abusive head trauma
  - shaking
  - direct blow
  - strangulation / suffocation
- Shaking alone is sufficient to cause fatal CNS injury (somewhat controversial)
Cranial Injury

• In the first year of life\textsuperscript{1}
  – 64\% of all head injuries requiring admission or with positive CT findings are inflicted (excluding simple skull fracture)
  – 95\% of all serious head injuries are inflicted

\textsuperscript{1}Bilmire ME, Myers PA. Pediatrics 1985; 75: 340-342
Evaluation of Head Trauma

- **CT**
  - Acute setting
  - Polytrauma

- **MR**
  - Delayed presentation
  - Normal or equivocal CT with high suspicion
  - Better evaluation of fluid collections
  - More sensitive for shear injury
  - Follow-up
Cranial Injury

• Edema - most common, but non-specific
• Shear injury
  – grey-white junction
  – large WM tracks
• Cortical contusion or laceration
• Subdural and subarachnoid hemorrhage
  – worrisome for abuse
Cerebral Edema - Nonspecific

- Non-abuse-related
  - Near-drowning
  - Accidental head trauma

- When abuse-related, may be due to
  - Direct brain injury
  - Strangulation
  - Increased venous pressure from chest compression
  - Post-traumatic apnea

- Controversy – small amount of extra-axial blood can be seen with severe global hypoxia

The reversal sign\textsuperscript{1,2}
AKA the bright cerebellum sign

- Diffuse cortical and subcortical WM edema
- Basal ganglia, thalami, brainstem, and cerebellum retain normal attenuation and appear relatively bright
- Dismal prognosis - multicystic encephalomalacia, atrophy

\textsuperscript{1}Han BK, Towbin RB, et al. AJNR 1989 10: 1191-1198
\textsuperscript{2}Harwood-Nash DC. AJNR 1992; 13:569-575
Sequellae
Extra-axial Fluid

- SDH much more common in inflicted than in accidental trauma (79% vs. 7%)\textsuperscript{1}
- Subarachnoid fluid (benign) vs. subdural fluid (suggests abuse)
- Interhemispheric hemorrhage - very worrisome for abuse\textsuperscript{2}

\textsuperscript{1}Dashti SR, Decker DD, Razzaq A, Cohen AR. Pediatr Neurosurg. 1999 Dec;31(6):302-6
\textsuperscript{2}Zimmerman RA, Bilaniuk LT, et al. Radiology 1979; 130: 687-690
Mixed Density Subdural

Table 2 from Vezina G\(^1\)

<table>
<thead>
<tr>
<th>DDX</th>
<th>Mechanism</th>
<th>Estimated age</th>
<th>Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Coexistent acute and hyperacute</td>
<td>High-density acute and iso to low unclotted blood</td>
<td>Few hours</td>
<td>Single</td>
</tr>
<tr>
<td>Acute hematoma</td>
<td>High density acute hem</td>
<td>Hours-1 week</td>
<td>Single</td>
</tr>
<tr>
<td></td>
<td>or clot retraction and serum</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Coexistent acute hem and subdural hygroma</td>
<td>Hematohygroma (blood and CSF)</td>
<td>Hours-1 week</td>
<td>Single</td>
</tr>
<tr>
<td>Acute and chronic</td>
<td></td>
<td>&lt;1 week and</td>
<td>Multiple</td>
</tr>
<tr>
<td></td>
<td></td>
<td>&gt;2-3 weeks</td>
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\(^1\)Vezina G. Pediatr Radiol 2009;39:586-590
## Mixed Density Subdural

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Interhemispheric Extra-axial Hemorrhage

- Blood adjacent to falx - usually asymmetric and posterior
- Difficult to distinguish SAH from SDH in this location
- Violent shaking causes bridging veins to sagittal sinuses to be torn
Interhemispheric Extra-axial Hemorrhage

- Versus normal falx (which may appear relatively bright in the setting of diffuse cerebral edema)
  - Thicker than normal falx
  - Irregular thickness
  - Asymmetric thickness
  - Extension into a posterior convexity or tentorial SDH
Wide
Asymmetric
Continuity with posterior SDH
Extends over tentorium
Subdural Hemorrhage - Dating

