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
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
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

<table>
<thead>
<tr>
<th>Complication</th>
<th>Fracture</th>
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</thead>
<tbody>
<tr>
<td>Cubitus varus</td>
<td>Supracondylar humerus fracture</td>
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<tr>
<td>Volkmann’s ischemic contracture</td>
<td>Supracondylar humerus fracture</td>
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<tr>
<td>Refracture</td>
<td>Femur fracture</td>
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<td></td>
<td>Mid-diaphyseal radius/ulna fractures</td>
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<tr>
<td>Overgrowth</td>
<td>Femur fracture (especially &lt; 5 years)</td>
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<tr>
<td>Nonunion</td>
<td>Lateral humeral condyle fracture</td>
</tr>
<tr>
<td>Osteonecrosis</td>
<td>Femoral neck fracture</td>
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<td>Talus fracture</td>
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<tr>
<td>Progressive valgus</td>
<td>Proximal tibia fractures</td>
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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 (>20-30°)

• 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
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

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 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

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
Bibliography


Bibliography


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