The Growth Plate: Anatomy and Injuries

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Disclosures

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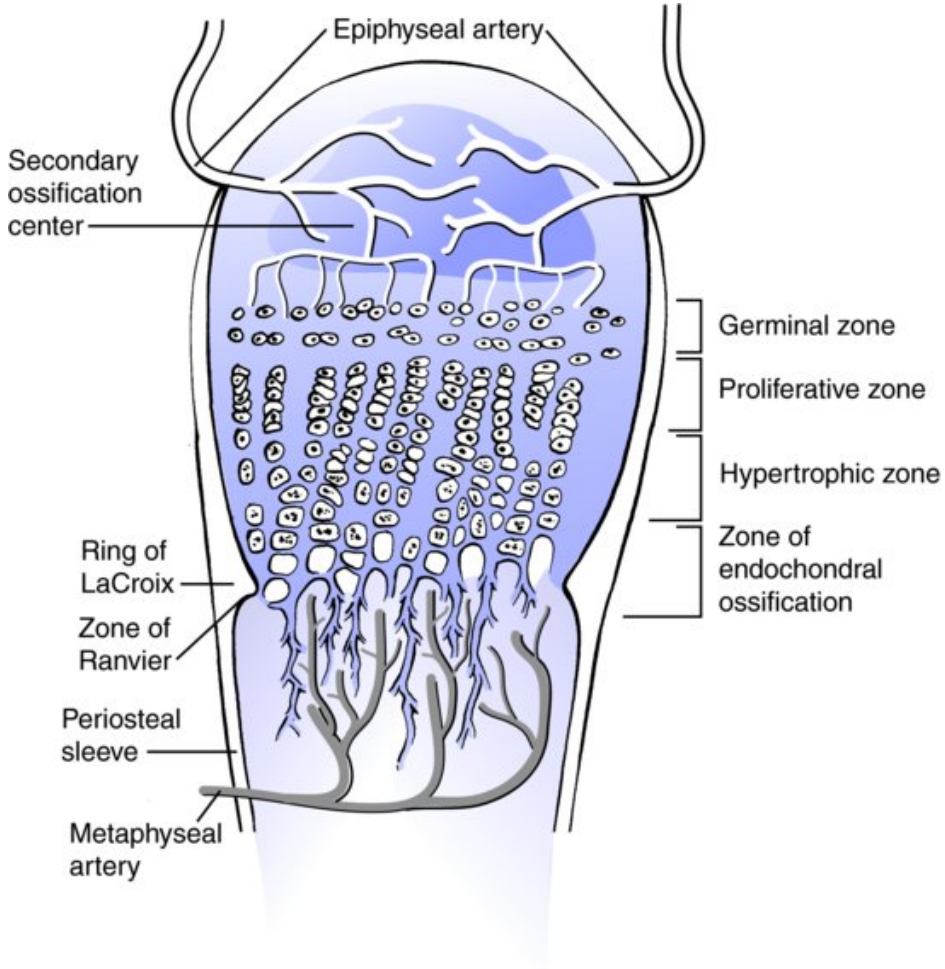
- Addition figures from the authors and editors personal collection

Objectives

- Physeal Fractures: Epidemiology and Etiology
- Salter-Harris Fracture Classification
  - Growth Plate Anatomy
  - Salter-Harris Types and Treatment
- Principles of Treatment
- Growth Plate Disturbance
  - Post Fracture Growth Arrest: What to do?
- Example Cases



Physeal Fractures: Epidemiology

- Incidence of physeal fractures ranges from 14.8%-30% in the literature.

Overall frequency of Fractures
% of children sustaining at least one fracture from0-16yrs of age Boys: 42-60% Girls: 27-40%
% of children sustaining a fracture in 1yr: 1.6-2.1%
Annual rate of fracture in childhood: 12-36/1000

Physeal Fractures: Etiology

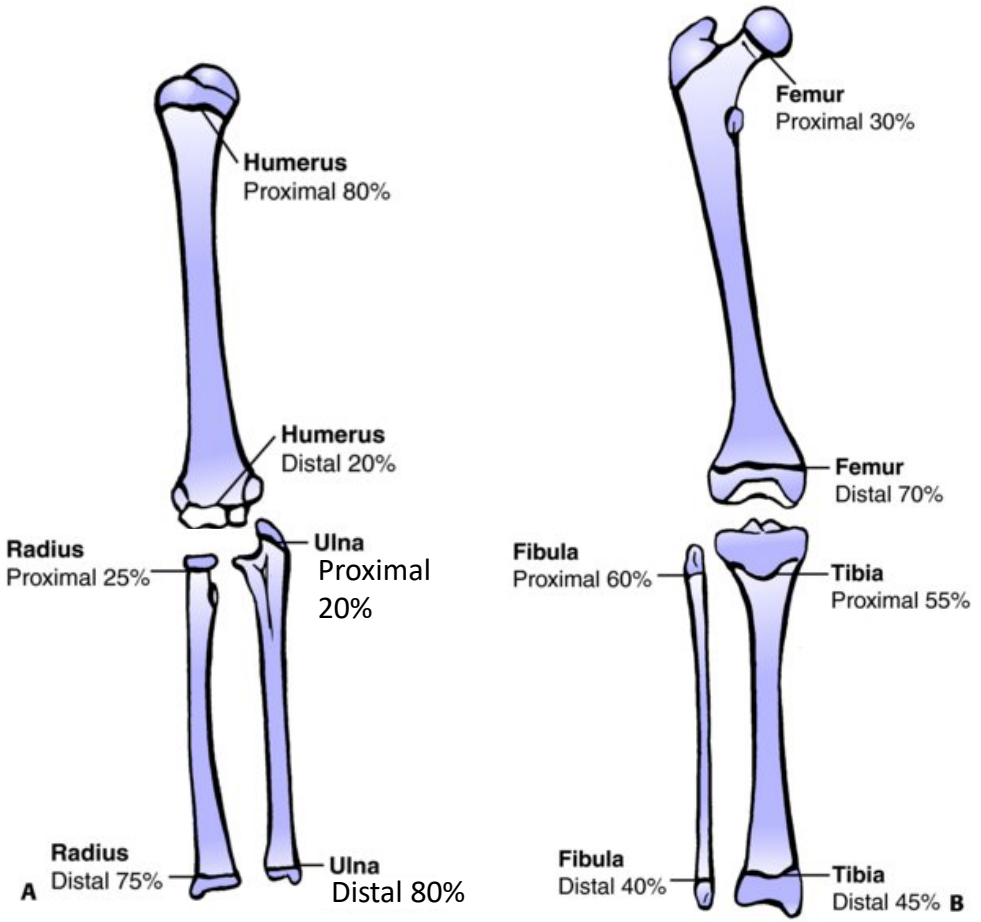
- 3 broad causes:
  1. Accidental Trauma (Sports related activities, Motor Vehicle Accidents)

