Imaging Basics of Child Abuse

Nandish Shah, Medical Student¹
Eglal Shalaby-Rana, MD²
Dorothy Bulas, MD²

¹University of North Carolina at Chapel Hill, School of Medicine
²Department of Radiology, Children’s National Medical Center, Washington, DC
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Definition

“Child abuse is the portion of harm to children that results from human action that is proscribed, proximate, and preventable.”

Types of Abuse

- Neglect
- Emotional Abuse
- Sexual Abuse
- Physical Abuse
Physical Abuse

World Health Organization (WHO): Inflicting injury upon a child, such as burning, hitting, punching, shaking, kicking, beating or otherwise harming a child. The parent or caretaker may not have intended to hurt the child.

Data is limited due to lack of proper documentation. Thus, existing data is likely underestimating the extent of this problem.

Per a WHO study on child maltreatment around the world, 25-50% of all children report being physically abused depending on the country.

Every year, globally, there are an estimated 34,000 homicide deaths in children under 15.

- Infants and pre-school children are at greatest risk.
- Risk of fatal abuse is 2-3x higher in low and middle-income countries than in high-income ones.
- Most common cause of death is head injury. 2nd is abdominal injury.

Reasons for abuse being underreported:
1. Fear: children and family members are afraid to report a more powerful family member
2. Society accepts certain forms of physical abuse as ‘discipline’ or ‘punishment.’
3. Lack of trust in police system, social services, and other authority figures in a country

Neglect makes up 62.4% of confirmed cases\(^1\)
Physical abuse is second making up 17.5%\(^1\)
By the age of 1 year, approximately 1 in every 50 children suffers some form of abuse or neglect\(^2\)
Studies show a range of 1200 to 2000 deaths in children per year from physical abuse alone\(^3,4\)
- The youngest are at greatest risk for fatality in the U.S: about 45% are younger than the age of 1\(^1\)

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\(^3\)Lonergan et al. Radiographics 2003.

Physical Abuse—
Statistics in the US and UK

- Data is limited even for the US on the exact prevalence of abuse injuries in children.
- Based on data from the US and the UK, here are some statistics on the breakdown of injuries:
  - **Skeletal**: 35 to 88% (In one study, 66% had multiple fractures)
  - **CNS**: 12 to 24%
  - **Visceral**: 2 to 9%

Lane et al. *Pediatrics* 2009.
Role of Diagnostic Imaging

Three-fold:

1. Recognize characteristic lesions of physical abuse to support a diagnosis or raise suspicion
2. Serve as evidence of the mechanism and pattern of healing of injuries in a court of law
3. May help exclude a diagnosis of child abuse

Fractures are the second most common finding after cutaneous injury, such as bruises and contusions.\(^1\)

SKELETAL SURVEY is the primary radiological exam in cases of suspected child physical abuse.

Skeletal Survey

- Per the 2011 ACR-SPR guidelines, it is a ‘systematically performed series of radiographic images that encompasses the entire skeleton.’

- Per the 2009 AAP guidelines, **ALL** children < 2 years, where physical abuse is suspected, should have a skeletal survey done.

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Skeletal Survey Imaging

Whole body: Appendicular & Axial

- Axial
  - Ribs (AP, lateral, left and right obliques)
  - Pelvis (AP)
  - Lumbosacral spine (AP and lateral)
  - Cervical spine (AP and lateral)
  - Skull (AP and lateral)
- Appendicular
  - Humeri (AP), forearms (AP), hands (PA), femurs (AP), lower legs (AP), feet (AP)

Skeletal Survey

Lateral Cervical Spine

Lateral Skull
Note:
Normal physiologic periosteal reaction (arrows).
Skeletal Survey-Ribs

AP Ribs
Rib fractures are the most commonly missed on skeletal surveys so it is important to include oblique views of the chest.

Studies show that these views increase the sensitivity of detecting rib fractures by 17% and specificity by 7%.

