Fun with the Physis
A Review of Growth Patterns, Important Pathology, and How it Changes Management

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No Disclosures
Learning Objectives

- Review the anatomy of the physis and the normal development patterns of long bones.
- Illustrate and discuss important congenital and acquired pathology involving the physis, underlying pathologic mechanisms, and key components of clinical management.
- Illustrate how traumatic injuries in the pediatric population differ from those in adults as a result of having physes in varying states of maturation.
- Discuss important normal anatomic and developmental variants of the physis which can mimic disease.
Anatomy of the Physis

- Epiphyseal Unit
- Secondary Ossification Center
- Metaphyseal Vessels
- Nutrient Vessel
- Epiphyseal Vessels
- Secondary Physis

Articular Hyaline Cartilage

Bone
Physis
Zone of provisional calcification (ZPC)
Metaphyseal spongiosa

(Ecklund et al. 2001, Trueta et al. 1960)
Long bone growth occurs due to longitudinal extension of a cartilage model at the epiphyseal margin of the physis. The chondrocytes mature as they move towards the metaphysis where calcification and subsequent ossification occur.
Anatomy of the Physis

**Zone of Reserve**
- Relatively high proportion of matrix
- Quiescent germinal cells
- Injury here results in growth cessation

**Zone of Proliferation**
- Active mitosis; cells multiply in columns, resulting in longitudinal growth

**Zone of Hypertrophy**
- Chondrocytes mature, terminally differentiate, swell, and develop vacuoles
- Weakest part of the physis

**Zone of Provisional Calcification**
- Chondrocytes die, releasing calcium and resulting in calcification of the matrix
- Dense on radiographs/CT

**Metaphyseal spongiosa**
- Rich in capillaries
- Site of newly formed bone
Anatomy of the Physis

On MRI, the physis has a typical trilaminar appearance with a central hypointense line (the zone of provisional calcification) and thin hyperintense lines on either side representing the physis and the metaphyseal spongiosa.

Physis (between arrows)

Germinal
Proliferative
Hypertrophic
Metaphysis

ZPC

Metaphyseal Spongiosa
Normal Maturation of the Physis

- Early on, the epiphyseal unit is made of thick, T2 hyperintense epiphyseal cartilage (chevrons) which early on is indistinguishable in signal intensity from articular cartilage and ossifies over time.

- The thick, trilaminar appearance of the physis (arrows) becomes more narrow and undulating in contour (white arrowheads) as children near skeletal maturity.

- Eventually, the last chondrocytes convert to bone result in loss of the T2 hyperintense physis (black arrowheads).
Patterns of Physeal Closure

- Physeal closure begins centrally and extends peripherally at many of the larger physes, like the distal femur and proximal tibia.

- The medial clavicle is the last physis to close, at around age 20-25 years.
Patterns of Physeal Closure

Distal Tibia: Kump’s Bump
The distal tibial physis begins anteromedially, at a convex-upward deflection of the physis known as “Kump’s Bump” (arrow). Do not mistake Kump’s Bump for a fracture or physeal bar.

Distal Humerus: CRITOE
This familiar acronym helps with remembering the order of appearance of the secondary ossification centers of the elbow: Capitellum at age 1, Radius at 3, Internal (medial epicondyle) at 5, Trochlea at 7, Olecranon at 9, and External (lateral) epicondyle at 11.
Different physes contribute unequally to the overall growth of long bones, but do so in a predictable way.
Which physes grow the most?

Imagine looking at the profile of a person drinking a beer while in the bathtub. The physes which would be seen above the water are those which contribute the most to long bone growth. These include the proximal humerus, the distal forearm, the distal femur, and the proximal tibia and fibula.