  2. Non-accidental trauma (Child-Abuse)

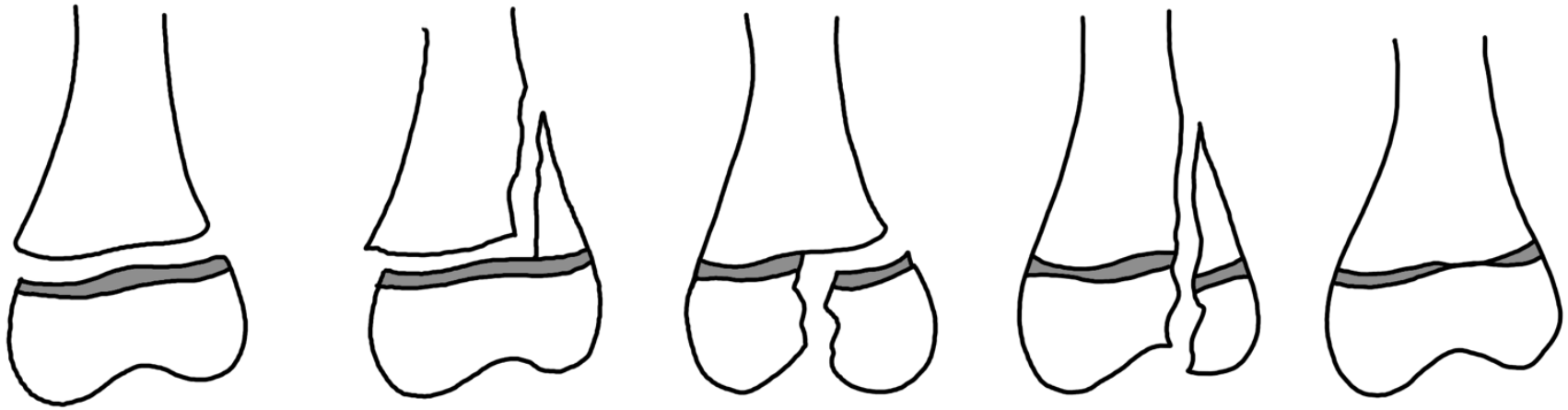
  3. Pathological Conditions

Growth associated to location

Location	Average Growth (mm/yr)	% of bone Longitudinal Growth
Proximal Humerus	7mm	80%
Distal Humerus	2mm	20%
Proximal Radius	1.75mm	25%
Distal Radius	5.25mm	75%
Proximal Ulna	5.5mm	80%
Distal Ulna	1.5mm	20%
Proximal Femur	3.5mm	30%
Distal Femur	9mm	70%
Proximal Tibia	6mm	60%
Distal Tibia	3-5mm	40%



Salter-Harris Fracture Classification



Type	Features
I	Separation through the physis
II	Fracture through part of the physis, extending through the metaphysis
III	Fracture through part of the physis, extending thru the epiphysis into the joint
IV	Fracture through the metaphysis, physis and epiphysis into the joint
V	Compression fracture at the growth plate

