Principle of Fracture in Children
Biomechanical Considerations

- The bones of children are less mineralized and have more vasular channels than adults bones.
- Lower modulus of elasticity.
- Lower bending strength.
- Greater energy absorption before failure.
- Capacity for plastic deformation.
stress

strain

Stiffness

Elastic

Plastic

Breaking point
strain

stress

Adult’s bone

Child’s bone

strain
Torsional load
Adult's bone
Child’s bone

Bending force

Plastic deformation
Anatomic Considerations

- Growth plates
- Epiphysis forms a secondary center of ossification
- Apophysis is a secondary growth center at a site of tendon attachment
- Periosteum
  Cambium or osteogenic layer
  Outer fibrous layer
Epiphysis
(Secondary ossification center)

Physeal plate

Metaphysis

Diaphysis
Epiphysis
Provisional calcification

Resting cartilage

Proliferating cartilage

Hypertrophic cartilage

Provisional calcification

Metaphysis

Primary spongiosa --> Secondary spongiosa
The chondrocytes of the physis are divided into a system of zones based on different stages of maturation in the endochondral sequence of ossification and their function.
Reserve/resting zone

• This zone is immediately adjacent of the epiphysis. It consists of irregularly scattered chondrocytes with low rates of proliferation. This layer supplies developing cartilage cells and stores necessary materials (lipids, glycogen, proteoglycan aggregates) for later growth.

• Injury to this layer results in cessation of growth.
Proliferative zone

- Chondrocytes are flattened and stacked upon each other in well-defined columns.
- These cells produce necessary matrix and are responsible for longitudinal growth of the bone via active cell division.
Hypertrophic zone

• This zone is divided into maturation, degeneration, and provisional calcification zones.

• Cells increase in size, accumulate calcium within their mitochondria, and deteriorate, ultimately leading to cell death.

• Upon their death, calcium is released from matrix vesicles, impregnating the matrix with calcium salt.
• The calcification of the matrix is necessary for invasion of metaphyseal blood vessels, destruction of cartilage cells, and the formation of bone along the walls of the calcified cartilage matrix.

• No active growth occurs in this layer; columns of cells extending toward the metaphysis are at various stages of maturation. This is the weakest portion of the physis and is commonly a site of fracture or alteration (eg, widening, as in rickets).
Groove of Ranvier and Perichondrial ring (of Lacroix)

- The periphery of the physis consists of two elements: the \textit{groove of Ranvier} and the \textit{perichondrial ring (of Lacroix)}. The groove of Ranvier is a wedge-shaped zone of cells contiguous with the epiphysis at the periphery. It supplies chondrocytes to the periphery of the physis, enabling lateral growth or increased width of the physis.
The perichondrial ring is a dense fibrous ring that surrounds the physis and is critical to the overall stability of the growth plate. The perichondrial ring's stabilizing effect may be lost in pathological conditions such as slipped capital femoral epiphysis (SCFE).
Apophysis

Medial epicondyle avulsion fracture
Role of periosteum

Periosteal hinge

Longitudinal section of periosteum
No periosteal hinge

Transverse section of periosteum
Secondary ossification center of elbow joint
First 6 months
12 months
- capitellum
24 months
- ossification center of lateral condyle extends into the lateral crista of trochlea
5 - 6 years of age
- medial epicondyle
- radial head
6 - 8 years of age
- olecarnon
9 years of age
- trochlea
10 - 12 years of age
- lateral epicondyle
In fusion process
Fat pads
Teardrop and anterior humeral line
Physiologic Considerations

- More rapid fracture healing than adults
- Potential for bone remodeling and overgrowth after fracture
- Nonunion is rare
Bone healing and remodeling
Phase of bone healing
**IMPACT**

From energy absorption to failure of bone

**INDUCTION**

From formation of fracture hematoma to appearance of inflammatory cell (48 hours)
Fracture Repair

This regenerative process may be described as consisting of 4 stages:

Stage 1: Inflammation

Reparative phase

Stage 2: Soft callus

Stage 3: Hard callus

Stage 4: Bone remodeling
Stage 1: stage of inflammation

Healing of Fracture

- Periosteum
- Hemorrhage
- Osteoblasts
- Endosteum
- Osteoblasts
Stage 2: stage of soft callus formation
Stage 3: stage of hard callus formation
Stage 4: stage of bone remodeling
Callus
Bone remodeling
Clinical