(Mnemonic courtesy of Lee Segal, MD)
Physeal Fractures: Salter Harris Classification

- **Type I**
  - 5-7% of physeal fractures
  - Imply a shearing or avulsion mechanism; periosteum is typically intact
  - Radiographs can be normal or show physeal widening or offset

- **Type II**
  - Most common, at 75% of physeal fractures
  - Result in a triangular shaped fragment of metaphysis, called a “Thurston Holland” fragment

- **Type III**
  - 7-10% of physeal fractures
  - Intra-articular

- **Type IV**
  - 10% of physeal fractures
  - Intraarticular
  - Higher risk of growth complications due to introduction of transphyseal vascularity

- **Type V**
  - Rare, <1% of physeal fractures
  - Described as crush injuries
  - Highest risk of growth complications
Salter Harris Type I injuries are postulated to occur due to the relative weakness of the epiphyseal plate compared to the surrounding ligaments and tendons.

However, subsequent research suggests that this may not be true, at least not in all locations:

A recent study of 135 pediatric patients (age 5-12) with clinically suspected distal fibular Salter Harris I (SH1) injuries with negative radiographs were braced for 1 week and then underwent ankle MRI:

- Only 3% of patients had SH1 injuries
- 80% had ligamentous injuries, some (35%) associated with radiographically occult distal fibular avulsion fractures
- All 135 patients were braced and allowed to return to weight-bearing as tolerated, without any difference in functional outcomes at 1 month between patients with fractures and those without.

(Boutis et al. 2016)
Fractures: Location, Location, Location

The ability of a fractured bone to remodel and correct residual malalignment or angulation depends on the expected future growth at the fracture site, which is determined by the site of the fracture and how near the patient is to skeletal maturity.

(a) Persistent mild angulation or displacement of a radial metaphysis Salter Harris II fracture (arrows) can still be managed conservatively, since the distal radius is predicted to undergo significant growth and remodeling.

(b) However, a similar degree of angulation at the distal humerus (arrowheads) would require surgical correction (c) to avoid a potentially unacceptable deformity when the patient matures.
Tillaux Fracture

- Horizontal fracture through the unfused lateral physis of the distal tibia. The medial physis is often fused or nearly fused.

- Vertical fracture through the lateral epiphysis

- The metaphysis is spared: Salter Harris III pattern

Above: Left ankle AP radiograph and coronal CT image of a 15-year old male presenting after falling from a motorcycle. Widening of the lateral physis of the distal tibia and a vertical epiphyseal fracture of the lateral epiphysis (dashed lines) result in a 3 mm step-off at the articular surface (arrowhead). Left: Axial CT image demonstrates the isolated fragment of the anterolateral epiphysis (arrow). The degree of articular step-off required surgical reduction and fixation.
Triplane Fracture

- Coronal fracture through the posterior metaphysis of the distal tibia
- Horizontal fracture through the lateral physis
- Vertical fracture through the lateral epiphysis
- Salter Harris IV pattern
- Patients are less skeletally mature than Tilleaux patients

Above: AP and coronal CT images of a 13-year old male presenting after a twisting injury while wrestling. In addition to the vertical epiphyseal fracture and the horizontal fracture through the physis, a coronal fracture isolating the posterior malleolus is present (dashed lines).

Left: Mortise and lateral radiographs of the ankle. The coronal portion of the fracture (arrows) is radiographically subtle. The articular surface step-off measures <2 mm in width (arrow); this fracture was managed non-operatively.
- **Common Mechanism:** Forced Supination-External Rotation

- Since both are transitional injuries, i.e. occurring in patients approaching skeletal maturity, the risk of growth complications (angulation, leg length discrepancy) is low

- As intra-articular fractures, they pose a risk of secondary osteoarthritis. Persistent articular surface gap or step-off of >2mm is an indication for surgical correction
13-year old male presenting after an injury during a soccer game: Right lateral ankle radiograph (a) demonstrates an angulated and mildly displaced Salter-Harris II fracture of the distal tibia (white chevron) with a mildly angulated fracture of the distal fibular (black arrowhead). Post-reduction radiographs (not shown) demonstrated persistent widening of the anterior tibial physis, prompting further evaluation with MRI. Sagittal T1 and STIR images of the right ankle (b-c) demonstrate the widened physis (white arrowheads) and a thin T1- and T2- hypointense band of periosteum (arrow) interposed within the anterior physis.
Physeal Fractures: Periosteal Entrapment

• Reduction of displaced physeal fractures can result in interposition of soft tissue (often periosteum but torn or dislocated ligaments and tendons can also interpose)

• Physeal widening > 3 mm or incomplete reduction on post-reduction radiographs is suspicious for entrapment and MRI is warranted.