Salter-Harris Fracture Classification

I

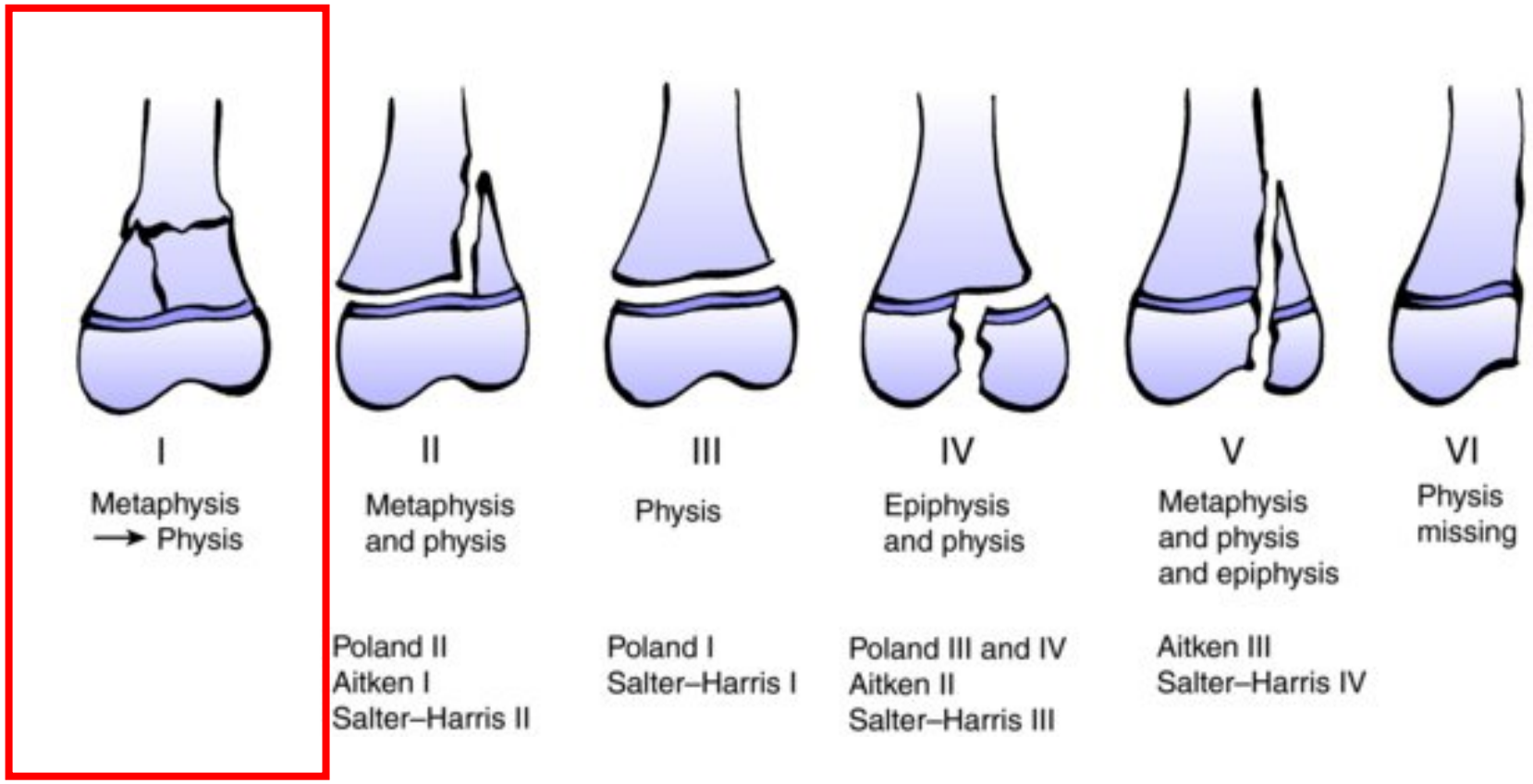
II

MOST COMMON

III

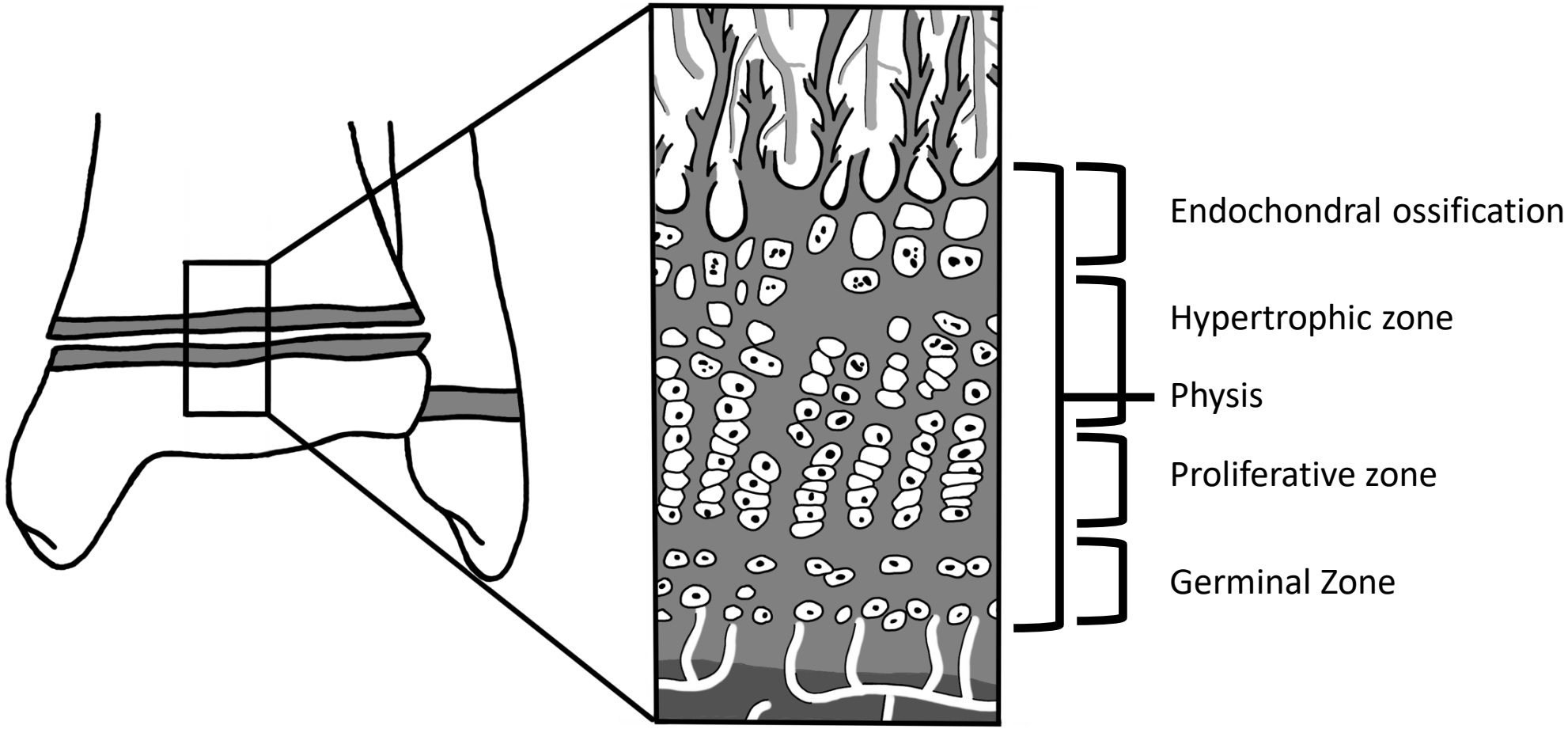
IV

Peterson Classification

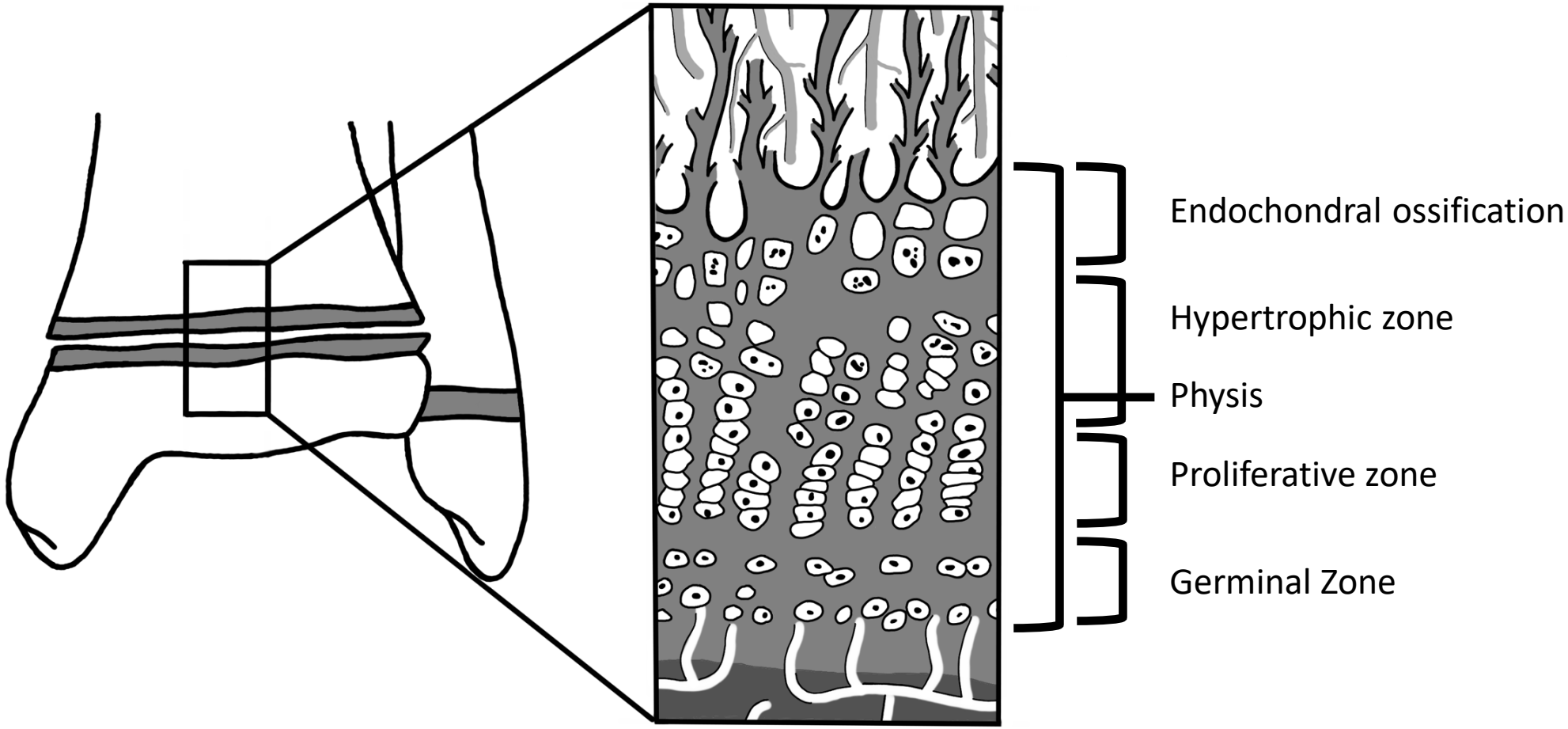


Peterson Type I is not described in other classifications

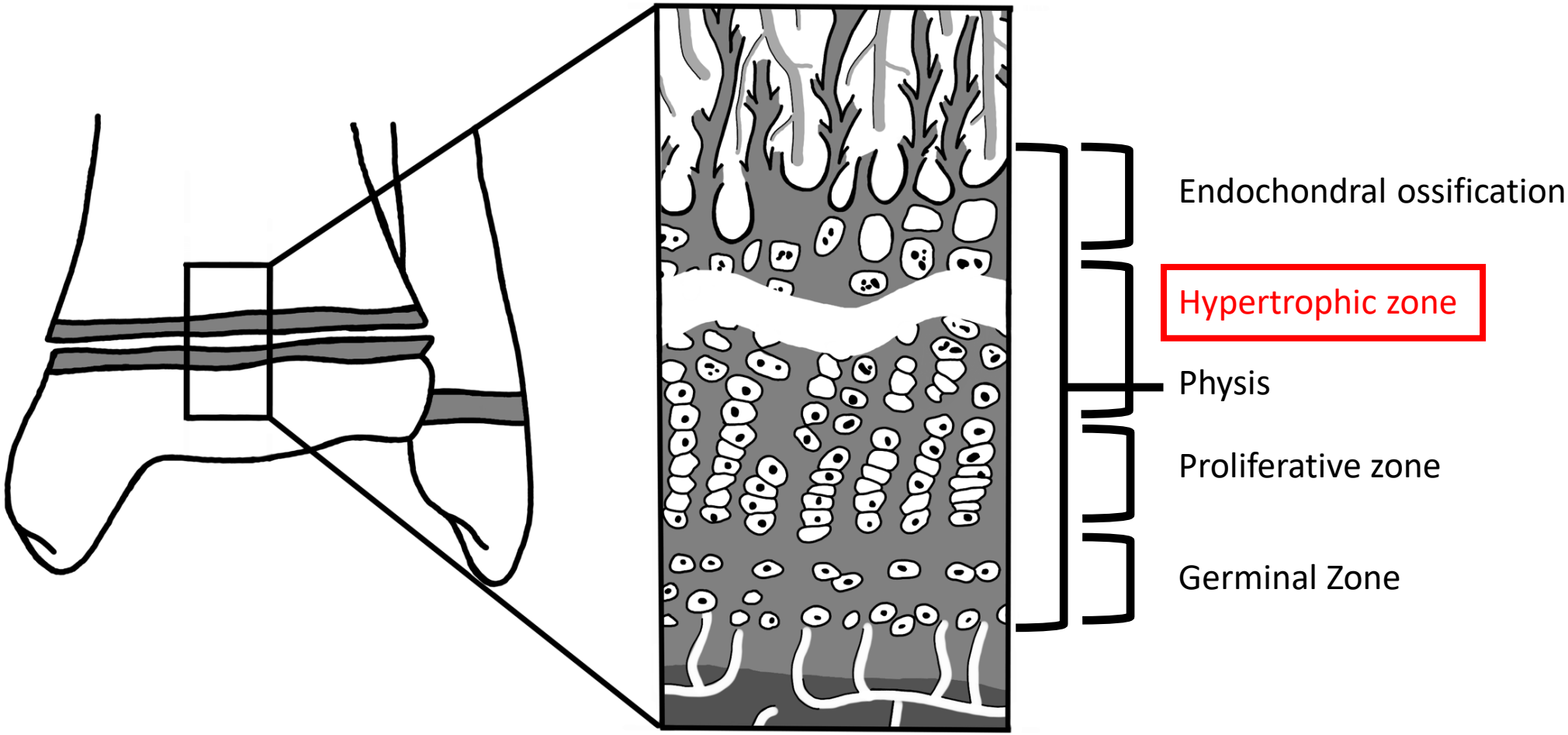
Growth Plate anatomy