- Can be hyperdense from hours to days
- Can resolve rapidly
- Can redistribute – first hours/days
- Chronic subdurals rare in infants
- Follow-up – look for evolution
- If there is clot and supernatant fluid, evaluate the clot.
## Evolution of Hemorrhage on CT

<table>
<thead>
<tr>
<th>Stage</th>
<th>Appearance</th>
<th>Estimation of age</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hyperacute</td>
<td>Isodense</td>
<td>&lt;3 hours</td>
</tr>
<tr>
<td>Acute</td>
<td>Hyperdense</td>
<td>Few hours to 7-10 days</td>
</tr>
<tr>
<td>Subacute</td>
<td>Isodense</td>
<td>2-3 weeks</td>
</tr>
<tr>
<td>Chronic</td>
<td>Hypodense</td>
<td>&gt;3 weeks</td>
</tr>
</tbody>
</table>

\(^1\text{Vezina G. Pediatr Radiol 2009;39:586-590}\)
Dating of Intracranial Blood

Bradley WG, Radiology 1993 189: 15

**Stage**
- hyperacute (<12-24 hrs)
- acute (1-3 days)
- early subacute (3-7 days)
- late subacute (1-2 wks)
- chronic (>2 wks)

**Form**
- oxy Hb
- deoxy Hb
- intracell met Hb
- extracell met Hb
- ferritin, hemosiderin, approaches CSF with time
<table>
<thead>
<tr>
<th>T1 MR</th>
<th>T2 MR</th>
</tr>
</thead>
<tbody>
<tr>
<td>• iso-low</td>
<td>• high (slightly)</td>
</tr>
<tr>
<td>• iso-low</td>
<td>• low</td>
</tr>
<tr>
<td>• high</td>
<td>• low</td>
</tr>
<tr>
<td>• high</td>
<td>• high</td>
</tr>
<tr>
<td>• iso &gt;&gt;&gt;&gt;&gt; low</td>
<td>• high in center</td>
</tr>
<tr>
<td></td>
<td>low in rim</td>
</tr>
</tbody>
</table>
Hemorrhage Dating by MR

• Above applies to intraparenchymal hemorrhage in adults
• Associated dural tear
  - Subdural fluid collections with different signal intensities are not necessarily of different ages.
  - If there is an associated dural tear on one side, the CSF mixing with the blood will alter the signal intensity
SDH’s of different signal - arachnoid tear
## Evolution of SDH on MR

<table>
<thead>
<tr>
<th>Stage</th>
<th>Hb breakdown prod/dist</th>
<th>Time</th>
<th>T1</th>
<th>T2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hyperacute</td>
<td>OxyHb/intracellular</td>
<td>&lt;12=24h</td>
<td>d or iso</td>
<td>b</td>
</tr>
<tr>
<td>Acute</td>
<td>Deoxy/intracellular</td>
<td>1-3 d</td>
<td>d or iso</td>
<td>d</td>
</tr>
<tr>
<td>Early sub</td>
<td>MetHb/intracellular</td>
<td>2-3d to 1-2w</td>
<td>b</td>
<td>d</td>
</tr>
<tr>
<td>Late sub</td>
<td>MetHb/extracell</td>
<td>1-2w to 1-2 m</td>
<td>b</td>
<td>b</td>
</tr>
<tr>
<td>Chronic</td>
<td>Hemosid (SD membrane)</td>
<td>Few w to mo/yr</td>
<td>iso</td>
<td>d</td>
</tr>
<tr>
<td>Chronic</td>
<td>Hemosid (SD content)</td>
<td>Few w to mo/yr</td>
<td>iso to d</td>
<td>d</td>
</tr>
</tbody>
</table>

Key: SD=subdural; iso=isointense; b=bright or hyperintense; d=dark or hypointense; h=hour; d=day; w=week, yr=year; sub=subacute

Rebleeding in a Chronic SDH

- Outer membrane itself shown to bleed frequently\(^1\)
- Elevated tissue plasminogen activator (TPA) found in chronic SDH fluid\(^1\)
- Little (if anything) in the literature to support a single, significant rebleed as cause of rapidly enlarging SDH\(^2\)
- Unlike adults, chronic subdurals are rare in infants because their brains are growing