Specificity of Fracture Locations of Abuse

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

**Moderate specificity**
- Multiple fractures, especially bilateral
- Fractures of different ages
- Epiphyseal separations
- Vertebral body fractures and subluxations
- Digital fractures
- Complex skull fractures

**Low specificity**
- Subperiosteal new bone formation
- Clavicular fractures
- Long bone shaft fractures
- Linear skull fractures

Common Fracture Patterns of Abuse

**Common**
- Multiple fractures (unsuspected and/or varying in age)
- Classic metaphyseal lesion (CML)*
- Multiple rib fractures*
- Diaphyseal fractures (non-ambulatory infant)
- Skull fractures
- Subperiosteal new bone formation

*Indicates high specificity for abuse

**Less Common**
- Spine
- Small bones of hands and feet
- Clavicular fractures
- Dislocations and epiphyseal separations

**Uncommon**
- Scapular fractures*
- Pelvic fractures
- Sternal fractures
- Facial and mandibular fractures

Clinical History

- While skeletal surveys are crucial in providing objective evidence, it is important to remember the significance of a good clinical history.
- Comparing the history given with the likely mechanism of injury is the first and most important clue to a diagnosis of non-accidental or abuse injuries.
Skeletal Injuries associated with Abuse

Classic Metaphyseal Lesion (CML)
Rib
Long Bone Diaphysis
Scapula
Spine
Classic Metaphyseal Lesion (CML)

- Term coined by Paul Kleinman, MD.
- Metaphyseal fracture is virtually pathognomonic of abuse.
- Series of microfractures in the primary spongiosa of bone, which is the most immature area of mineralized matrix in the growing metaphysis.
- Most common location is the lower extremities, especially the knees.
primary spongiosa
CML-Mechanism

- Precipitating force: shearing injury in a horizontal direction across the metaphysis.
- Thus, mechanism of injury:
  - Torque force on the extremity
  - Manual to-and-fro motion of the extremities
    - Example: shaking an infant by the feet or hands, or whiplash back-and-forth of extremities when child is held around chest
- **No outward sign of injury** is seen with CML.
When complete, it is a disk with a broad, thin center and a thick circumferential rim.

On radiography, the thicker rim is more visible and appears as a triangular fragment (commonly called a ‘corner fracture’).

CMLs may have the appearance of ‘bucket handles.’ On a view obtained through beam angulation, the subepiphyseal area of lucency goes all around giving the fragment a ‘bucket handle’ appearance.
Bucket handle fracture

Corner fracture
Rib Fractures

- In infants, they are strongly correlated with abuse because the mechanism of injury is specific.
- Acute rib fractures are difficult to visualize since fractures are often incomplete and nondisplaced, and/or in an area with multiple superimposed structures.
Rib Fractures-Mechanism

- Mechanism of injury:
  - Squeezing force from adult hands wrapped around an infant’s chest → **anterior-posterior compression of the ribs** → fractures of the posterior, lateral, and anterior aspects of the rib
Rib Fractures—Radiology

- They occur most commonly in the posterior and lateral aspects of the ribs.
- Also, they often occur in multiple ribs and are often bilateral.

- With healing, most fractures become more visible due to subperiosteal new bone and callus formation.
  - Thus, a follow-up skeletal survey 2 weeks after the initial increases sensitivity of initial study and should be considered when abuse is strongly suspected
  - Oblique views of the chest can also improve sensitivity of detecting rib fractures.
AP ribs

Left posterior oblique
CPR and Rib Fractures

- Unlike adults, CPR almost never causes fractures in infants.
  - One study showed that out of 446 infants who received CPR, 3 had CPR-related fractures. All 3 were of the anterior rib\(^1\).

- While posterior rib fractures can occur from CPR, they are rare.
  - Posterior rib fractures are **highly specific** for abuse.

\(^1\)Lonergan et al. Radiographics 2003.
Skeletal Fractures

- Long bone, diaphyseal fractures: can be transverse, oblique, or spiral
  - A spiral fracture is NOT specific for abuse
    - Common in ambulatory infants (e.g. spiral tibia fractures or "toddler’s fracture) and studies have shown accidental spiral fractures in nonambulatory infants.
    - Spiral fractures require torsional force as when infants are grabbed by the extremities and shaken. Thus, it is important to compare radiological findings with the clinical history given.

