Basic Principles in the Assessment and Treatment of Fractures in Skeletally Immature Patients

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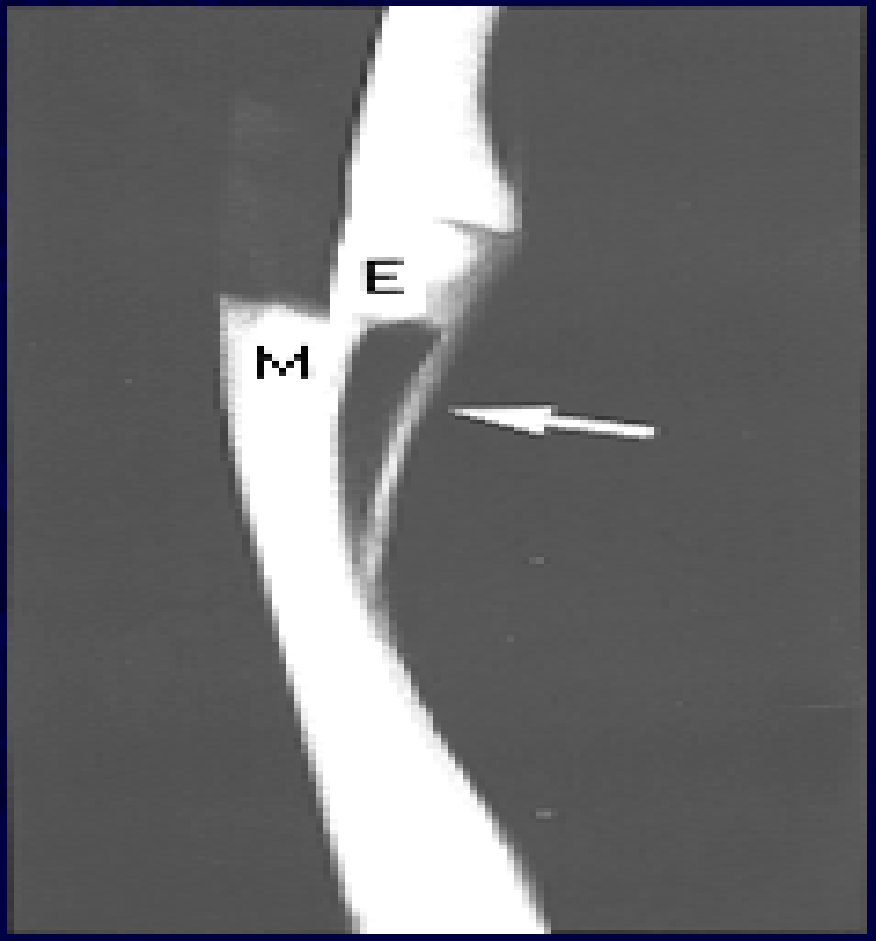
1st Revision: Steven Frick, MD; August 2006
2nd Revision: Joshua Klatt, MD; December 2010

Anatomy Unique to Skeletally Immature Bones

- Anatomy
  - Epiphysis
  - Physis
  - Metaphysis
  - Diaphysis
- Physis = growth plate

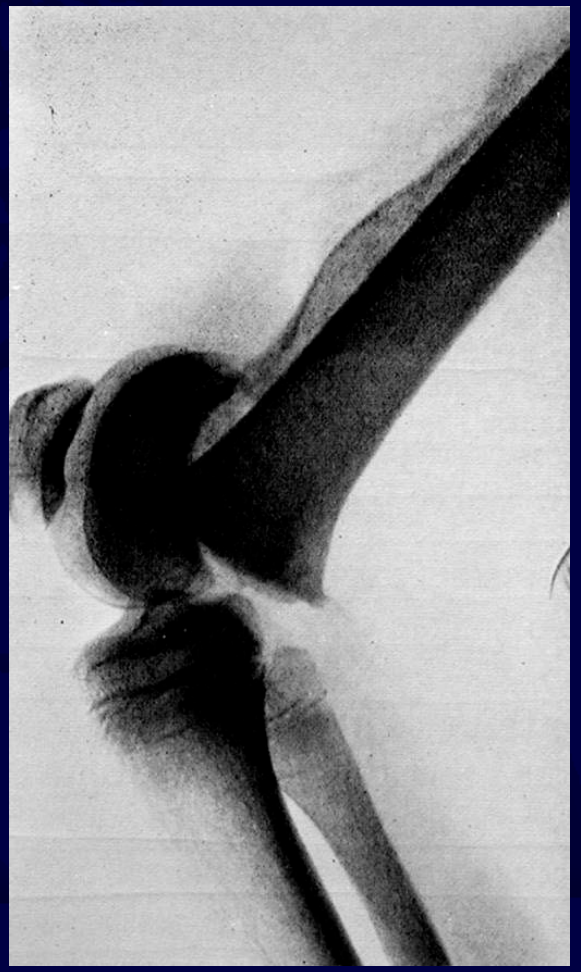
Anatomy Unique to Skeletally Immature Bones

- Periosteum
  - Thicker
  - More osteogenic
  - Attached firmly at periphery of physes
- Bone
  - More porous
  - More ductile



