Pediatric Knee Injuries

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Objectives:

• Highlight the importance of an anatomical reduction in physeal fractures to prevent growth arrest, malalignment, and leg length discrepancy

• Discuss fixation options that balance the need to maintain a reduction while respecting the biology of the physis

• Recognize injury patterns that are associated with neurovascular compromise

• Understand the differential diagnosis of acute knee effusion and strategies for managing intra-articular fractures in the pediatric knee
Overview:

Extra-articular Injuries:
• Distal Femoral Physeal Fractures
• Proximal Tibia Physeal Fractures
• Tibial Tubercle Fractures

Intra-articular Injuries:
• Tibial Eminence Fractures
• Patellar Sleeve Injuries
• Osteochondral Fractures
Distal Femur Physeal Fractures
Distal Femoral Physeal Fractures

• 1898 - “Wagon-wheel injury” described by Poland
  • Often resulted in open injury w/ neurovascular compromise
  • High rate of popliteal ischemia and uncontrollable infection

• 1952 - Aitken & Magill - series of distal femoral physeal fxs in football players
  • Noted high rate of leg length discrepancies and angular deformities

• Complex contour of physis makes it possible for shearing of the fracture line across several physeal zones (Brashear)
Epidemiology

• Fracture Epidemiology
  • Rare injury (<1% of pediatric fractures)
  • Mechanism:
    • Often the result of high energy trauma in <11 y.o. (pedestrian struck or fall from a height)
    • Sports injuries in teens (2/3 of distal femoral fractures)

• Associated Injuries
  • Do not miss VASCULAR INJURY or TIBIAL/PERONEAL NERVE INJURY
  • Do not miss COMPARTMENT SYNDROME
Mechanism of Injury

• Hyperextension $\rightarrow$ epiphysis displaced anteriorly, metaphysis displaced into popliteal fossa
  • Neurovascular injury
  • Reduction often unstable
  • Extreme knee flexion sometimes necessary to tighten anterior soft tissue hinge

• Varus-Valgus – due to adduction/abduction force
  • Periosteal hinge intact on concavity
  • Periosteum can be entrapped on convexity

Images courtesy of Greg Osgood, MD
Anatomy

- First physis to ossify, last long bone to fuse
- Contributes 70% growth of the femur, 37% growth of the lower extremity
  - Grows at rate of 9mm/year
- Medial and lateral collateral ligaments, as well as the anterior and posterior cruciate ligaments originate distal to femoral physis
- Physis fractures before ligaments tear

Fractures of the distal femur and proximal tibial physis account for 2.2% of physeal fractures BUT they account for 51% of growth plate arrest.\(^{39}\)
Distal Femur: Anatomy

• Both heads of gastrocnemius & plantaris originate just proximal to physis
  • Posterior epiphyseal displacement or angulation is uncommon
  • Ligament, rather than muscular pull more likely explains initial displacement at time of injury

• Sciatic nerve divides into peroneal and posterior tibial branches just proximal to the physis

• Popliteal artery is posterior at the level of the distal femur
  • Tethered at adductor hiatus proximally and soleus hiatus distally
  • Displaced fxs need surveillance of vascular injury

Distal Femur: Exam

• Effusion

• Ecchymosis of distal thigh and popliteal fossa within 72 hours

• Deformity
  • Varus/valgus – metaphyseal spike dimpling vastus medialis/lateralis
  • Anterior – patella prominence and fullness of popliteal fossa
    • Can feel for adductor tubercle to differentiate from knee dislocation

• Point tenderness along the physis & adductor tubercle
  • Tenderness medially at the physis can be a nondisplaced fracture
    • MCL injury is less likely
Distal Femur: Exam

• Motor and sensory
  • Peroneal and tibial nerves
    • Most common with varus displacement

• Vascular
  • Popliteal artery injury
    • Most common with anterior displacement
    • ABI testing

  \[
  \text{ABI} = \frac{\text{Ankle systolic BP}}{\text{Brachial systolic BP}} < 0.9
  \]

  * concerning for vascular injury

• MRI can detect nondisplaced fractures
  • Stress examination NO longer recommended due to risk of additional physeal injury

image courtesy of Alfred Mansour, MD (2016 version)

ABI = Ankle systolic BP / Brachial systolic BP < 0.9

* concerning for vascular injury

image courtesy of Alfred Mansour, MD (2016 version)
Treatment

Goals:

Healing of the fracture in acceptable alignment

• Gentle reduction of the distal femoral physis
  • Reduce the risk of growth arrest

• Anatomic reduction of articular surface
  • Decrease likelihood of premature arthritis
Treatment

• Salter-Harris classification useful in description and treatment planning
  • Not strongly predictive of growth disturbance

• Direction and degree of displacement predict type and severity of complications (Arkader et al. JPO 2007)
Reduction under Anesthesia

Intact tether of periosteum on the side of the epiphyseal displacement:
1) increase deformity slightly + traction
2) then realignment of angular deformity
   - 90% traction, 10% leverage to avoid physeal injury

Medial/Lateral Displacement:
- Knee in extension, hip in slight flexion
- Assistant holds thigh
- Traction w/ 1 hand, palm placed at concavity of deformity for leverage

Image from R&W Fractures in Children 9th Ed. Figure 25-12A
Reduction under Anesthesia

Anterior Displacement:

- Traction to leg, hip flexed to 60
- Assistant holds thigh
- Longitudinal traction and downward pressure on epiphysis
- Knee is flexed to 45-90 degrees

* Closed reduction can be performed up to 10 days after injury.

Image from R&W Fractures in Children 9th Ed. Figure 25-12B
Treatment

• Acceptable alignment for SH I & II
  • < 15-20 degrees in sagittal plane (Sharrard et al.)
  • < 5 degrees varus/valgus – does not remodel

• Anatomic reduction required for SH III & IV
  • CRPP vs ORIF

• Open treatment required for:
  • Open fractures
  • Entrapped tissues preventing reduction
  • Neurovascular injury
Salter Harris I

- Can be non-displaced or displaced
  - Nondisplaced fracture demonstrates TTP at the physis on exam
  - F/u radiographs demonstrate bony reaction

- Tx:
  - long leg cast x 4 weeks if nondisplaced
    - LLC in 15-20 degrees flexion w/ 3-point mold
      - Thomson et al. – many displaced fractures lost reduction with cast immobilization – recommend internal fixation of all displaced fx's
    - Follow up XR in 1 week
  - CRPP for displaced fractures
    - Maintain pins and LLC x 4 weeks
Salter Harris II

- Most common type fracture type
- Displacement typically to side of Thurston Holland (TH) fragment
- Varus/valgus stress to reduce then percutaneous screws
  - Screw from TH fragment into intact metaphysis
  - Smooth wires used if TH fragment is small
    - Treated like a SH-1
- ORIF required if entrapped soft tissues block reduction
  - Opened on convexity

Images courtesy of Chris Souder, MD
Salter Harris II

• Tendency to produce premature physeal closure (~30-50%)
  • Riseborough et al: 11/25 pts closed prematurely resulting in >2.4cm LLD
  • Growth arrest related to the severity of displacement (Stephens et al.)
  • Signs of premature closure typically evident within 6 months of injury

• Angular deformity more common
  • Metaphyseal fragment physis spared

Images courtesy of Chris Souder, MD
Salter Harris III

• Tends to occur as physis is closing (decreased risk of LLD)
  • Typically involves the medial physis and MFC
• Medial femoral condyle fracture results from valgus force
  • MCL attachment leads to epiphyseal avulsion
  • Can be associated with cruciate ligament injury

• Tx: ORIF w/ transepiphysial screws
  • Anatomic reduction of articular surface

Image courtesy of Chris Souder, MD

images courtesy of Alfred Mansour, MD (2016 version)
Salter Harris IV

• Uncommon injury

• Anatomic reduction necessary
  • Possibly decrease risk of physeal arrest
  • Restores the joint surface

• Highest risk for partial growth arrest

• Tx: ORIF w/ cannulated screws avoiding physis

Images courtesy of Chris Souder, MD
Distal Femur: Early Complications

• Recurrent physeal displacement

• Knee ligament injury (37%)
  • 14/29 patients w/ physeal injury and associated ligament instability (Bertin and Goble)
  • SH3 associated with ACL tears (Brone and Wroble)

• Neurovascular injury
  • Peroneal nerve (3%)
  • Popliteal artery (1%)
Distal Femur: Late Complications

• Physeal arrest (~30-50%)
  • Partial arrest
    • Angular deformity
    • Most common
  • Complete arrest
    • Leg length discrepancy
  • Usually evident by 6 months post injury