***Remember to compare radiologic findings with developmental stage of the child***
Humerus, spiral fracture -- Acute
Humerus, spiral fracture -- Healing
Other Skeletal Fractures

- Scapular fracture: although uncommon, it is highly specific for abuse, particularly when it occurs at the acromion
  - Mechanism: Shaking an infant → stretching of deltoid muscle → avulsion of acromion

- Spinal fracture: rare.
  - Mechanism: hyperflexion and hyperextension. Called an “axial loading injury” because patient is thrown down on a hard surface with the spine perpendicular to the surface
  - Imaging: manifest as compression deformities of the vertebral bodies (most commonly near the thoracolumbar junction)
  - “Hangman’s fracture”: severe fracture-dislocation of the C2 vertebral
Bilateral acromion and left clavicular fracture
Skull Fracture

- Account for 8-13% of fractures among all abused children and about one-third in abused children under the age of 2.¹
- Unlike sutures, fractures appear as linear or branching lucent areas with sharp margins.
- However, NO skull fracture pattern correlates highly with abuse.²
  - Fractures suggestive of abusive head trauma:
    - Multiple, bilateral, ones that cross suture lines¹,³
    - Fracture diastasis and asymmetric suture diastasis²,³

¹ Lonergan et al Radiographics 2003.
Complex skull fractures
Radiography is preferred over CT because fractures that are roughly parallel to the section orientation may be missed on CT.

Complete skull radiographic series includes 4 views:\(^1\):
- AP
- both lateral
- Towne view

\(^1\)Lonergan et al Radiographics 2003.
Stairway Falls

- Often offered as explanation for abusive head trauma
- Head injury is most commonly seen

- However, injury is mild to moderate because stairway falls, unlike free falls, have an initial fall of moderate impact followed by short, low impact falls down the remaining stairs
  - Linear, non-diastatic, frontal and parietal skull fractures, concussion, and brain contusion can be seen
  - Falls can result in severe injury if child falls down stairs from arms of an adult or while in a walker

- Injuries sustained must be compared to clinical history given
- Suspicion for abuse increases when there is more than one area of injury, such as a femur fracture and a skull fracture.

Linear, non-diastatic skull fracture
Follow-Up Skeletal Survey

- In a follow-up skeletal survey, skull, spine, and pelvic films can be omitted.
  - This is because studies show that the majority of additional fractures found are of the ribs and long bones of the extremities.

- Separate studies have shown that follow-up skeletal surveys provide additional information in 38% to 61% of cases regarding the age and number of fractures.

Zimmerman et al. Child Abuse and Neglect 2005
Harlan et al. Pediatr Radiol 2009
Follow-Up Skeletal Survey

Initial skeletal survey

Follow-up skeletal survey
13 days later
Follow-Up Skeletal Survey

Initial skeletal survey

Follow-up skeletal survey
13 days later
Dating of Fractures

- There is no consensus in the literature for the precise dating of fractures.
- Of note, an infant’s fractures heal faster than older children and adults.

As a general rule:\(^1\):
- Resolution of soft tissue swelling: 4-10 days
- Periosteal new bone formation: 10-14 days
- Soft callus formation: 14-21 days
- Hard callus formation: 21 to 42 days

\(^1\)Offiah et al *Pediatr Radiol* 2009.
Imaging Recommendations for Skeletal Injury

- O-24 months:
  - Skeletal survey
  - Follow-up skeletal survey (done 2 weeks later)

- > 2 years of age:
  - Skeletal survey at the discretion of examining pediatrician
  - Radiographs of individual sites of injury per clinical history and exam if physical abuse strongly suspected

CNS Injuries associated with Abuse

Subdural Hemorrhage
Subarachnoid Hemorrhage
Cerebral Edema and other Parenchymal Injury
Statistics

- In children under 2, non-accidental head injury, also known as abusive head trauma, accounts for 80% of deaths from head injury.

