Nuts and Bolts
A Radiologist’s Guide to Orthopedic Hardware Utilized in the Lower Extremities of Children

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Learning Objectives

• Understand the basic anatomy and physiology of the long bone physis

• Gain familiarity with basic tenets of pediatric orthopedic surgery useful for radiologists to understand

• Recognize orthopedic implants used in the lower extremities through an image-rich atlas providing radiographic, fluoroscopic, and photographic correlation
No Disclosures
Long bone growth occurs due to longitudinal extension of a cartilage model beginning 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**
Quiescent chondrocytes surrounded by a relatively high proportion of acellular matrix

**Zone of Proliferation**
Site of mitosis, where 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
Patterns of Physeal Closure

- A typical pattern is for physeal closure to begin centrally and extend peripherally, as seen in the distal femur and proximal tibia.

- The medial clavicle is the last physis to close, at around age 20-25 years.
Unequal Contribution to Growth

Different physes contribute unequally to the overall growth of long bones, but do so in a predictable way.
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)
Fractures: Location, Location, Location

The ability of a fractured bone to remodel and correct residual malalignment depends on expected future growth at the fracture site, which is determined by both age and location.

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

(b) However, a similar degree of angulation at the distal humerus (arrowheads) which undergoes significantly less growth would require surgical correction (c) to avoid a potentially unacceptable deformity when the patient matures.
Important Differences Between the Pediatric and Adult Musculoskeletal Systems

In addition to open physes:

**Periosteum:** Thicker, more vascular and more metabolically active in children than adults. This contributes to faster healing in children.

**Ligaments and tendons:** In children, ligament and tendon attachments are stronger than the attachment between the bones on either side of a physis. This results in the relatively high frequency of avulsion fractures in pediatric patients compared to adults, and helps explain the tendency for pediatric fractures to extend into the physis.

This gradually changes as the patient matures. This is why pivot shift injuries result in tibial spine avulsion fractures in school age children, whereas the same mechanism tends to result in ACL tears in adolescents.
Hardware Around The Physis

• Orthopedic surgeons placing hardware near the joints of skeletally immature patients must carefully consider the location and status of the physis.

• Efforts are made to avoid traversing the physis with drills, screws and plates.

• If the physis must be crossed, the smallest caliber device should be used to minimize the potential for growth arrest or physeal bar formation. Traditional K wires are good options, as they are very small in caliber and lack threads.

The surgical approach to repairing this Salter-Harris type IV fracture in the distal femur on this 14-year old boy includes fracture reduction and placement of several cancellous screws across the fracture, but care is taken to avoid traversing the distal femoral physis.
### Basic Hardware Overview

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*Diagram showing examples of hardware and their applications.*
Cortical Screws

• Have small threads along their entire length

• Often engage both sides of the cortex, a.k.a. “bicortical screws”

• Narrow pitch. “Pitch” refers to the distance between the threads of the screw. Screws with narrow pitch have threads spaced very closely together

• Can be ‘self-tapping’, implying a fluted end that can be drilled directly into bone without requiring a pre-drilled hole

17-year old girl status-post tibial tubercle transfer for patellar instability. Two bicortical screws affix the tubercle in place.
a) 16-year old girl status-post MCL reconstruction. Fully threaded cancellous screw holds the proximal ligamentous graft in place.

b) 14-year old girl status-post internal fixation of juvenile Tillaux fracture. Three partially threaded cancellous screws were placed, taking care to spare the closing physis.

Cancellous Screws

- Wider pitch with larger threads to gain purchase into cancellous bone (trabeculae)
- Can be fully or partially threaded
Lag Screws

- The ‘lag’ descriptor implies that the screw is used to apply compression between two bone fragments, and can be used to describe both cortical and cancellous screws.

a) 17-year old girl with a fracture of the base of the 5th metatarsal (gold arrows). The non-threaded portion of the cancellous screw traverses the fracture, resulting in compression applied across the fracture between the screw head and the threaded portion of the screw.

b) The aim is to apply compression across the two fragments of a fracture (black arrowheads).

c) A screw tract is drilled perpendicular to the fracture. The proximal screw tract is overdrilled, so the diameter of the screw tract is slightly larger than the screw diameter (gold arrowheads).