- localized joint pain
- inability to bear weight
- impaired function
- reduced range of motion
Fracture patterns

- Simple transverse fracture
- Comminuted fracture
- Oblique fracture
- Spiral fracture
- Longitudinal fracture
- Impacted fracture
- Depressed fracture
- Avulsion fracture
Fracture alignment

- Displacement
- Angulation
- Rotation
- Length discrepancy (e.g. bayonet apposition)
Incomplete fracture

Plastic deformation (Bowing fracture)

Green-stick fracture

Buckle fracture (Torus fracture)
Bending force

Tension force

Compression force

Plastic deformation
Tension force

Compression force

More bending force

Tension side failure

Green-stick fracture
Tension force

Compression force

More bending force

Compression side failure

Buckle fracture
Plastic deformation

Monteggia’s fracture
Green-stick fracture
Buckle fracture
Epiphyseal plate injury

Salter and Harris Classification
Salter-Harris Type I
• **SH I**: This fracture typically traverses through the hypertrophic zone of the cartilaginous physis, splitting it longitudinally and separating the epiphysis from the metaphysis
Salter–Harris Type II

Thurstan–Holland’s fragment
• **SH II**: The fracture splits partially through the physis and includes a variably sized triangular bone fragment of metaphysis

• This fragment is often referred to as the Thurstan–Holland’s fragment
Salter–Harris Type III
• **SH III:** This fracture pattern combines physeal injury with an articular discontinuity.

• This fracture partially involves the physis and then extends through the epiphysis into the joint
Salter–Harris Type IV
• **SH IV**: This fracture runs obliquely through the *metaphysis*, traverses the *physis* and *epiphysis*, and enters the joint

• The Thurstan Holland sign (ie, a Thurstan Holland fragment) is also seen with this fracture pattern
Salter–Harris Type V
• **SH V**: These lesions involve compression or crush injuries to the physis and are virtually impossible to diagnose definitively at the time of injury.
• **SH VI**: An additional classification of physeal fractures not considered in the original SH classification but now occasionally included is SH VI, which describes an injury to the peripheral portion of the physis and a resultant bony bridge formation that may produce considerable angular deformity.
Treatment

• SH I and SH II physeal injuries usually can be managed adequately with closed manipulative reduction

• SH III and SH IV proper management of SH III and SH IV injuries requires anatomic reduction and internal fixation to restore anatomic alignment of the joint surfaces and proper alignment of juxtaposing physeal surfaces. Nondisplaced fracture fragments have migrated subsequent to cast immobilization only
SH V and VI physeal injuries often result in partial or complete growth arrest (physeal bar formation). As a result, physeal bar resection may be required or other surgical procedures may be necessary in order to prevent or correct deformity.
## Complications of Fracture in Children

- Vascular injuries
- Nerve injuries
- Compartment syndromes
- Fat embolism
- Hypercalcemia of immobilization
- Ectopic bone formation
- Superior mesenteric artery syndrome (Cast syndrome)
- Traction-induced hypertension
- Spontaneous deep vein thrombosis
- Avascular necrosis

<table>
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<th>Left Column</th>
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<td>Malunion</td>
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<td>Late angulation</td>
<td>Injury to the triradiate cartilage</td>
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<td>The overgrowth phenomenon</td>
<td>Growth disturbances (Growth arrest, partial growth arrest)</td>
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<td>Nonunion</td>
<td>Refracture</td>
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<td>Ligamentous instability</td>
<td>Reflex Sympathetic Dystrophy</td>
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Central ischemic growth arrest
Harris’s growth arrest line
Limb length discrepancy

Galleazzi’s sign
Cubitus varus
Lateral Condylar Fracture of the Humerus
Nonunion of Lateral Condylar Fracture of the Humerus
QUIZ ????????
Gartland III
Gartland II
Lazy “S” deformity
Skin dimple/Puckering sign
Casting
Monteggia fracture
Juvenile Tillaux fracture
Both bone forearm fracture