Periosteum

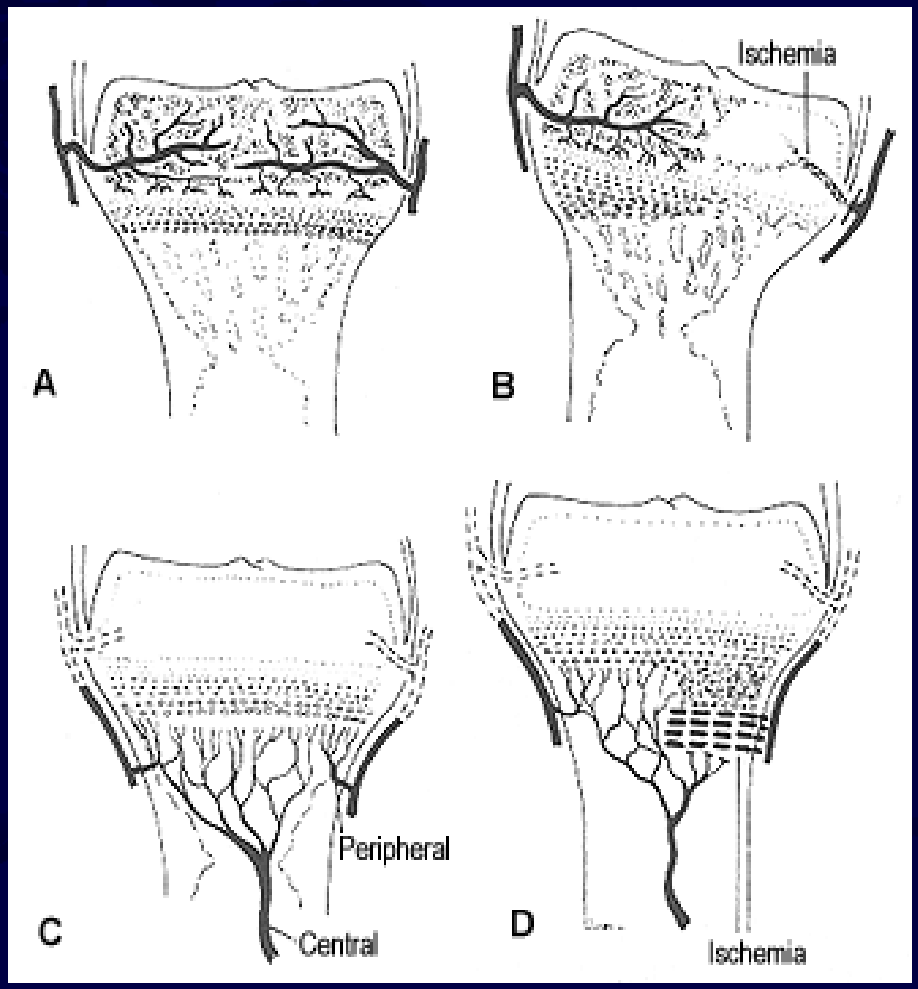
- Osteogenic
- More readily elevated from diaphysis and metaphysis than in adults
- Often intact on the concave (compression) side of the injury
  - Often helpful as a hinge for reduction
  - Promotes rapid healing
- Periosteal new bone contributes to remodeling



From: The Closed Treatment of Fractures, John Charley

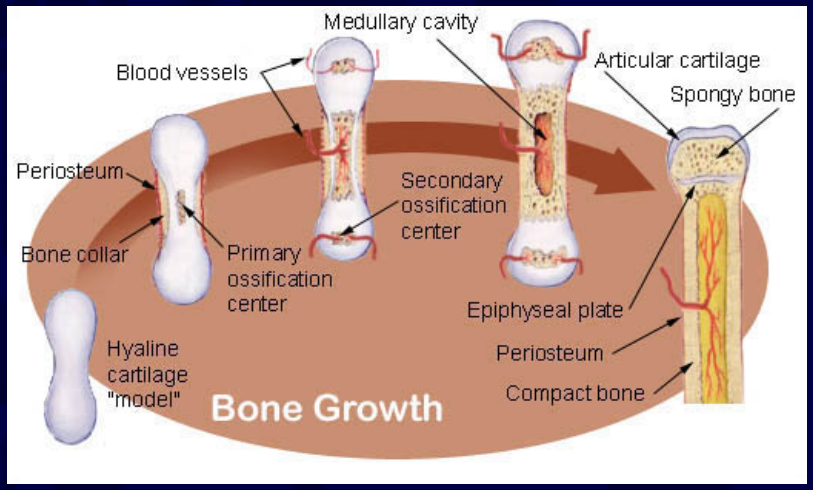
Physeal Anatomy

- Gross - secondary centers of ossification
- Histologic zones
- Vascular anatomy



Centers of Ossification

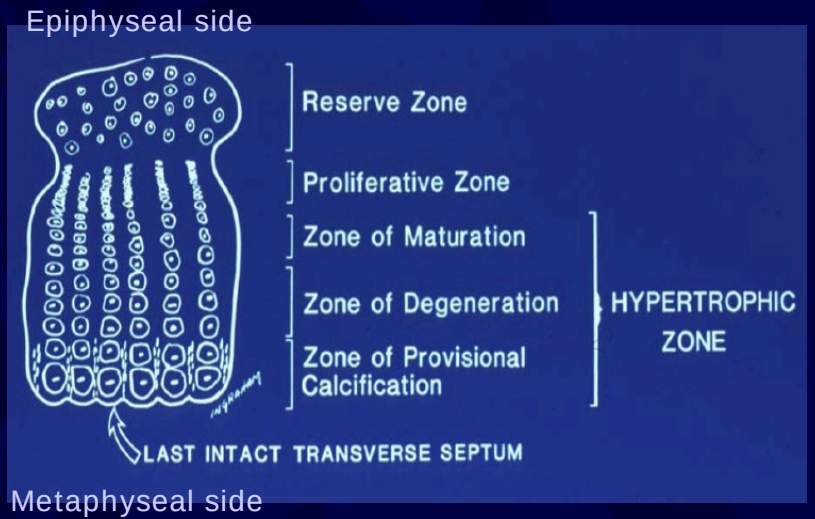
- 1° ossification center
  - Diaphyseal
- 2° ossification centers
  - Epiphyseal
  - Occur at different stages of development
  - Usually occurs earlier in girls than boys



source: http://training.seer.cancer.gov

Physeal Anatomy

- Reserve zone
  - Matrix production
- Proliferative zone
  - Cellular proliferation
  - Longitudinal growth
- Hypertrophic zone
  - subdivided into
    - Maturation
    - Degeneration
    - Provisional calcification



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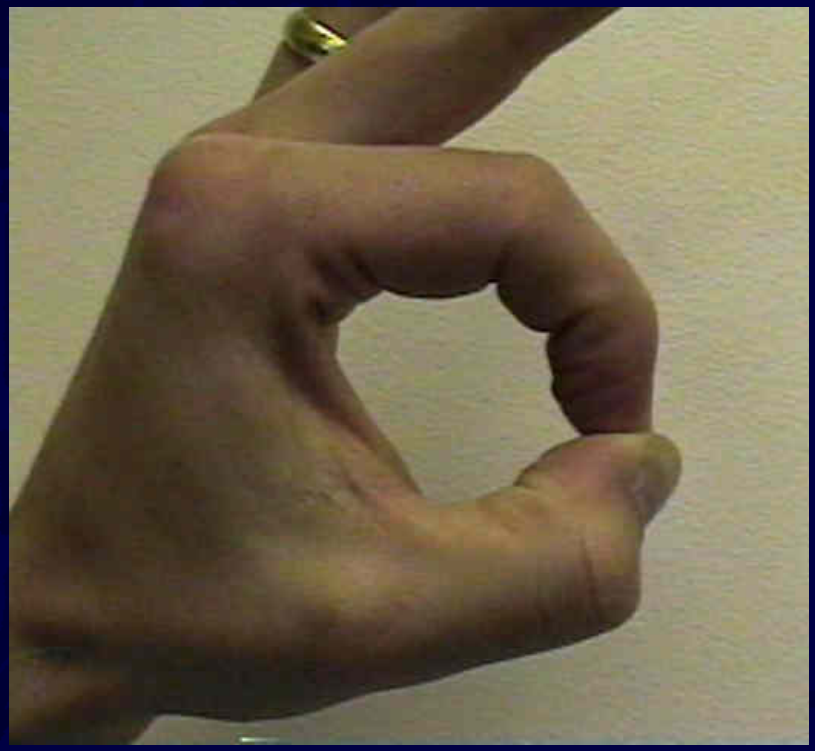
McMaster University, Hamilton, Ontario