*Smooth pins across physis not statistically associated w/ growth arrest
Garrett et al. BJJ 2011

<table>
<thead>
<tr>
<th>Classification</th>
<th>Growth Disturbance:</th>
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<tbody>
<tr>
<td>SH 1</td>
<td>36%</td>
</tr>
<tr>
<td>SH 2</td>
<td>58%</td>
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<tr>
<td>SH 3</td>
<td>49%</td>
</tr>
<tr>
<td>SH 4</td>
<td>64%</td>
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<table>
<thead>
<tr>
<th>Displacement</th>
<th>Growth Disturbance:</th>
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<tbody>
<tr>
<td>Non-displaced</td>
<td>31%</td>
</tr>
<tr>
<td>Displaced</td>
<td>65%</td>
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</tbody>
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Basener et al. JOT 2009
Distal Femur: Late Complications

• Stiffness
• Quadriceps weakness
• Persistent knee instability
  • Must perform ligamentous examination after fixation
Proximal Tibia Physeal Fractures
Proximal Tibia Physeal Fractures

- Rare injury (0.8% of physeal fractures)
  - Inherent stability by surrounding structures: fibula (laterally), superficial MCL (medially), semimembranosus (posteromedially), tibial tubercle (anteriorly)
  - Epiphysis typically displaces anterior, anteromedial, or anterolateral
  - Rare posterior displacement results in epiphysis and tubercle moving as unit

- Fuses ~ 15 years (posteriorly $\rightarrow$ anteriorly)
- Contributes 6mm growth/year

Image courtesy of Greg Osgood, MD
Mechanism

• Varus/Valgus → occurs near maturity
  • Apex medial implies partial tear of superficial MCL

• Flexion injury – boys age 15-16 during jumping
  • Early closure → results in genu recurvatum deformity
  • Pes anserinus or periosteum may be entrapped
  • Transition between tibial physeal separation and tibial tubercle fx

• Hyperextension – risk of vascular injury and compartment syndrome
Classification

SH 1
- 50% nondisplaced
- Medial or posterior physeal widening
- Associated proximal fibula physeal injury

SH 2
- 30% nondisplaced
- Displacement typically medial w/ metaphyseal spike laterally – valgus deformity

SH 3
- Most common is vertical fracture through lateral epiphysis
- Associated with MCL injury

SH 4
- Can involve medial or lateral plateau

SH 5
- Rare, usually made in retrospect after progressive angulation or LLD

Images courtesy of Greg Osgood, MD
Treatment

• Closed reduction and long leg cast in stable fracture patterns
  • Not common

• CRPP
  • Most common technique

• Screw fixation if metaphyseal fragment is large

Complications

• Physeal disturbance
  • Most common complication
    • 25% incidence
  • Shortening or angulation
    • Recurvatum is common

• Popliteal artery injury
  • 10% incidence (Gautier, 1998)

• Peroneal nerve palsy
  • Spontaneous recovery is typical

• Knee ligament instability (40% in SH3 & 4)
  • 5/15 concomitant avulsion of ACL (Poulsen, 1989)
  • SH3 fx associated with MCL tears

Images courtesy of Chris Souder, MD
Vascular Injury

• Popliteal artery injury (10%)\(^2\)
  
  • Tethered near posterior surface of proximal tibial epiphysis by geniculate branches and trifurcation
    
    ➢ Proximal tibial artery passes under soleus hiatus
    
    ➢ Anterior tibial artery travels above proximal border of interosseous membrane

Tibial Tubercle Fractures
Tibial Tubercle Fractures

- < 1% of all epiphyseal fractures
- Occurs almost exclusively in adolescent males during jumping activities
  - Explosive quad contraction during jumping
  - Rapid passive knee flexion against contracting quad while landing
- Fracture pattern depends on amount of physeal closure and degree of knee flexion at time of injury\(^{42}\)
  - Physis closes posterior → anterior
  - > 30 degrees of flexion results in SH3 of proximal tibial physis\(^{23}\)
Tibial Tubercle: Exam

• Inability to fully extend knee
• Anterior knee pain
• Effusion, hemarthrosis
• Skin tenting
• Patella alta

• Must evaluate for compartment swelling
  • Pulses, palpate compartments, stretch testing of anterior compartment musculature
Tibial Tubercle: Modified Ogden Classification