Which Growth Plate zone is typically injured in a growth plate injury?



Growth Plate fractures typically involve the **Hypertrophic zone!**

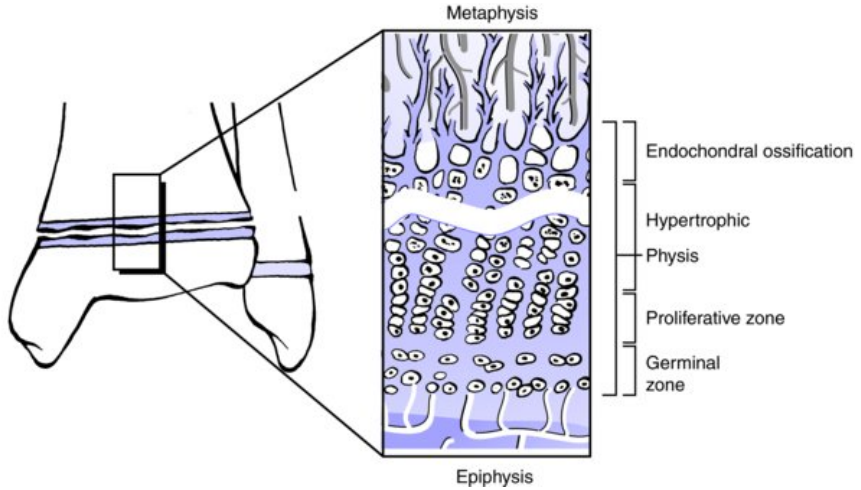


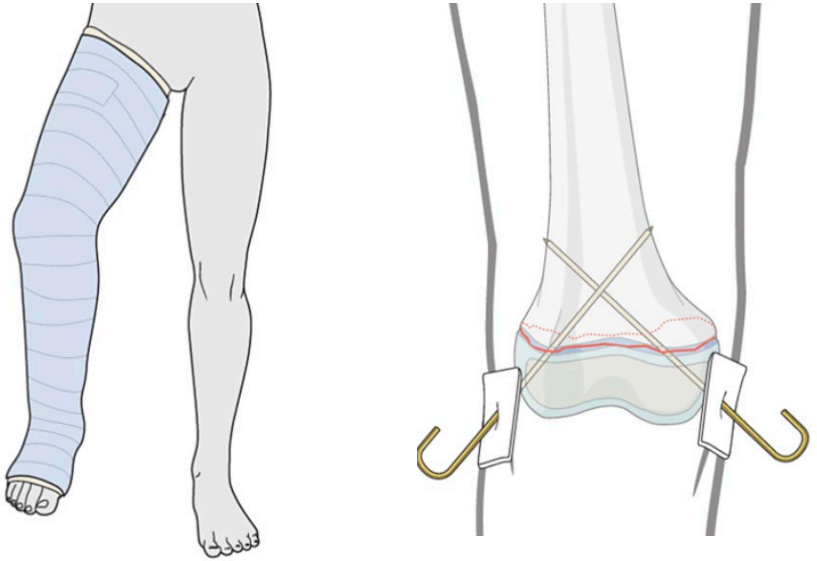
Salter-Harris I

- **Physis only injured**
- Most commonly involves the zone of hypertrophy

- Non-displaced SH1
  - Exam reveals tenderness, swelling at physis
  - Often with normal radiographs
  - Treated with casting/immobilization

- Displaced SH1
  - Exam reveals obvious deformity and pain
  - Displacement seen on radiographs
  - Closed reduction and casting favored
    - Often with percutaneous smooth K-wire fixation