Examination of the Injured Child

- Assess location of deformity or tenderness
- Carefully assess and document specifically distal neurologic and circulatory function
- Radiographic evaluation

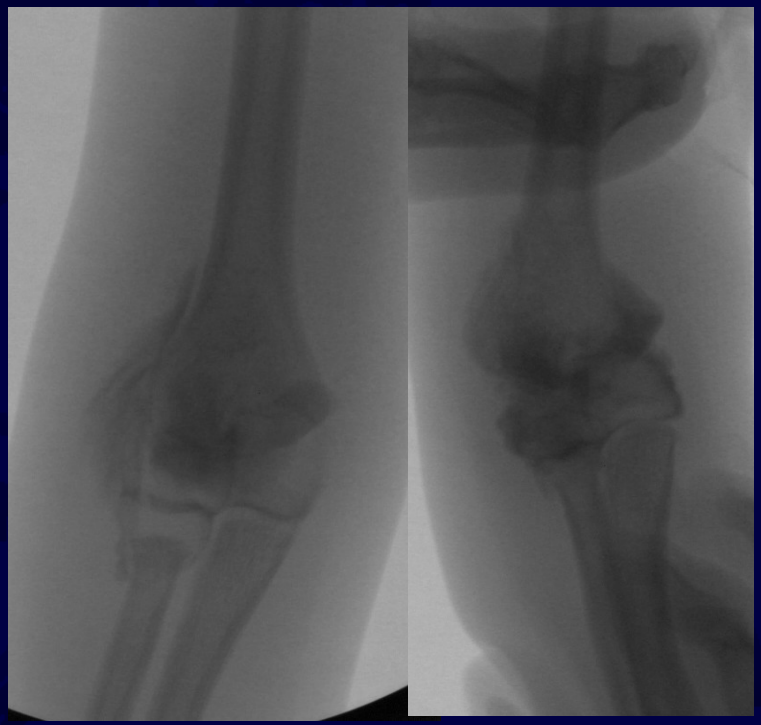


Radiographic Evaluation of the Injured Child

- At least 2 orthogonal views
- Include joint above and below fracture
- Understand normal ossification patterns
- Comparison radiographs rarely needed, but can be useful in some situations

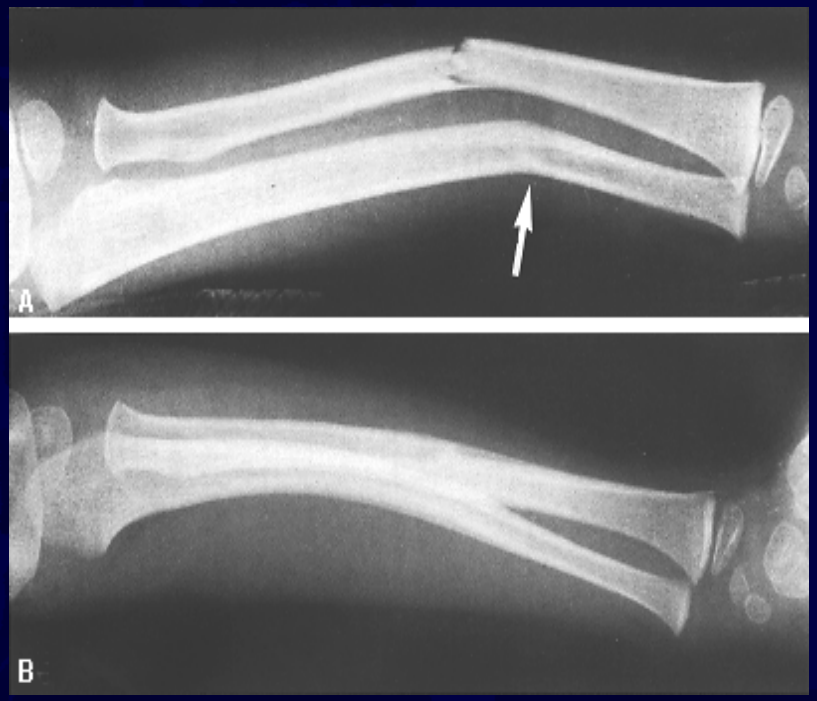
Special Imaging

- Evaluate intra-articular involvement
  - Tomograms, CT scan, MRI, arthrogram
- Identify fracture through nonossified area
  - Arthrogram, MRI
- Identify occult (or stress) fractures
  - Bone scan, MRI
- Assess vascularity (controversial)
  - Bone scan, MRI



Fractures common only in skeletally immature

- Physeal injuries
  - "weak link" = physis, especially toward end of growth
- Buckle or Torus Fracture
- Plastic Deformation
- Greenstick Fracture



Buckle or Torus Fracture

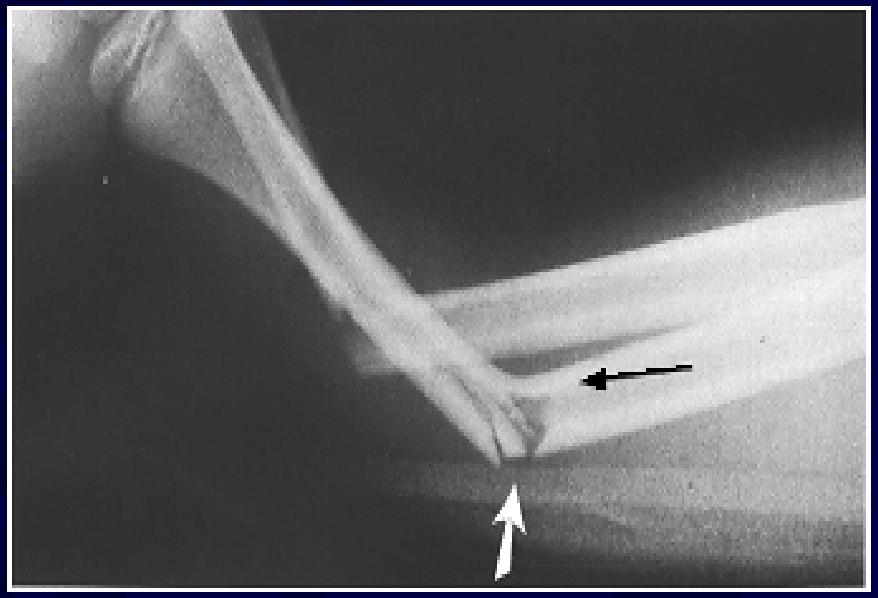
- Compression failure
- Stable
- Usually at metaphyseal / diaphyseal junction