- In children under 1, 64% of all head injuries are a result of abuse.

- Abusive head trauma is the leading cause of morbidity and mortality in abused children.

Mechanism of abusive head trauma

- Biomechanics involve movement either by the child’s head, an object, or both.

- **Direct** injury: occurs when the head strikes a stationary object, vice versa, or both colliding.
  - Results in distortion or fracture of the skull, intracranial hemorrhage (ICH), and brain injury.

- **Indirect** injury: occurs when head is shaken causing sudden acceleration and deceleration of the brain relative to the skull.
  - Results in shearing strain between tissue interfaces → parenchymal brain injury, hemorrhage.

Skull Fracture

- The presence of a skull fracture is NOT predictive of intracranial injury.\textsuperscript{1}

- Often, in an infant, deformation of the skull injures the underlying brain and meninges without causing a fracture.\textsuperscript{2}

\textsuperscript{1}Fernando et al, Pedatr Radiol 2008.
\textsuperscript{2}Lonergan et al Radiographics 2003.
Intracranial Injury

- Most deaths from child abuse are secondary to intracranial injury, especially among infants.
- Subdural hemorrhage (SDH) and subarachnoid hemorrhage (SAH) are two common abusive, intracranial injuries.
  - SDH occurs due to tearing of the bridging cortical veins that bleed into the potential space between the dura mater and arachnoid membrane.
  - SAH occurs when vessels beneath the arachnoid membrane tear causing bleeding between the arachnoid membrane and pia mater.
In an acute setting, non-contrast head CT is the first study of choice when intracranial injury is suspected.

- On CT, SDH appears as a “crescent-shape” convexity.
  - High attenuation when acute hemorrhage; becomes isoattenuating relative to brain and then hypoattenuating as the SDH ages over days to weeks.
- CT contrast enhancement can show membranes which would suggest that a SDH is a week or more old.
CT images of subdural hemorrhages
MRI is superior to CT for differentiation of hypoattenuating SDH and cerebrospinal fluid (CSF), and for the detection of small, extraaxial fluid collections.

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<th>T1</th>
<th>T2</th>
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<tr>
<td>Acute SDH (1-3 d)</td>
<td>Iso- to hypo-intense</td>
<td>Hypo-intense</td>
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<td>Subacute SDH (3-7d)</td>
<td>Hyper-intense</td>
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<td>Late SDH (8-14d)</td>
<td>Hyper-intense</td>
<td>Hyper-intense</td>
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<tr>
<td>SDH &gt; 14d old</td>
<td>Iso- to hypo-intense</td>
<td>Hypo-intense</td>
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Late Subdural

Regional Societies

Founding Societies
Ultrasound can be used on infants with open fontanels to differentiate benign enlarged subarachnoid space (BESS) from SDH in developmentally normal infants with macrocephaly.

BESS is a self-limiting, transient condition in which there is symmetric, diffuse enlargement of the subarachnoid space likely from a communicating hydrocephalus.

On US:
- BESS: multiple cortical veins in the subarachnoid space in anechoic fluid
- SDH: few or no cortical veins in a variable echogenicity fluid; sometimes, a thickened inner membrane
Difficult to differentiate the first few months of life.

Common characteristics of birth trauma include:\footnote{Fernando et al. Pedatr Radiol 2008.}
- lack of presenting symptoms or significant sequelae
- resolution of subdural hematoma by 6 weeks of age
- indistinct appearance of skull fracture by 2 months of age
- resolution of skull fracture by 6 months of age
Brain Parenchymal Injury

- Cerebral edema
  - Most common
  - Can be global, localized to a vascular territory, or focal.
  - May be a manifestation of primary, blunt impact or a hypoxic ischemic encephalopathy

- Shear injury
  - Occurs at the gray-white junction
  - Also called axonal injury and can be focal or diffuse
    - Diffuse axonal injury is a devastating consequence of abusive head trauma

- Contusion
  - A focal hemorrhage within the brain parenchyma
  - Frontal and temporal lobe locations common
Cerebral Edema

CT Day 1 post-abuse. Early cerebral edema with decreased grey – white contrast. Also left anterior SDH.