• Periosteal entrapment is a risk factor for premature physeal closure and/or physeal bar formation, postulated to be due to the bone-forming reaction of periosteum in response to injury

• A study in sheep showed that physeal bars or arrest occurred significantly more frequently when periosteum was interposed in surgically created physeal injuries compared to when epiphyseal cartilage was interposed.

(Chen et al. 2015, Wirth et al. 1994)
Mimic of Pathology:
Focal Physeal Edema (FOPE) Zone

- Small linear or flame shaped areas of high T2 signal emanating from either side of the physis
- Commonly found in the physes of adolescent patients (femur > tibia > fibula)
- Typically occur at the site of earliest physeal fusion
- Usually an incidental finding, but can be symptomatic (Zbojniewicz et al. 2011)

14-year old male with right patellofemoral syndrome. Sagittal T2-weighted MR image (a) demonstrates a linear area of high signal radiating obliquely from the central closing physis (arrows), compatible with a FOPE. Coronal T2 weighted image (b) demonstrates the FOPE (chevron) at the site of the fused central physis; the peripheral aspects of the physis remain open (arrowheads).
Bracketed Epiphysis: Clinodactyly

An longitudinal bridge of bone connecting the distal and proximal epiphyses of the small finger middle phalanx (arrow) and small toe (arrowhead) results in a ‘bracketed’ epiphysis.

Restricted growth of the radial/lateral side of the bone causes characteristic inclination of the distal finger towards the radius/great toe, a finding called clinodactyly.

Clinodactyly most commonly involves the middle phalanx and the small finger. While it can be sporadic, it is also associated with several syndromes (Trisomy 21, Apert Syndrome)
Post-Traumatic Genu Valgum: Cozen’s Phenomenon

- A rare complication of proximal tibial metaphyseal fractures of young children

- Sometimes delayed in presentation, arising even after the fracture has healed radiographically

- Often the valgus deformity resolves spontaneously, although surgical hemiepiphyseodesis can be performed for patients with persistent deformity

- Thought to be due to overgrowth of the tibia as part of the healing response, while the proximal tibiofibular joint acts as a lateral tether

(Burton et al. 2016, Dorman et al. 2013)
Post-Traumatic Genu Valgum: Cozen’s Phenomenon

Above: 11-month old female found to have a minimally displaced fracture of the left proximal tibial metaphysis (arrowheads) after a fall. Follow-up radiographs demonstrate ongoing fracture healing.

Right: Serial standing TVO series of this patient reveal progressive downsloping of the lateral tibial metaphysis (arrow) with mild genu valgum at age 22 months. The patient had a mild gait abnormality. She will continue orthopedic follow-up until either her alignment normalizes or it progresses to the point of requiring surgical correction.
Post-Traumatic Epiphyseal Ischemia: “Fishtail Deformity”

• Traumatic injury to the developing physis can rarely result in the lack of further growth and the appearance of central distal humeral concavity due to the adjacent normal growth.

• Patients present with limited range of motion and pain from secondary degenerative changes, intra-articular bodies, cubitus valgus deformity, or radial head subluxation.

16-year old female with a history of displaced supracondylar fracture as a child. AP radiograph of the left elbow (a) demonstrates focal concavity of the distal humerus (arrow). Coronal T2 MRI image (b) demonstrates focal bone marrow edema (black arrowhead) and subchondral cyst formation (white arrowhead).