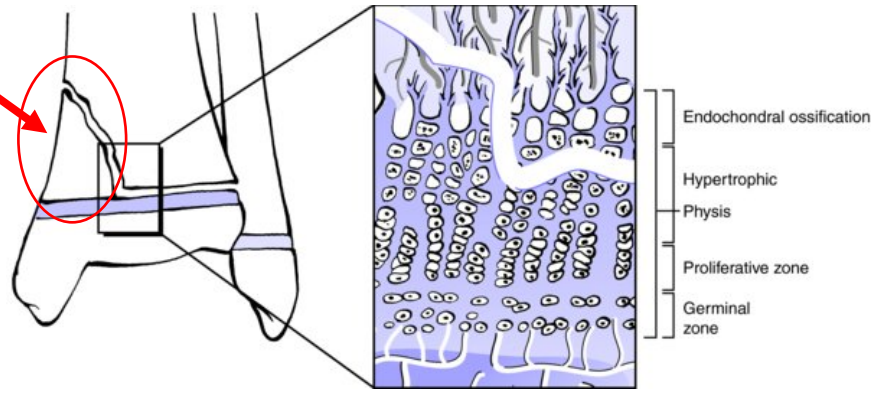




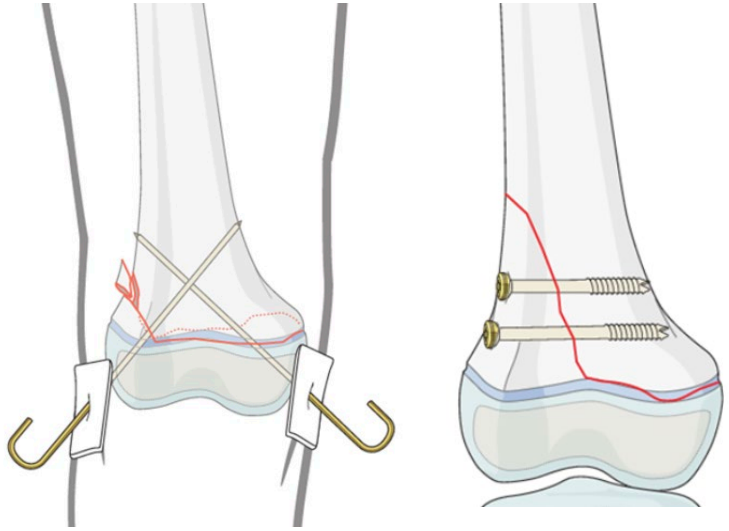
Salter-Harris II

- **Physis & metaphysis injured**
  - *Thurston-Holland* metaphyseal fragment
- Zones of endochondral ossification and hypertrophy fractured

Thurston-Holland fragment

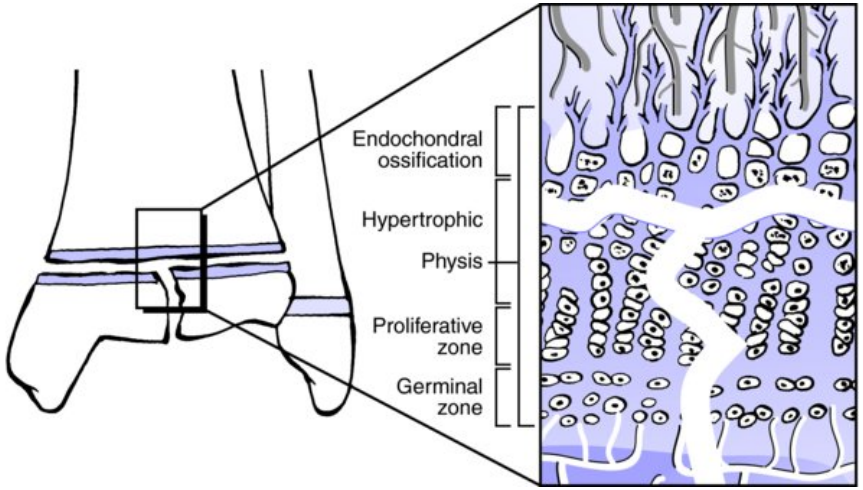


- Treatment options include:
  - Closed reduction and casting
  - Closed reduction and percutaneous screw or wire fixation
    - Screw for larger metaphyseal fragment
    - Wires crossing physis for smaller metaphyseal fragmer

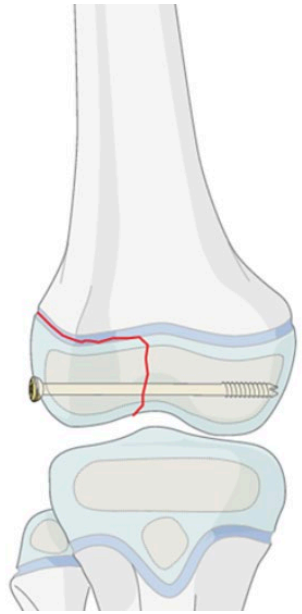


Salter-Harris III

- **Physis & epiphysis injured**
- Hypertrophic, proliferative, and germinal zones fractured
- Advanced imaging may be needed to evaluate articular displacement

