Fractures

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Deformation

- Deformation is one of the possible effects of a force acting on a body; the other effect of force acting on a body is acceleration (like in the classic physics equations)
- Factors influencing deformation are strength, elasticity, and geometry of object
- Deformation permanent once elastic limit of object is reached
- When deformation exceeds ultimate failure point, mechanical failure of structure results (fracture, in our case)
Properties of mature vs immature bones

- Adult cortical bone strongest in compression, weaker in tension, weakest in shear loading
- Immature bone weakest in compression
  - An edge effect exists in the transition from cortex to metaphysis, making the metaphysis more susceptible to failure in compression

Mechanical properties of mature and immature bone

- Children’s bones have lower mineral content than adult bone, and are more elastic, but less stiff
- Children’s bones can absorb relatively more energy before permanent deformation and fracture occurs
- Explains some fractures that are unique to children (i.e., greenstick, buckle (torus) fractures)

What is a fracture?

- A fracture is a disruption in the bone due to externally applied forces
- Fractures have multiple configurations which can give important information about the type of force causing the fracture
- Understanding this relationship between type of force and fracture type can permit an experienced clinician to determine whether the fracture history is consistent with the injury
- Bruises are often not present at the fracture site because many fractures occur via indirect forces

Evaluation of fractures

- There is no single fracture type which is diagnostic of abuse
  - Rib, metaphyseal fractures highly associated with abuse
- Diagnosis of abuse depends upon age and developmental ability of child, along with history of injury
  - When fractures occur in a child who is not ambulatory (able to get around on their own), there is a heightened suspicion for abuse in the absence of a plausible explanation for the injury

Screening for skeletal trauma

Skeletal survey
- detects occult skeletal injury
- includes all extremities individually, hands and feet, 2 views of the chest/spine, 2 views of the skull
- Recommended for all infants < 2 years old
- used occasionally in children 2-5 and not indicated over 5 years old
- One x-ray of the entire body is not sufficient for diagnosis of fractures
Bone structure, illustrated

Bone has a complex structure composed of compact bone, spongy bone, marrow, and periosteum. The periosteum is a thin membrane overlying the bone which contains blood vessels and nerves. When a bone is fractured, there is disruption of the periosteum which causes bleeding into the area surrounding the fracture, and severe pain at the fracture site.


Fracture types which are very highly associated with abuse

Metaphyseal fractures

These are subtle fractures which can be overlooked by a non-pediatric physician, as they occur in the non-calcified portion of a developing bone and do not show up well on x-ray. Two can be seen on the x-ray to the right; the white arrow shows a fracture which appears to be a "bucket handle" above the proximal end of the tibia (bone in the lower leg, just below the knee), and the black arrow indicates a fracture which appears to be a chip off of the distal tibia (bone in the lower leg, just above the ankle). Despite the different appearances, these are both metaphyseal fractures.

Metaphyseal fractures are seen most often in abused children, and rarely occur accidentally, which is why they have a high specificity for abuse. They occur when pulling or twisting forces are applied to the involved arm or leg; they can also occur as a result of a direct blow. They could occur accidentally if a child's arm or leg is trapped while someone forcefully pulls the child.

Thackeray et al. The classic metaphyseal lesion and traumatic injury. Pediatr Radiol 2016;Feb 22 [Epub ahead of print]

Rib fractures

Rib fractures in infants most frequently occur as a result of abusive injury, which is why they are highly specific for abuse. Forceful compression of the ribcage causes fractures at the lateral (at the sides) and posterior (along the spine) ribcage. Blunt trauma to the ribcage can also result in a rib fracture, but the location varies when fractures are caused by a direct blow to the chest. Although rib fractures could rarely be caused by an accident, they are almost always inflicted when seen in an infant.

Illustration of how compressive forces deform the ribcage

In the above schematic diagram of a cross-section of a chest, the dashed lines represent the uncompressed ribcage. With compressive forces (represented by solid lines), the ribcage bends outward at the sides. The ribs are also forcibly pushed against the bones of the vertebral bodies, which protect the spinal cord. In this way, it can be seen that fractures occur laterally and posteriorly with ribcage compression.

In this cross-sectional CT image, multiple rib fractures can be seen. In the upper right corner of the image (black arrow), a healing rib fracture with soft callus (new bone) formation is seen. An acute (new) rib fracture is seen at the bottom of the image (black arrow). A rib fracture in an advanced state of healing can be seen on the left (aqua arrow).