CT Day 2 post-abuse. Severe edema and swelling with “reversal sign” (white matter denser than grey matter). SDH in the anterior interhemispheric fissure.
Cerebral Edema

MRI-Axial T2-Normal

MRI-Axial T2-5 days post-abuse. Diffuse cortical cerebral edema seen by the loss of grey-white matter contrast.
Visceral Injuries associated with Abuse

Solid organ laceration, transection
Bowel hematoma, perforation
Thoracic injuries
Second most common cause of death from abuse

Recent data shows mortality rates from visceral injury at 13-30%.\(^1\)

\(^1\)Hilmes et al *Pediatr Radiol* 2011.
Imaging Recommendations for Thoraco-abdominal Trauma

1. Helical CT of abdomen and/or thorax with IV contrast

2. US of abdomen, usually as a follow-up

3. Upper GI series as needed

Normal CT Abdomen
Liver Injury

- One recent study found the liver to be the most commonly injured abdominal organ\(^1\)

\(^1\)Hilmes et al Pediatr Radiol 2011.
Pancreatic Injury

- In children, trauma is the leading cause of pancreatic injury.
  - About one-third of all posttraumatic pancreatitis in children is abuse-related.¹

- Pancreatic injury includes: pancreatitis, hemorrhage, and contusion, which can all result in pseudocyst formation.
  - Among infants and preschool children, any pancreatic injury is more likely to be inflicted than accidental.

¹Lonergan et al Radiographics 2003.
Pancreatic Injury-Radiology

- Children present with abdominal pain, vomiting, fever, and elevated serum amylase.

- CT and US can show pancreatitis and pseudocyst, but CT is superior
  - US: Shows an enlarged, hypoechoic pancreas.
  - CT: Pancreas is hypo-attenuating. Extapancreatic fluid is the most common imaging finding.

- Interestingly, pancreatitis associated with child abuse may lead to widespread intramedullary necrosis of bone manifested by multifocal, lytic skeletal lesions.

- Pancreatic transection can also be observed on imaging of abusive injury.
Pancreatic Laceration

Pancreatic Transection

Normal
Bowel Injury

- Most common hollow organ injury in the abdomen is the small bowel
  - Injury usually occurs in the duodenum and proximal jejunum.
    - Rich vascular supply of duodenum $\rightarrow$ hematomas
    - Fixed position of the jejunum $\rightarrow$ perforation

- Blunt impact and acute deceleration of the abdomen cause these injuries
Bowel Injury - Radiology

- **Hematoma:**
  - Child presents with pain and vomiting
  - Upper GI series will show a submucosal mass, often at the descending duodenum
    - Also shows strictures in the small bowel due to injury
  - On CT, it is a high attenuation mural mass that diminishes over time
  - On US, mass starts as hyperechoic and become hypoechoic over days to weeks.
CT of duodenal hematoma
Bowel Injury-Radiology

- Perforation
  - Child presents with pain and fever
  - Plain radiography and CT may show free intraperitoneal air, which is highly specific for bowel perforation. However, it is only seen about one-third of the time with perforations
  - Free fluid (ascites) is the most common finding on CT
    - It occurs due to bleeding or peritonitis.
Free intraperitoneal air

Free intraperitoneal fluid (ascites)

Free intraperitoneal fluid (ascites)
Other Visceral Injuries

- Lacerations, contusion, and rupture can occur in the stomach, liver, spleen, adrenal gland, kidney, colon.
  - Children often present with nonspecific abdominal symptoms.

- Thorax: lung contusion, pneumothorax, pleural effusion, hemothorax, and cardiac laceration have been observed secondary to abuse.