d) When the cortical screw is placed, the threads engage the distal but not the proximal bone, pulling the distal bone towards the screw head (red arrows).
Standard Orthopedic Stabilization Plate

- Used to hold bone fragments in a desired position

16-year old boy with comminuted Weber C distal fibula fracture with syndesmotic ligament rupture. a) A lateral fluoroscopic image demonstrates cortical lag screws which are placed first (gold arrows) to apply compression between the bone fragments. b) AP fluoroscopic image demonstrates the stabilization plate subsequently fixed in position using both cortical screws (black arrowheads) and cancellous screws (red arrowheads), placed through circular shaped holes. A long cortical screw is used to bridge the disrupted ankle syndesmosis (red arrow).
Dynamic Compression Plate
• Applies compression across the fracture fragments.

Dynamic Compression Plate
Oval shaped plate holes allow for eccentric drilling of screw holes. The screws can be placed eccentrically within the oval on the side closest to the fracture (red arrow); this helps to pull the two bone fragments together.

Low Contact Plate
A subtype of plate that has one scalloped surface (gold arrowheads). The scalloped side abuts the cortex. The interrupted contact is theorized to decrease vascular compromise to the periosteum, since periosteal blood flow is a critical component of fracture healing.

Deep side which abuts the periosteum
Superficial side
Locking Plates and Screws

- Both the holes in the plates and the heads of the screws are threaded.

- The threads on the screw head engage the threads on the plate, minimizing motion between the bone, plate and screws.

Example of a locking screw and plate. This plate has figure-of-8 shaped holes, which make this a “combination” style of locking plate. The smaller holes are locking holes (red arrow), with threads that fit locking screws (gold arrowhead). The larger holes (gold arrow) are non-threaded and accept regular cortical or cancellous screws.
Summary of Screw Types

- **Self Tapping Cortical Screw**: Narrow pitch with a fluted end
- **Self Tapping Locking Cortical Screw**: Threaded head, very narrow pitch with a fluted end
- **Fully Threaded Cancellous Screw**: Wide pitch
- **Partially Threaded Cancellous Screw**: Wide pitch; commonly used as lag screws
- **Tapping Locking Cortical Screw**: Threaded head, very narrow pitch with a fluted end
- **Self Tapping Cortical Screw**: Narrow pitch with a fluted end
Hemiepiphyseodesis Plate

- Used to slow/stop growth at one side of an open physis. The normal growth plate is sacrificed in hopes of correcting malalignment.

- Result in asymmetric guided growth to resolve or improve deformities caused by prior trauma, congenital malalignment, or infection.

- Because of their shape, hemiepiphyseodesis plates are sometimes called “peanut plates”

Two examples of peanut plates being used in guided growth. a) 7-year old girl with cerebral palsy and genu varum with patellar instability treated with medial distal femoral hemiepiphyseodesis. b) 13-year old boy with bilateral genu valgum due to multiple hereditary exostoses (MHE). In both cases, growth is hindered on the medial side to correct the valgus deformity.
Reconstruction Plates

- These plates are notched on the sides, allowing them to be contoured to fit bones that do not have flat surfaces.
- Most commonly used in the pelvis to internally fix complicated pelvic fractures.

Two examples of reconstruction plates in internally fixed pelvic fractures. a) 13-year old boy with a right acetabular fracture following a skateboarding accident. b) 15-year old boy with a left acetabular fracture following a fall while snowboarding. Both are held in place with cortical screws.
Blade Plates

- Used most commonly to internally fix bones following osteotomy
- The chisel-shaped end is driven into the bone. The other end is positioned flat against the cortex and affixed with screws
- They vary in their degree of angulation, with 90, 95, and 135 degree options in common use

a) 17-year old boy with a history of previously treated slipped capital femoral epiphysis (SCFE). This patient required osteotomy and blade plating to address a persistent valgus and flexion deformity of the proximal femur

b) 6-year old girl with a history of cerebral palsy and coxa valga status-post bilateral varus derotational osteotomies. The chisel portions of the plates are driven into the femoral metaphysis. Note that the right sided osteotomy is complicated by delayed union (red arrow).
Intramedullary Devices

- Includes rods and nails. The terms are often used interchangeably, but in general rods are smaller in caliber than nails, which usually fill the marrow cavity at its narrowest point.