- Degree of displacement depends on severity of injury to adjacent soft tissue attachments (Ogden et al)
Treatment

• Extend leg to reduce
• Splint and admit for observation
  • Increased risk of compartment syndrome
    • Risk of bleeding from anterior tibial recurrent artery

• Non-operative treatment
  • Minimally displaced fractures
  • Long leg cast in full extension x 4-6 weeks
Treatment

• Surgical fixation
  • Open reduction with internal fixation
    • Allows removal of large periosteal flap
      • Anatomic reduction
    • Inspect joint through fracture site ensure meniscus is not entrapped
  • Knee extension reduces the fracture
  • Screw fixation most commonly used
    • Smooth k-wires in young children
      • Tension band suture can be used to reinforce repair
  • Consider prophylactic anterior compartment fasciotomy
Treatment

Image from R&W Fractures in Children 9th Ed. Algorithm 26-1
Complications

• Compartment syndrome
  • Risk of bleeding from anterior tibial recurrent artery
    • Near base of tubercle

• Low rate of tendon avulsion (2%), meniscal tear (2%), & cruciate ligament laxity (1%)
  (Pretell-Mazzini et al, JPO 2016)
Intra-articular Knee Injuries
Intra-articular Knee Injuries

Differential diagnosis for acute hemarthrosis within 2 hours of injury includes:

- Tibial eminence fracture
- Patellofemoral dislocation
- Osteochondral fracture
  - Typically associated with a PF dislocation
- Cruciate ligament rupture
- Peripheral meniscal tear
Tibial Eminence Fractures

- Most commonly caused by bike accidents & athletic injuries (Meyers & McKeever JBJS 1959)
- Chondroepiphysseal avulsion of ACL
  - Incompletely ossified tibial spine weaker to tensile strength than ACL
- Mechanism: forced valgus and external rotation of tibia

Associated injuries:
- 37% associated meniscal injury\(^{15}\)
  - Increased incidence with age, Tanner stage & pubescence
  - 90% involved lateral meniscus
    - Anterior horn remains attached to tibial spine fragment\(^{28}\)
    - Collateral ligament injury uncommon

Tibial Eminence: Evaluation

Lateral imaging helps determine:

- Fracture classification
- Amount of displacement
- Size of fragment
- Degree of comminution
- Status of physis
- Entrapped soft-tissue

MRI may be helpful to assess concomitant injuries (Ishibashi et al, CORR 2005)
Myers & McKeever Classification

*Modification by Zaricznyi

Closed reduction + Long leg casting

Type 1
Minimally displaced

Type 2
Posterior hinge intact

Open vs arthroscopic reduction and internal fixation

Type 3
Complete separation

Type 4*
Comminuted

Image adapted from R&W Fractures in Children 9th Ed. Figure 27-4
Treatment: Type I & II

• Knee aspiration & reduction in extension
• If < 3mm of displacement – long leg cast in 10° flexion x 4 to 6 weeks, followed by hinged brace
• If >3mm of displacement or block to extension – open vs arthroscopic reduction +/- internal fixation
• Meniscus may block anatomic reduction
  • Kocher et al. entrapment of anterior horn of medical meniscus, lateral meniscus or intermeniscal ligament in 26% of type II fractures and 65% of type III (Kocher et al, AJSM 2003)
  • Entrapment may cause knee pain after fracture healing (Chandler et al, Arthroscopy 1995)
Treatment: Type III & IV

• Open or arthroscopic reduction

• Fixation options include:
  • Transosseous suture, screw, K-wire, suture anchor
    • Similar strength between bioabsorbable and metallic screw\textsuperscript{30}, and nonabsorbable vs absorbable suture\textsuperscript{27}
    • Increased strength with suture fixation over internal fixation\textsuperscript{8} \& \textsuperscript{14}
    • Inconsistent strength with suture fixation\textsuperscript{3}
  • For Type IV fractures suture fixation is preferred
Complications

• Loss of extension (60%)
• Arthrofibrosis (10%)
  • Early motion minimizes risk
• Residual knee laxity
  • Common occurrence
  • Rarely symptomatic
• Nonunion
• Malunion
  • May cause mechanical impingement in extension
  • Growth disturbance
  • Due to hardware crossing proximal tibial physis resulting in recurvatum deformity or shortening