Plastic Deformation

- The non-reversible deformation after elastic limit surpassed (yield strength)
- Caused predominantly by slip at microcracks
- Permanent deformity can result
  - These do not remodel well
- Forearm, fibula common

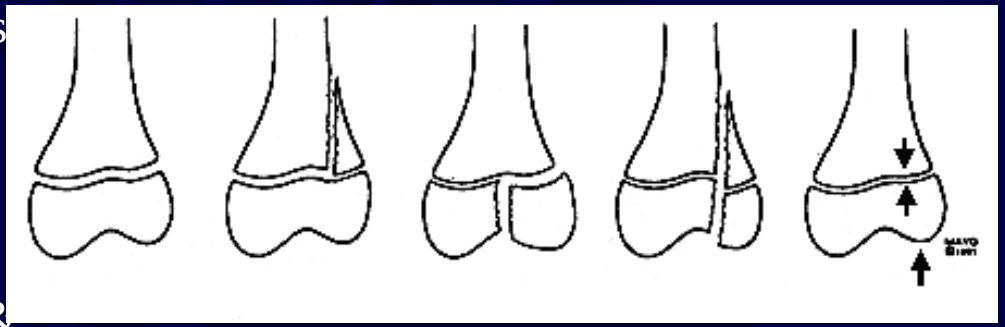
Greenstick Fractures

- Bending mechanism
- Failure on tension side
- Incomplete fracture, plastic deformation on compression side
- May need to complete fracture to realign



Salter - Harris Classification

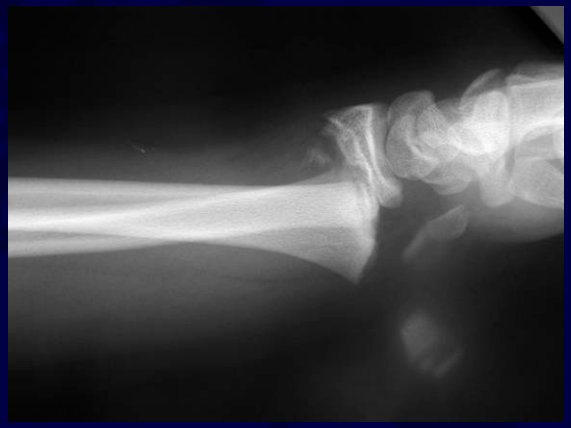
- Type I
  - Through physis only
- Type II
  - Through physis & metaphysis
- Type III
  - Through physis & epiphysis
- Type IV
  - Through metaphysis, physis & epiphysis
- Type V
  - Crush injury to entire physis
- Others added later by subsequent authors



Described by Robert B. Salter and W. Robert Harris in 1963.

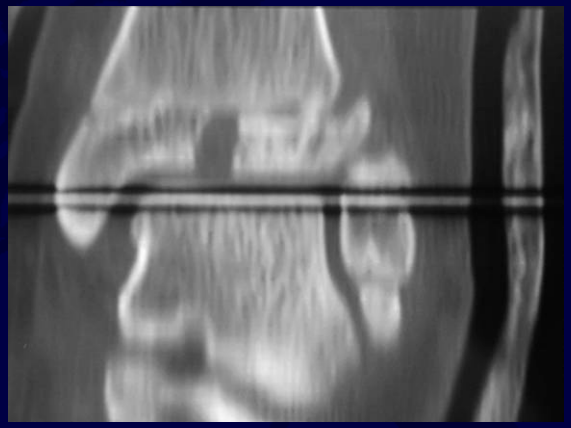
Salter Harris Classification General Treatment Principles

- Type I & Type II
  - Closed reduction & immobilization
  - Exceptions
    - Proximal femur
    - Distal femur



Salter Harris Classification General Treatment Principles

- Type III & IV
  - Intra-articular and physeal step-off needs anatomic reduction
  - ORIF, if necessary



Physeal Fractures

- Traditionally believed to occur primarily through zone of hypertrophy
- Recent studies show fractures often traverse more than one zone
- Growth disturbance/arrest potentially related to
  - Location of fracture within physeal zones
  - Disruption of vascularity

Jaramillo et al, Radiology, 2000.
Johnson et al, Vet Surg, 2004.
Kleinman & Marks, Am J Roentgenol, 1996.

Fracture Treatment in Children General Principles

- Children heal faster (factors)
  - Age
  - Mechanism of injury
  - Fracture location
  - Initial displacement
  - Open vs. closed injury
- Growing bones remodel more readily
- Need less immobilization time
- Stiffness of adjacent joints less likely

Treatment Principles

- When possible, restore:
  - Length, alignment & rotation
- Maintain residual angulation as small as possible using closed treatment methods
  - molded casts, cast changes, cast wedging, etc.
- Displaced intra-articular fractures will not remodel
  - anatomic reduction mandatory

Treatment Principles
Closed Methods

- Achieve adequate pain control and relaxation
  - Anesthesia
    - Local
    - Regional
    - General
  - Conscious sedation (often combination of drugs)
    - Propofol
    - Ketamine
    - Benzodiazepines
    - Narcotics

Treatment Principles
Closed Methods

- Vast majority of pediatric fractures treated by closed methods.
  - Exceptions - open fractures, intra-articular fractures, multi-trauma
- Attempt to restore alignment (do not always rely on remodeling)
- Gentle reduction of physeal injuries (adequate relaxation, traction)

Treatment Principles
Closed Methods

- Well molded casts/splints
  - Use 3-point fixation principle
- Consider immobilization method on day of injury that will last through entire course of treatment
  - Limit splint or cast changes
- Consider likelihood of post-reduction swelling
  - Cast splitting or splint
- If fracture is unstable, repeat radiographs at weekly intervals to document maintenance of acceptable position until early bone healing

Excellent reduction maintained with thin, well-molded cast/splint

Fiberglass cast applied with proper technique and split/spread is excellent way to safely immobilize limb, maintain reduction and accommodate swelling

Treatment Principles
Loss of Reduction

- Metaphyseal/diaphyseal fractures can be remanipulated with appropriate anesthesia/analgesia up to 3 weeks after injury
- In general, do not remanipulate physeal fractures after 5-7 days
  - increased risk of physeal damage

Treatment Principles
Open Methods

- Respect and protect physis
- Adequate visualization
  - resect periosteum, metaphyseal bone, if needed
- Keep fixation in metaphysis / epiphysis if possible when much growth potential remains
  - Use smooth K-wires if need to cross physis

ORIF Salter IV
Distal Tibia

* Note epiphyseal/metaphyseal wires to track postoperative growth

Complications of Fractures
- Bone -

- Malunion
- Limb length discrepancy
- Physeal arrest
- Nonunion (rare)
- Crossunion
- Osteonecrosis