(Narayanan et al. 2015)
2-year-old male with avascular necrosis of left femoral head. AP radiograph (a) shows subtle lucency of left femoral head ossification center (arrow). Coronal MR post-contrast image (b) shows epiphyseal fragmentation and non-enhancement (chevron). Follow-up at 4.5 years (c) shows a flattened left femoral head with narrowed and irregular physis. Note central metaphyseal bony peak (arrowhead) and phyeal narrowing of remaining physis suggesting impending closure.

- Legg-Calve Perthes typically presents in pre-adolescent children as a painful limp
- Underlying pathophysiology is uncertain; LCP is idiopathic and is a diagnosis of exclusion
- Risk factors include male sex, white/Caucasian ethnicity
- It can be bilateral; bilateral cases are often asynchronous
- Patients who present at older ages have worse outcomes

(Dillman et al. 2009)
Slipped Capital Femoral Epiphysis (SCFE)

9-year-old obese presenting with right hip pain and inability to bear weight after a twisting injury. AP radiograph of the pelvis (a) shows subtle medial offset of the right capital femoral epiphysis (arrow). Frog-leg lateral view of the right proximal femur (b) confirms epiphyseal slippage (arrowheads).

- Abnormal mechanical forces on the maturing proximal femoral physis result in instability of the femoral head, which eventually slips posteriorly and medially.
- Patients present in early adolescence with hip pain or, less commonly, knee pain.
- More common in obese children, boys, and black children.
- Treatment is typically percutaneous fixation to prevent further slippage, and long-term follow-up to detect complications.

(Boles et al. 1997)
5-year old female treated as an infant for bacterial septic arthritis of the left with antibiotics and surgical washout, presenting with left length discrepancy: AP radiograph of the left ankle (b) demonstrates focal central indistinctness of the physis (black arrowhead) compared to the normal contralateral side (a) and a vertically oriented sclerotic band in the metaphysis (arrows).

Sagittal fluid sensitive MRI image (c) confirms a central physeal injury (white arrowhead), with upward physeal displacement towards the metaphysis. The vertically oriented irregular band on the radiograph is seen as a T1-hypointense T2 hyperintense irregular channel in the metaphysis that tethers the physis (black arrows), probably sequelae of prior infectious osteonecrosis.
Blount’s Disease

• Postulated to be due to abnormal mechanical forces on the developing physis

• More likely to occur in:
  – Early walkers
  – Black children
  – Children who are large for their age

• Usually unilateral or asymmetric
  – In contrast to physiologic bowing which is typically symmetric

• Though many cases resolve spontaneously, severe cases can result in progressive gait abnormality, meniscal pathology, tibial subluxation or genu recurvatum. Surgical treatment options include guided growth and femoral/tibial rotational osteotomy.

3-year old female presenting with genu varum: Standing TVO images demonstrate medial downsloping of the left proximal tibial metaphysis and epiphysis (arrow), with epiphyseal fragmentation

(Cheema et al. 2003)
Blount’s Disease: Complications

14-year old male followed for Blount’s disease since age 10, now with knee pain and continued mild varus deformity.

AP knee radiograph: In addition to mild medial downsloping of the proximal tibial epiphysis, there is a band of linear sclerosis emanating from the medial physis (arrow).

Coronal T1 and STIR MR images: Periphyseal low signal on the T1-weighted image confirms sclerosis arising from a small medial physeal bar (chevron). There is associated reactive edema on the fluid-sensitive image (arrowheads). More medially, the physis remains open.
Summary & Key Points

• The slow progression from open physis to closed results in unique patterns of injury and a remarkable range of variation among normal individuals.

• The management of patients with physeal/epiphyseal pathology is driven in large part by the location of the injury, the potential for growth at that specific location, and how near the patient is to skeletal maturity.

• Physeal injuries can occur due to a range of mechanisms (trauma, infection, altered biomechanics, idiopathic), all of which can result in the end complications of premature physeal closure or physeal bridge formation.

• Close attention to the physes on pediatric imaging studies, especially in the setting of known injuries, can help identify complications early and direct the patient to appropriate treatment.
References


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