\(^2\) Block RW. Curr Prob Pediatr 1999; 29: 258-263
Overshunting

Before

After
8m old boy: “unresponsive in high chair”

at admission

2 hours later
Spinal Cord Injury

- Cervical – associated with brain injuries; helpful adjunctive finding
- Hemorrhage in 9 of 11 abuse fatality autopsies in infants\(^1,2\)
  - Subarachnoid, subdural, epidural
  - 4 of 6 with ventral cord contusion
- Found in 36% of children under 36 mo evaluated for possible abusive head trauma who had MR of brain and cervical spine\(^3\)
  - Mostly ligamentous injuries

---

\(^1\) Hadley MN et al. Neurosurg 1989; 24: 536-540
Skull Fracture

- Overall, poorly correlated with CNS injury
  - Linear fx most common in NAT
  - 10-24% of all abuse cases have skull fx
  - Plain radiographs more sensitive than CT
  - Look at CT scout image

Skull Fracture

- Non-specific (though common) unless
  - Stellate / eggshell
  - Multiple
  - Diastatic (>3 mm)
Skull Fractures – Household Falls

- Falls
  - In 529 falls from heights up to 150 cm, 4 skull, 4 clavicle, 1 humerus (1.7% incidence) fractures and no significant neurologic injuries occurred
  - Conclusion: “household” falls rarely associated with fx, almost never with any intracranial injury

3 Lyons TJ, Oates RK. Pediatrics 1993;92:125-127
Household Falls

- Stairs - more injurious, though significant injuries usually single (not multiple body parts)

Visceral Injury

- Seen in all ages of abused children
- Usually blunt trauma - punch or kick to abdomen or rapid deceleration after being thrown
- 50% mortality rate of clinically apparent visceral injury
  - delay in seeking treatment
- Estimated to account for 12% of all abuse fatalities
  - 2-4% of all abusive injuries
Small Bowel

- Hematoma – proximal
- Perforation - distal
- Duodenal and prox jejunal hematoma most common abdominal injury
  - Most near ligament of Treitz
- Unexplained ascites
Small Bowel Hematoma

• Presents with pain, vomiting, sepsis (late)
• Plain film
  – +/- free air if perforation
• UGI
  – asymmetric, mural mass
  – coiled spring appearance
Small Bowel Hematoma
22 yo found unresponsive next to 6 storey building
Pancreas

- Probably compressed against spine with blunt trauma
- Laceration or pancreatitis
- Trauma is the most common cause of pancreatitis in children
- May develop pseudocysts
Pancreatic laceration
Hypoperfusion Complex

- Severe abdominal injury causes hemodynamic instability
- Imaging findings
  - Small caliber Aorta and IVC - intravascular volume depletion
  - Fluid-filled bowel with enhancing wall due to concentrated contrast in relief
  - Ascites
  - Intensely enhancing kidneys
Differential Diagnosis of Abuse Injuries

- Birth trauma - clavicle/humerus fractures, intracranial hemorrhage$^1$
- Dural venous sinus thrombosis
- Unsafe sleeping position (SIDS)
- Periosteal new bone formation
  - Normal variant in infants 2-8 mos of life
  - Single layer, smooth, symmetric
  - Femora, tibia, and humeri
- Periosteal reaction alone is not due to abuse (Ddx: scurvy, vit A intox, Caffey disease)

Birth Trauma
Dural Venous Sinus Thrombosis

- Ddx: Venous sinus thrombosis/venous infarct
- Associated with infection/dehydration
- MRV/CTV to exclude
Hemorrhagic venous infarcts
SSS thrombosis
Scurvy
Osteogenesis Imperfecta

- Multiple fractures
- Osteopenia
- Wormian bones in some
- Blue sclera in some
- Fibroblast culture diagnoses 90%
- Can never exclude this diagnosis, but should not have only abuse specific fractures
Rickets

- Widened irregular metaphyses
- Poorly defined zone of provisional calcification
- Osteopenia
- Knees and wrists most affected
- Rachitic rosary
Leukemia

- Metaphyseal lucent bands
- Well defined zone of provisional calcification
- Osteopenia
Causes of Bizarre-Appearing Fx

- Congenital insensitivity to pain
- Neuromuscular disorder, especially spinal dysraphism
• Radiologist often first to suspect

• Radiographic findings among the most specific and diagnostic

• Findings may be PIVOTAL to investigation and prosecution