Difficulty with recognition of acute rib fractures is illustrated by these x-rays of the same child at two different points in time. Although rib fractures are suspected at multiple areas, the true extent of fractures cannot be detected until two weeks later, when an x-ray reveals multiple areas of callus (new bone) formation.

4 month old infant with multiple fractures of varying ages

The small white arrow at the top of the x-ray points to subperiosteal new bone formation at the distal femur. The large white arrow indicates a healing fracture at the midshaft of the tibia, which is healing with callus formation.

Dating fractures

- Can obtain general time ranges for long bone fractures by looking at x-rays
  - e.g., few days; approximately 2 weeks; several weeks old; exception is metaphyseal fractures
- Cannot distinguish specific times from review of x-rays
  - For example, there is no way to determine whether a fracture occurred on Tuesday at 6 vs Thursday at 12 by looking at x-rays
- More precise injury timing can be obtained by finding out information regarding onset of symptoms

Dating fractures

- General timing information comes from looking at stage of fracture on radiograph
  - Subperiosteal new bone formation [SPNBF] (10-14 days)*
  - Loss of fracture line definition (14-21 days)
  - Soft callus formation (15-21 days)
  - Hard callus formation (21-42 days)
  - Remodeling (at least 3 months)

*Timeframes given are the early or peak timeframes associated with that stage of injury healing, and are not meant to be exact

What are fracture symptoms?

- Pain with movement or manipulation of the involved area
  - e.g., inconsolable crying with diaper changes or attempts to dress a child with femur fracture
  - Increased fussiness when picked up, crepitus (crackling under skin) of chest wall specific for rib fracture
- Onset of pain is immediately after fracture, so a careful history can provide information about when fracture occurred
- Child may be able to sleep after a fracture has occurred, but the parent usually describes a restless sleep with frequent awakening/cries as the injured area is moved during sleep

Case history

- 2 year old went out for dinner with parents and 4 year old brother
- Restaurant was busy, children and parents walked outside to wait for table
- Children started playing “WWE”, and 4 year old sat on 2 year old and twisted his leg
- Parents heard “pop”, 2 year old started screaming, could no longer bear weight on leg

Spiral fracture

When evaluated in the Emergency Department, this spiral fracture of the femur (thighbone) was found. This type of fracture occurs with torsion (twisting) of the affected arm or leg. Conventional wisdom is that spiral fractures are always abusive, because they involve twisting force, but in this instance, the injury was accidental in nature. When a child is old enough to get around on their own and independently engage in activities, they can sustain injuries on their own, and may even hurt themselves during a fall which is not witnessed by caregivers.

Case history

- 2 month old brought to hospital this morning by his babysitter, who was concerned about child not moving arm
- This morning was the first time babysitter had seen child in two days
- Parents told babysitter that child had not moved his arm in past 24 hours
- Babysitter stated that parents did not provide history of injury
Oblique fracture
This fracture was seen when the infant’s arm was x-rayed. An oblique fracture is caused by a complex combination of forces, usually bending with compression, or bending with torsion (twisting). Snatching an infant by the arm could lead to this fracture. Grabbing a falling infant by the arm or leg in an attempt to keep the baby from striking the floor could also cause such an injury.

Vertebral compression fracture
Vertebral compression fractures are disruptions of the vertebral body (the anterior part of the bones protecting the spinal cord; see arrow in figure) which cause flattening of these normally tall bones. This type of fracture is caused by axial loading forces on the spine (severe forces which transmit vertically along the spine). Axial loading occur when a child is slammed onto their buttocks against an unyielding surface (e.g., furniture or floor). These injuries can occur through accidental means, generally in ambulatory children. A plausible accidental history could be a fall from playground equipment in which a child lands on their buttocks.

Linear skull fractures – often accidental, but not always

Complex skull fracture – high force trauma

Differential diagnosis of skeletal trauma
• Obstetric trauma
  – Clavicle fracture common, humerus or femur fracture less common, rib fracture rare
• Osteopenia of prematurity
• Nutritional deficiency
• Metabolic disease
• Infection
• Neuromuscular defects
• Skeletal dysplasia
  – Osteogenesis imperfecta
  – Hypophosphatasia
  – Osteopetrosis

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