- Larger bore nails are more stable, but they require reaming of the intramedullary cavity prior to placement to avoid further fracturing/comminution of the diaphysis.

- Reaming can increase the risk of fat emboli syndrome.

8-year old boy with fibrous dysplasia of the proximal left femur (black arrowheads) complicated by pathologic fracture. The femur was reamed in the OR to allow placement of this cephalomedullary nail, with 2 screws extending toward the femoral head to provide stability across the intertrochanteric region. The lack of interlocking screws at the distal aspect of the nail increases compression across the fracture, which can accelerate healing.
Intramedullary Devices

Ender Nails

Thin, flexible intramedullary rods which provide good rotational stability, important for fixation of this spiral fracture of the femur in a 5-year old boy. These are designed to be extracted percutaneously.
Magnetic Lengthening Nails

a) 15-year old boy with Noonan syndrome, short stature and a 4 cm limb length discrepancy (red arrows).
b) Femoral diaphyseal corticotomy is performed (red arrowhead) and the lengthening rod (PRECICE™) is placed and fixed at the metaphysis using interlocking screws (black arrows).
c) The distal segment of the nail is then gradually lengthened using a device that interacts with the magnetic component of the rod (gold arrow to dashed gold arrows), forming a distraction gap across the corticotomy (gold arrowheads).
d) The corticotomy gap heals with bridging callus (black arrowhead), resulting in resolution of the limb length discrepancy.
e) The magnetic component of the nail is seen as a dense rectangle (white arrow) in the proximal aspect of the nail.
Rush Rods

Thin intramedullary rods with a hook at one end (red arrow). Used in this 14-year old boy with osteogenesis imperfecta and recurrent lower extremity fractures. These are also designed for percutaneous extraction.
a) 14-year old boy with a Salter-Harris 4 fracture of the distal femur from a bicycle accident. K wires were used to hold the fragments in anatomic position. Partially threaded cancellous lag screws are then driven over the wires and the K wires are removed.

b) 8-year old girl with a displaced distal femoral metaphyseal fracture from a fall while skiing. Trimmed K wires were used in this case as definitive percutaneous fixation hardware.

**Kirschner “K” Wires**

- Stainless steel pins with sharpened points
- Most are smooth, but threaded options are also available
- Most often used as an intermediate step in fixation. They serve as guides, ultimately being replaced by definitive hardware
- In the smaller bones of the hands and feet and in younger children with overall smaller bone structures, K wires are commonly used as the definitive hardware
Kirschner “K” Wires

- Often placed percutaneously
- Sometimes the wires are trimmed short with the ends left protruding through the soft tissues
- The ends can be capped using plastic balls called ‘olives’ or Jurgan Balls™

a) 12-year old girl with Salter-Harris II fractures of the 3rd-5th metatarsals from a skid loading accident (red arrows) fixed percutaneously with K wires. The wire ends are capped using Jurgan balls (gold arrows, and (b) photo at right).
Two examples of Endobuttons used in pediatric patients. a) 15-year old boy status-post ACL reconstruction and b) 14-year old boy status-post internal fixation of tibial spine avulsion fracture.

Endobutton™

- Tiny titanium plate with a loop of polyester suture
- Used to apply and maintain tension across surgically reconstructed ligaments or repaired tendons

Titanium Plate
Polyester Suture
ACL Graft

Doubled back on itself through the suture, the other ends are secured with a screw.
Summary & Key Points

• Interpreting follow-up examinations for pediatric patients following orthopedic surgery makes up a large part of the practice of both general and pediatric radiologists.

• It is important for the radiologist to have a basic understanding of the principles that guide orthopedic surgeons in the treatment of patients with fractures or malalignment from other causes.

• Utilizing correct terminology to describe hardware in radiologic reports on post-surgical patients builds trust with ordering providers.
References


We hope you enjoyed our exhibit

Please direct any questions or comments for the authors to hallen@uwhealth.org