Complications of Fractures
- Soft Tissue -

- Vascular Injury
  - Especially elbow/knee
- Neurologic Injury
  - Usually neuropraxia
- Compartment Syndrome
  - Especially leg/forearm
- Cast sores/pressure ulcers
- Cast burns
  - Use care with cast saw

Complications of Fractures
- Cast Syndrome -

- Patient in spica/body cast
- Acute gastric distension, vomiting
- Possibly mechanical obstruction of duodenum by superior mesenteric artery

Location Specific Pediatric Fracture Complications

Complication	Fracture
Cubitus varus	Supracondylar humerus fracture
Volkmann's ischemic contracture	Supracondylar humerus fracture
Refracture	Femur fracture Mid-diaphyseal radius/ulna fractures
Overgrowth	Femur fracture (especially < 5 years)
Nonunion	Lateral humeral condyle fracture
Osteonecrosis	Femoral neck fracture Talus fracture
Progressive valgus	Proximal tibia fractures

Remodeling of Children's Fractures

- Occurs by physeal & periosteal growth changes
- Greater in younger children
- Greater if near a rapidly growing physis

Treatment Principles Immobilization Time

- In general, physeal injuries heal in half the time it takes for nonphyseal fracture in the same region
- Healing time dependent on fracture location, displacement
- Stiffness from immobilization rare, thus err towards more time in cast if in doubt

Remodeling of Children's Fractures

- Not as reliable for:
  - Midshaft angulation
  - Older children
  - Large angulation (>20-30º)
- Will not remodel for:
  - Rotational deformity
  - Intraarticular deformity

Remodeling more likely if:

- 2 years or more growth remaining
- Fractures near end of bone
- Angulation in plane of movement of adjacent joint

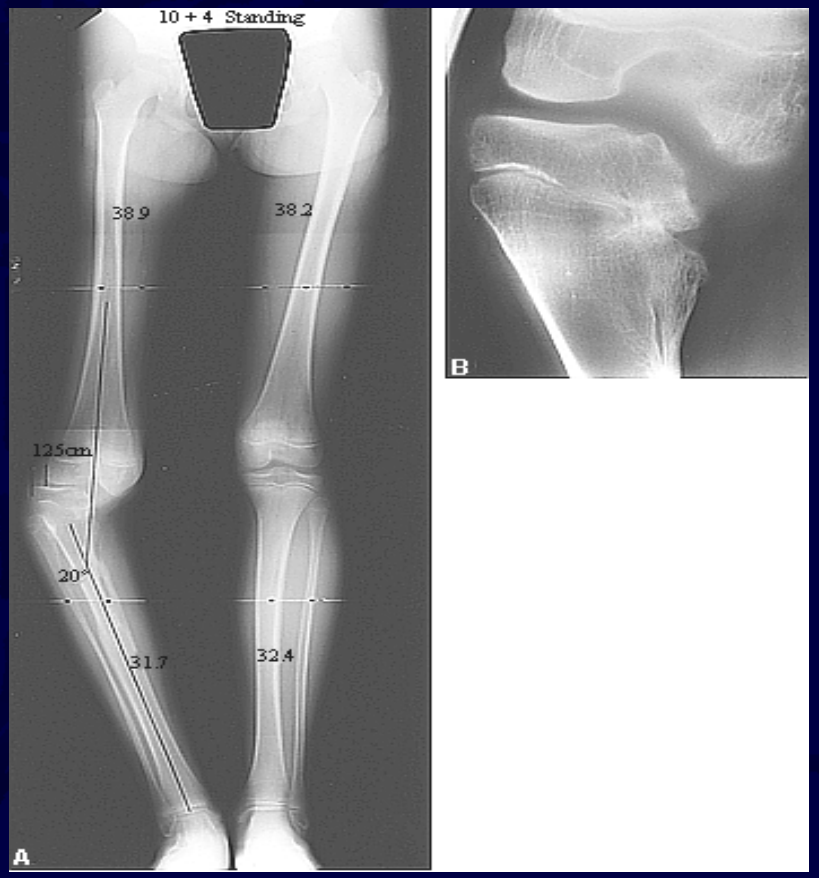
1 week post-injury

10 weeks post-injury

Healing Salter I Distal Tibia Fracture

Growth Arrest Secondary to Physeal Injury

- Complete cessation of longitudinal growth
  - leads to limb length discrepancy
- Partial cessation of longitudinal growth
  - angular deformity, if peripheral
  - progressive shortening, if central



Physes Susceptible to Growth Arrest

- Large cross sectional area
- Large growth potential
- Complex geometric anatomy
- Distal femur > distal tibia, proximal tibia > distal radius

Growth Arrest Lines

- Transverse lines of Park-Harris Lines
- Occur after fracture/stress
- Result from temporary slowdown of normal longitudinal growth
- Thickened osseous plate in metaphysis
- Should parallel physis

Growth Arrest Lines

- Appear 6-12 weeks after fracture
- Look for them in follow-up radiographs after fracture
- If parallel physis - no growth disruption
- If angled or point to physis - suspect bar

Physeal Bar
- Imaging -

- Scanogram / Orthoroentgenogram
- Tomograms/CT scans
- MRI
- Map bar to determine location and extent

Physeal Bars
- Types -

- I - peripheral, angular deformity
- II - central, tented physis, shortening
- III - combined/complete - shortening