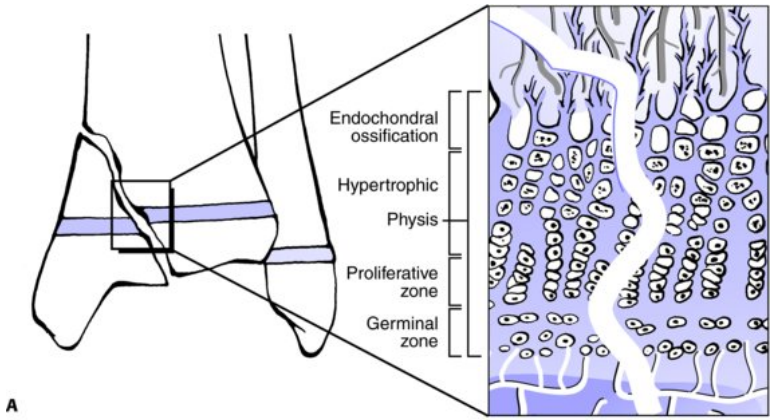


- Treatment options include:
  - Immobilization and casting
    - Non-displaced fractures
  - ORIF typically with screws (or K-wires)
    - Displaced fractures

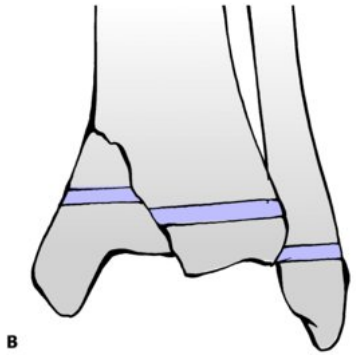


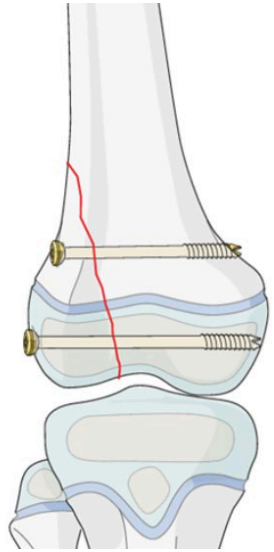
Salter-Harris IV

- **Epiphysis, physis, metaphysis injured**
- All four zones of physis involved



- Treatment options include:
  - Closed treatment
    - Non-displaced fractures
  - ORIF with ccrews (or K-wires)
    - Displaced fractures

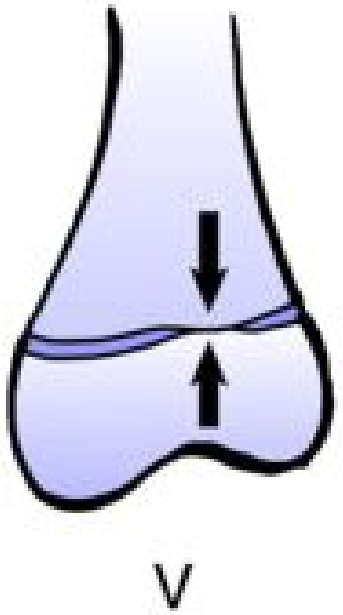




- *Anatomic reduction of physis required to minimize risk of physeal bar formation*

Salter-Harris V

- Difficult to diagnosis in the emergency room unless associated with very high energy trauma. This is a rare, essentially crush injury to physis
- Initial non-operative treatment
- Late diagnosis after complication of physeal arrest and deformity has occurred



Principles of Treatment

- Perform a careful reduction
  - **90% traction**
  - 10% manipulation

- Limit iatrogenic injury to physis
  - Repeated, forceful reduction attempts (>2)
  - Late reductions (>7-10d from injury)
  - Hardware across physis

- Maintain of reduction
  - Cast, screws, pins

Images courtesy of Chris Souder, MD

Post-operative Care

- If pins cross the physis, typically remove at 4 weeks
- Further immobilization based on healing
- Growth Plate check recommended 6 months and 1yr after injury
- Obtain standing hip to ankle x-rays and x-ray of injured lower extremity part

Growth Plate Injuries- What to look for ?

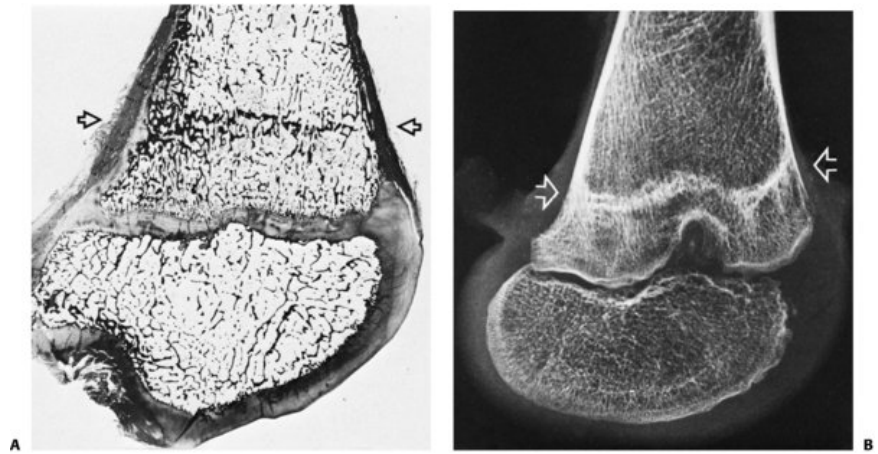
- Loss of abnormal physeal contour
- A bony connection between epiphysis and metaphysis
- Tapering of Park-Harris growth line towards area of growth arrest
- Obvious angular deformity or segment shortening

Loss of physeal contour and separation of epiphysis and metaphysis

Images courtesy of Chris Souder, MD

Park-Harris Growth Lines

- Dense trabecular line of ossification within the metaphysis
  - Secondary to transient slowing of the growth or increased mineralization
    - Local trauma, infection, systemic illness, etc
- Will progress away from and **parallel** to the physis with normal growth
  - Asymmetric with disturbed growth



Physeal arrest

Physeal Disturbance

- Complete physeal arrest (SH1,2)
  - Longitudinal bone growth ceases completely at that physis
    - Asymmetric growth of neighboring bone if 2 bones present in the segment
      - Tibia and fibula in the leg
      - Radius and ulna in the forearm
- Partial physeal arrest (SH 3,4)
  - Angular deformity associated with shortening
  - Treatment necessary to address <u>progressive</u> angular deformity

Images courtesy of Chris Souder, MD

How do you detect a possible physeal disturbance?