Image from R&W Fractures in Children 9th Ed. Figure 27-13
Osteochondral Fractures

• Associated with acute patellar dislocation (19-50%)\textsuperscript{34}
  • Either dislocation or relocation of patella can cause fracture
  • Less common for chronic dislocations due to soft tissue laxity

• Most common locations: inferior medial patellar facet, lateral aspect of lateral femoral condyle

Mechanism:
1) direct blow to knee with shearing force to LFC or MFC
2) flexion rotation injury internal rotation of tibia on a fixed foot w/ quad contraction
Osteochondral Fractures

• Shear stress in juvenile joint \( \rightarrow \) forces transmitted to subchondral bone by interdigitating cartilage resulting in failure at porous trabecular bone interface\(^{16}\)
  - Fragments often contain subchondral bone and are visible on XR
  - XR fail to detect fragment in 36% of cases\(^{30}\)

• MRI helpful in diagnosis of the injury
  - Can also aid in differentiating osteochondral versus chondral-only fragments

Image from R&W Fractures in Children 9th Ed. Figure 27-17B
Treatment

Based on:
• Patient age & activity level
• Size, location & viability of fragment
• Degree of surrounding injury

Fixation indicated for:
• Large pieces
• Sufficient bone attached
• Central weightbearing fragments

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**Small fragment (<5mm)**
- Chronic loose body
- Poor subchondral bone
- Non-weight bearing area
- Potential to cause mechanical symptoms

**Removal of Loose Bodies**

**Large fragment (>5mm)**
- Acute fracture (<6 weeks)
- Adequate subchondral bone
- Weight bearing surface

**Fragment Fixation**

+/− Medial patellofemoral ligament repair, proximal medial retinacular repair, lateral retinacular release

Adapted from R&W Fractures in Children 9th Ed. Algorithm 27-2
Complications

- Arthrofibrosis
  - Treat with aggressive therapy & dynamic splinting during first 3-4 mo. (Pace et al., JPO 2018)

- Loss of fixation/nonunion

- Osteoarthritis
  - Excision of large weightbearing fragments predictably leads to degenerative changes (Anderson et al., AJSM 1997)

- Repeat patellar dislocation
  - Controversial whether concomitant MPFL repair decreases risk of recurrent instability
Patella Fractures

• Patella ossifies at 3-5 years of life
• Injury is rare because patella mostly cartilaginous and has greater mobility than adults
• Avulsion fractures are more common in children than adults

Mechanism:
• Eccentric quadriceps contraction
• Direct blow
  • Results in comminuted pattern
Examination

- Painful, swollen knee
- Inability to extend knee
- Hemarthrosis
- Patella alta

- Palpable defect at affected patellar pole
- Apprehension test may be positive if fracture secondary to patellar dislocation

- Sagittal plane fractures best seen on sunrise view
- Comparison views of contralateral side may be helpful
  - Sleeve fractures – may only contain small subchondral fragment

Image courtesy of Greg Osgood, MD
Classification (Grogan JPO 1990)

**Primary Osseous Fractures**

**Avulsion Fractures:**

- NO significant avulsion of cartilage
- Superior, inferior, medial (often w/ acute patellar dislocation), lateral (chronic stress from repetitive pull of vastus lateralis)

**Sleeve Fractures:**

- Avulsion of pole of patella WITH a large portion of articular cartilage
  - Cartilage, retinaculum, and periosteum may be involved
- Typically occur at inferior or superior poles
Treatment

Closed treatment with long leg casting

Indications:
1. Extensor mechanism intact
2. < 2-3mm of articular displacement

Open reduction and internal fixation:
- AO tension band, cerclage wire/nonabsorbable suture, interfragmentary screws
  - Sutures alone sufficient for sleeve fractures
- Recommended to repair retinaculum
- Splint for 4-6 weeks

Left: image courtesy of Alfred Mansour, MD (2016 version)
Right: image courtesy of Greg Osgood, MD
Summary

• Extra-articular knee injuries require an anatomical reduction to prevent physeal arrest, malalignment, and leg length discrepancy

• Fixation must be adequate to prevent loss of reduction while respecting the biology of the physis
  • Postoperative supplemental splint/cast may be necessary

• Understand the differential diagnosis of acute knee effusion and strategies for managing intra-articular fractures in the pediatric knee
References


Figure References

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