Physeal Bar
- Treatment -

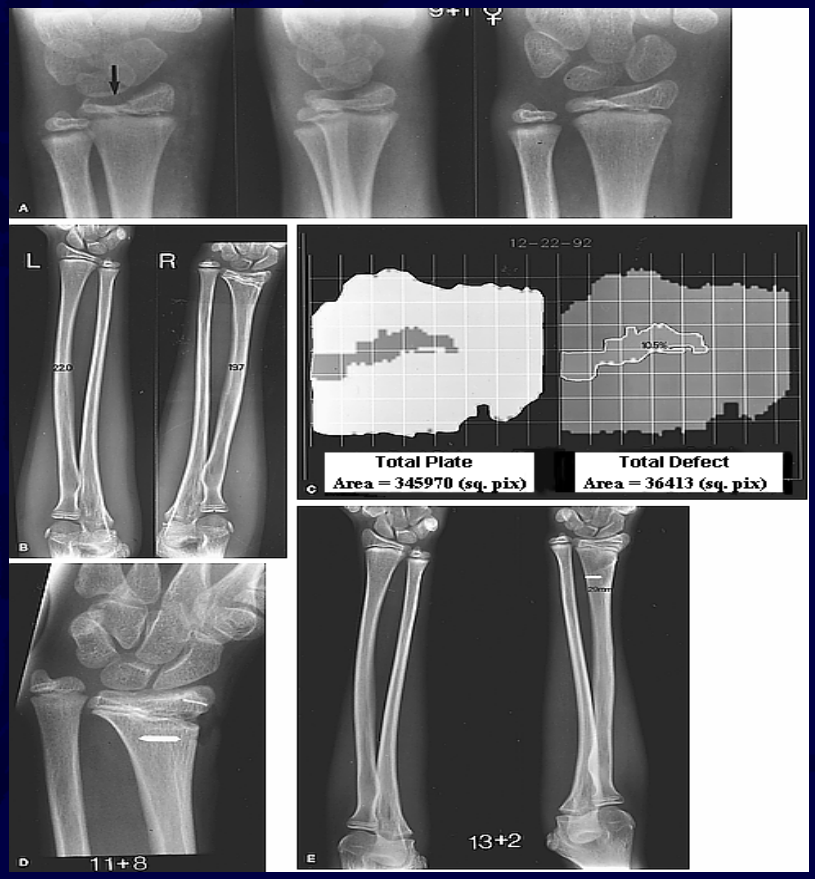
- Address
  - Angular deformity
  - Limb length discrepancy
- Assess
  - Growth remaining
  - Amount of physis involved
  - Degree of angular deformity
  - Projected LLD at maturity

Physeal Bar Resection
- Indications -

- >2 years remaining growth
- <50% physeal involvement (cross-sectional)
- Concomitant osteotomy for >15-20º deformity
- Completion epiphyseodesis and contralateral epiphyseodesis may be more reliable in older child

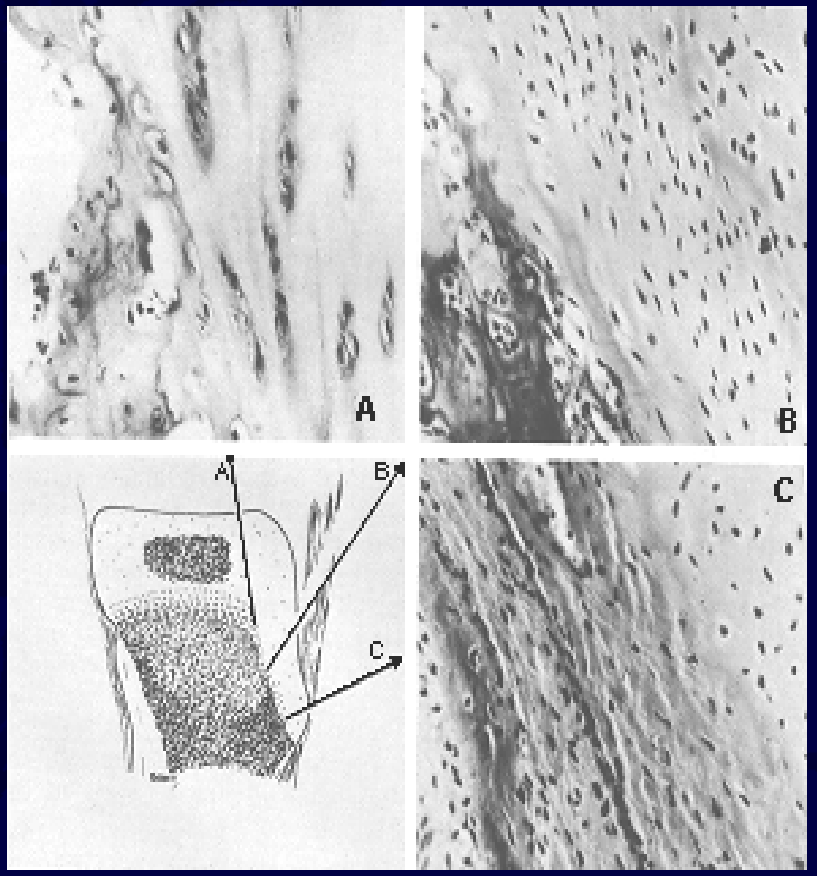
Physeal Bar Resection - Techniques

- Direct visualization
- Burr/currettes
- Interpositional material (fat, cranioplast) to prevent reformation
- Wire markers to document future growth



Epiphysis or Apophysis?

- Epiphysis - forces are compressive on physeal plate
- Apophysis - forces are tensile
- Histologically distinct
  - Apophysis has less proliferating cartilage and more fibrocollagen to help resist tensile forces

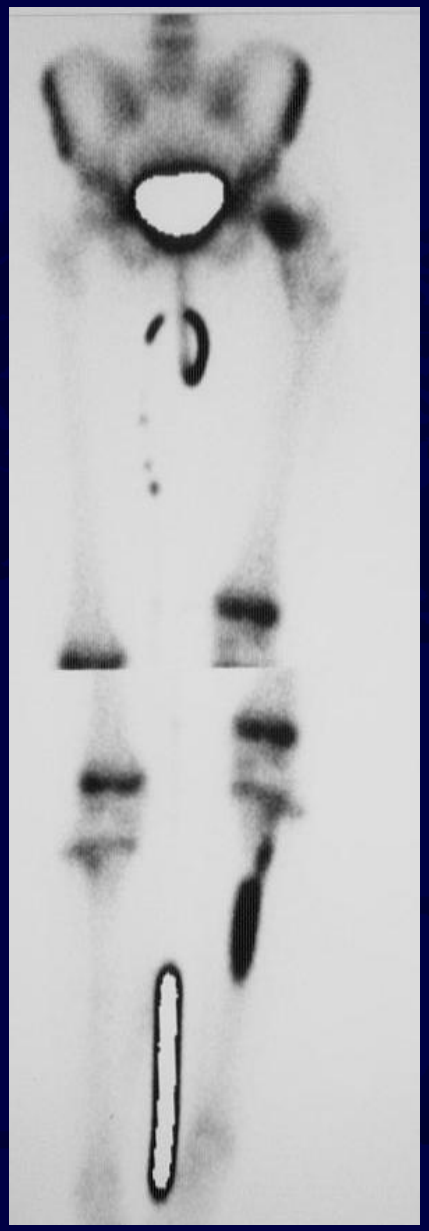


Apophyseal Injuries

- Tibial tubercle
- Medial Epicondyle
  - Often associated with dislocation
- May be preceded by chronic injury/reparative processes