- Traumatic perforation of the pharynx has been reported as well
  - Chest and neck radiographs, water-soluble contrast studies, and CT scans aid in its diagnosis.
Differential Diagnosis
Regional Societies

Founding Societies

Osteogenesis Imperfecta (OI)

- Generalized disorder of connective tissue
- 4 types of which I and IV are mild enough to be confused with abuse
- Major clinical findings:
  - blue sclerae
  - abnormal skin texture
  - hearing loss
  - joint laxity
  - dentinogenesis imperfecta
Findings primarily via plain films

Essential to the diagnosis is the finding of demineralization in the axial and appendicular skeleton

Sometimes find bowing (long bone angulation), especially in weight-bearing areas

Excessive wormian bones (> 10)
Unlike the corner and bucket-handle CML fractures seen in abuse, long bone fractures in OI are typically metadiaphyseal in nature.

Rib fractures are rare in OI.

- Rib fractures here are singular occurrences unlike the multiple, same location, and bilateral fractures seen in abuse.

Even mild cases of OI show excessive wormian bones and some demineralization.
1st: Skeletal survey in patient suspected of being physically abused
2nd: If demineralization found on radiographs, collect thorough family history and conduct physical exam to assess for clinical findings of OI
3rd: If physical exam is negative, obtain blood test specific for OI
4th: If test is negative, patient most likely does not have OI
It is important to remember that the fractures associated with OI occur with minimal trauma.

It is important to always compare radiographic findings with the clinical history given to decide whether to pursue a workup for OI.
Osteogenesis Imperfecta
OI—Bowing of long bones; also notice the osteopenia and thin bones.
Rickets

- Similar to cases of abuse, one can see metaphyseal irregularity and subperiosteal new bone formation
- Unlike abuse, see decreased bone density, and poor definition and fraying of long bone metaphyses
- Acute and healing fractures may be present, but will have underlying features of rickets
Other Diseases mimicking Skeletal Injuries of Abuse

- Spinal dysraphism
  - Acute fractures appear like CMLs, but often happen only in the lower extremities.
    - Closer inspection usually reveals the fractures are of Salter-Harris type II variety

- Osteomyelitis
  - Metaphyseal lesions seen, but the lucencies are less well-defined and corner fractures are not present
  - Over time, bone destruction can be seen in cases of osteomyelitis unlike in abuse
Other Diseases mimicking Skeletal Injuries of Abuse

- Congenital syphilis
- Scurvy
- Caffey’s Disease
- Leukemia
- Menkes’ Syndrome
- Inherited bone dysplasias
Obstetric Trauma mimicking Skeletal Injuries of Abuse

- Clavicle is the most common site of obstetric fracture, especially in the middle third.
  - Callus formation is rapid in young infants; if no callus on radiographs by 11 days of age, birth injury is excluded

- Humerus is the most commonly fractured long bone
  - Long bone fractures usually only occur with breech and difficult vaginal deliveries

- Obstetric rib fractures have been reported in large babies undergoing difficult vaginal delivery
  - Unlike cases of abuse, will see signs of trauma, such as cephalohematoma, bruising, swelling, and crepitus
Normal Variants mimicking Skeletal Injuries of Abuse

- **Metaphyseal**
  - Step-off
  - Spur
  - Beak
- **Diaphyseal**
  - Nutrient canals
  - Cortical irregularity
- **Rib**
  - Ossification defect
  - Posterior synostosis
  - Lateral Notch
Metaphyseal Spur

Initial

2 week follow-up (No change unlike corner metaphyseal fracture)
Mimics of CNS Injuries of Abuse

- Accidental trauma
- Coagulopathies
- Meningitis
- Glutaric aciduria type I
  - Can cause SDH, and retinal hemorrhages
  - Also see macrocephaly, seizures, motor delay, and mental retardation
- Hemophagocytic Lymphohistiocytosis
  - Retinal hemorrhage seen is not typical of that seen in nonaccidental trauma. Can also see SDH
  - Clinical manifestations differ greatly from abuse. Includes hepatomegaly, fever, and coagulopathy

Mimics of Visceral Injuries of Abuse

Accidental injury involves high energy impact
- MVA
- Lap belts
- Handle bars
- Long falls
References

References