Pathologic Fractures

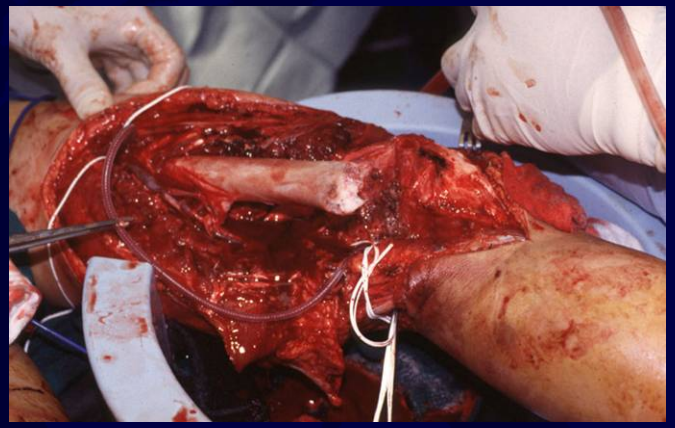
- Diagnostic workup important
  - Local bone lesion
  - Generalized bone weakness
- Prognosis dependent on biology of lesion
- Often need surgery

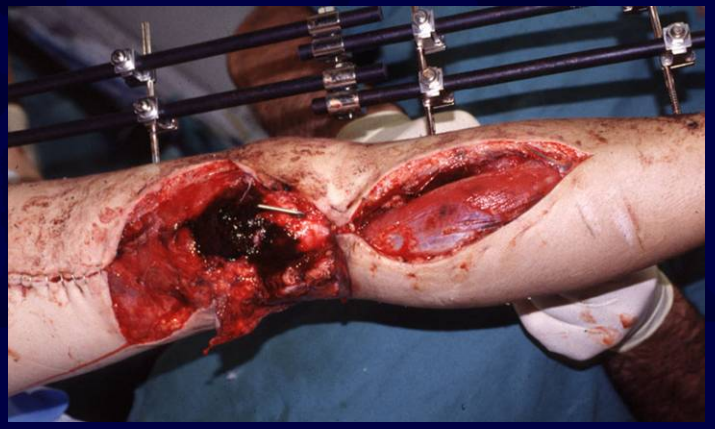


Polyostotic Fibrous Dysplasia

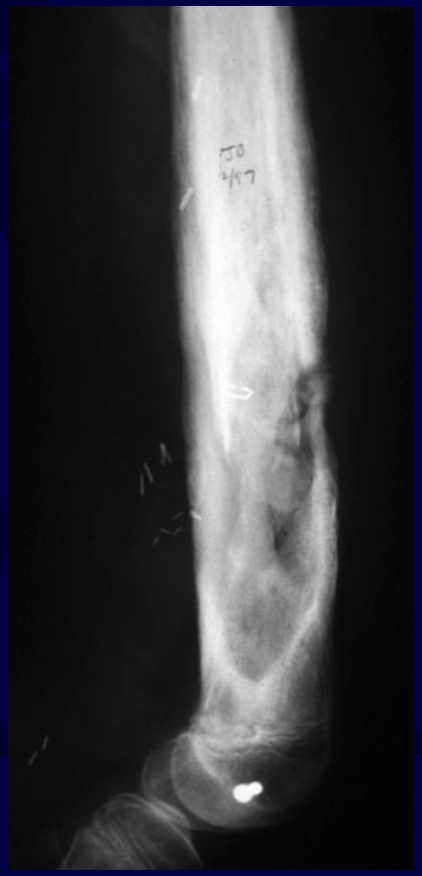
Open Fractures Principles

- IV antibiotics, tetanus prophylaxis
- Emergent irrigation & debridement
  - Ideally within 6-8 hours of injury
- Skeletal stabilization
- Soft tissue coverage





Chronic Osteomyelitis following Open Femur Fracture



- Extremely rare in children
- Serial debridement
- Followed by simultaneous bone graft and soft tissue coverage

Monsivais, J South Orthop Assoc, 1996.

Lawnmower Injuries

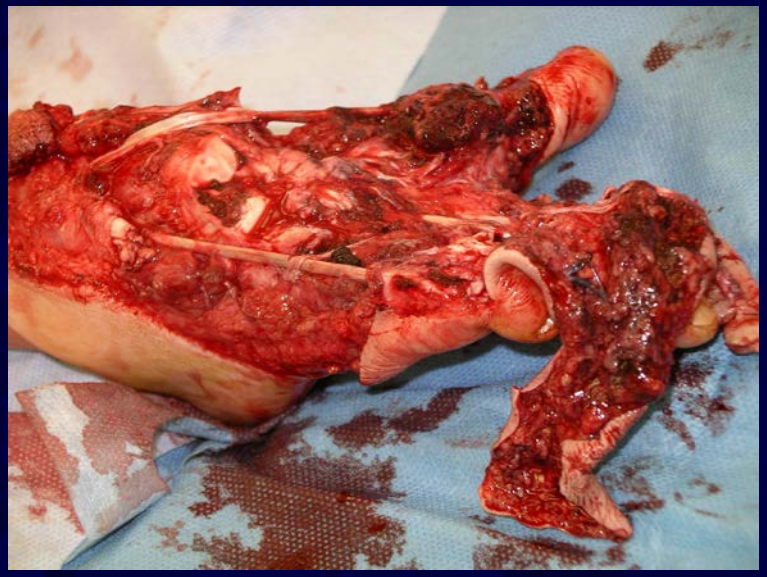
- Common cause of open fractures & amputations in children
- Most are
  - A rider or bystander (70%)
  - Under 5 years old (78%)
- High complication rate
  - Infection
  - Growth arrest
  - Amputation
- > 50% poor results

Loder, JBJS-Am, 2004

Lawnmower Injuries – often Result in Amputations

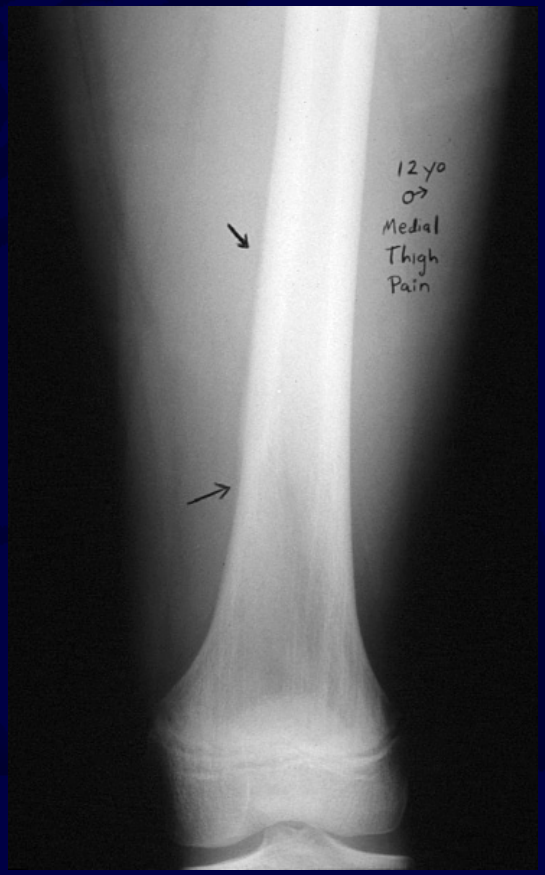
Lawnmower Injuries

- Education/ Prevention key
- Children < 14 y
  - Shouldn't operate
  - Keep out of yard
- No riders other than mower operator



Overuse Injuries

- More common as children and adolescents participate in high level athletics
- Soccer, dance, baseball, gymnastics
- Ask about training regimens
- Mechanical pain

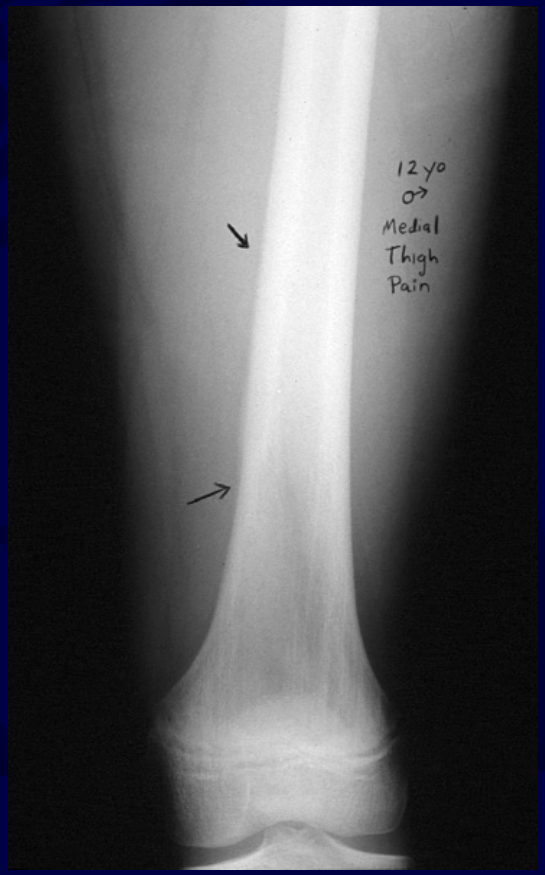


Femoral stress fracture

Heyworth, Curr Opin Pediatr, 2008.

Overuse Injuries

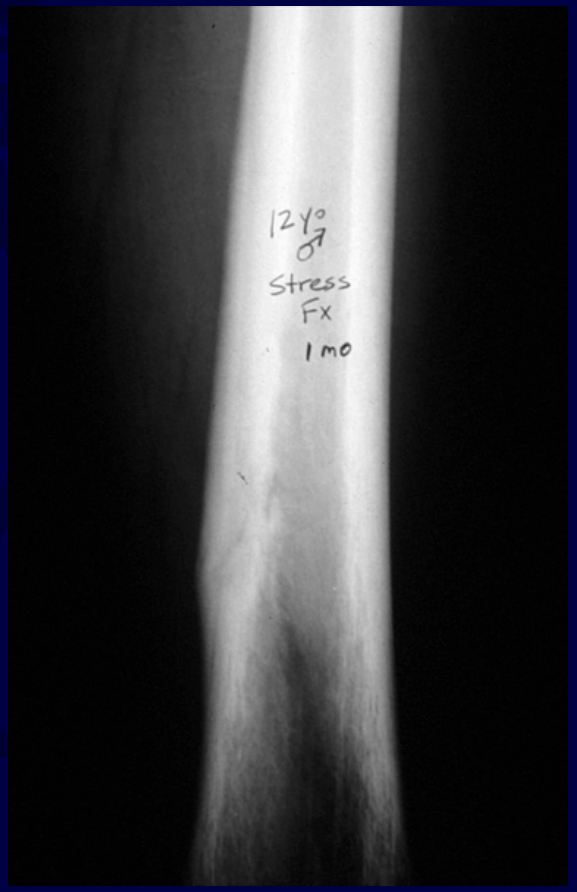
- Diagnosis
  - History/Exam
  - Serial radiographs
  - Bone scan
  - CT/MRI
- Treatment
  - Abstinence from sport/activity
  - Cast if child is overly active
  - Spica/Fixation for all femoral neck stress fxs



Femoral stress fracture

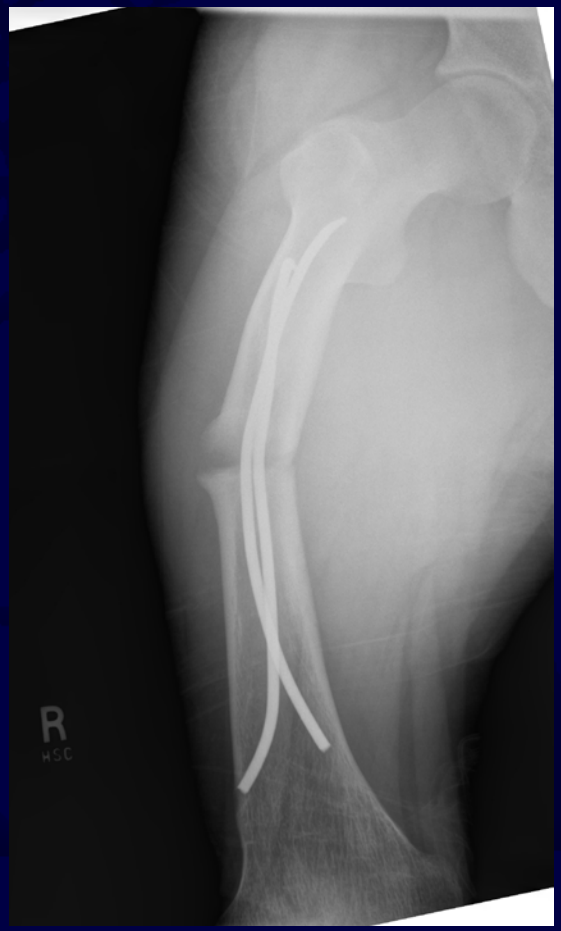
Heyworth, Curr Opin Pediatr, 2008.

Femoral Shaft Stress Fracture in 12 year old Male Runner



Metal Removal in Children

- Controversial
- Historically recommended if significant growth remaining
- Indications evolving
- Intramedullary devices and plates /screws around hip still removed by many in young patients



Kim, Injury 2005.
Peterson, J Pediatr Orthop, 2005.

Summary

- Pediatric musculoskeletal injuries are relatively common
- General orthopaedic surgeons can treat majority of fractures
- Remember pediatric musculoskeletal differences
- Most fractures heal, regardless of treatment

Summary

- Most important factors:
  - Patient age
  - Mechanism of injury
  - Associated injuries
- Good results – possible with all types treatment
- Trend for more invasive treatment
- Must use good clinical judgment and good technique to get good results

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