- Traditionally a fine cut CT has a been the gold standard for the evaluation of osseous bars across the growth plate.

- However, with advancement of MRI technology and sequences, this methodology can also demonstrate physeal anatomy and growth plate pathology very well.

- Both CT and MRI can be used to map the percentage of total amount of growth plate involved in the injury and the subsequent disturbance of the physis.

Can you list factors associated with a higher rate of growth disturbance?

Can you list factors associated with a higher rate of growth disturbance?

1. Type of Salter Harris Fracture
   - Salter Harris IV fractures are believed to have the highest rate over Types III,II, or I
     - V>IV>III>II>I
2. Anatomic location of the growth plate fractures
   - Fractures around the knee (proximal tibia & distal femur) have a much higher rate of growth disturbance than similar fractures at the distal radius

Rate of Growth arrest by anatomic location of the growth plate fracture

Region	Rate of Growth arrest	Reference
Proximal Humerus	rare	Baxter JBJSB 1986
Distal Radius	4-5 % of displaced fractures	Cannata JOT 2013
Distal femur	50%	Basener JOT 2019
Proximal Tibia	40%	Poulsen Injury 1989
Distal Tibia	40%	Rohmiller JPO 2006

Can you list factors associated with a higher rate of growth disturbance?

3. Fracture mechanism, **higher energy**
4. Amount of initial **fracture displacement**
5. **Delayed (> 1 week) reduction**
6. Amount of residual **displacement** after a closed **reduction**
7. **Forceful or repeated closed reduction**

Physeal Disturbance Treatment

- Completion of epiphysiodesis
  - ± contralateral epiphysiodesis
    - Based on growth remaining
  - Must consider neighboring bone
    - Ulnar epiphysiodesis after distal radial physeal arrest

- Physeal bar resection
  - ± osteotomy
    - Based on amount of deformity present

Images courtesy of Chris Souder, MD

Treatment Considerations

Affected Leg:

- Is there remaining growth potential?
- Is there a Longitudinal deformity?
  - Final predicted LLD
- Is there an Angular deformity?
- Is there a neighboring bone with remaining growth
  - Ulna and radius; tibia and fibula

Unaffected Leg:

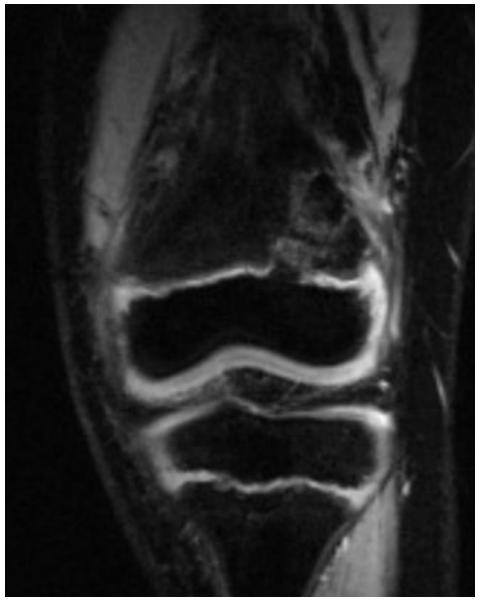
- Limb length discrepancy that may require treatment

Image courtesy of Chris Souder, MD

What are the prerequisites to consider a surgical bar excision for a post fracture growth arrest?

What are the prerequisites to consider a surgical bar excision for a post fracture growth arrest?

- > 2 years of growth remaining
- Size of bar should be less than < 50% of the physis



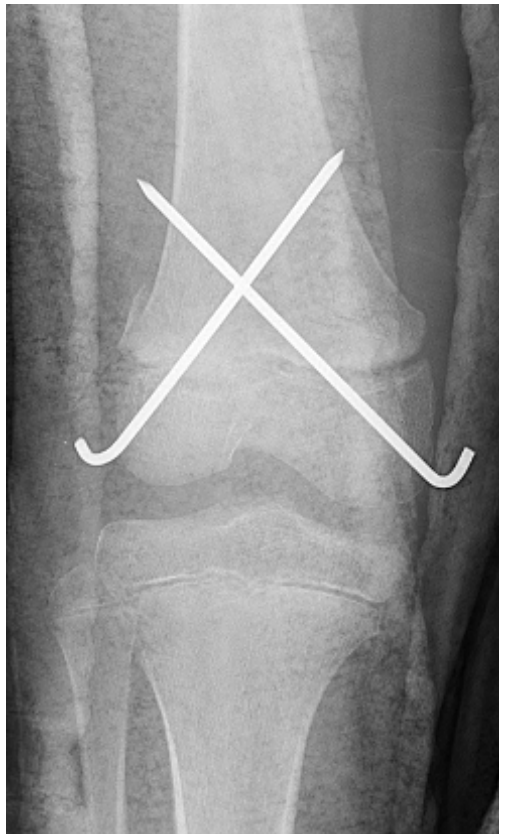
Images courtesy of Chris Souder, MD

Conditions for successful bar excision

- Smaller bars
  - < 30-40% of the growth plate
- Younger children
  - Greater than 2yrs of growth remaining
- Central bars are more amenable than peripheral bars
- Traumatic growth arrests have better outcomes than treating a growth plate pathology secondary to infection, metabolic bone disease or ischemia

MRI and CT scan 6 months after a 12 yo female had a closed reduction and pinning of a SH 2 distal femur fracture

→A large central growth arrest is present



What should the treatment be for this 12 yo girl's distal femoral growth arrest?

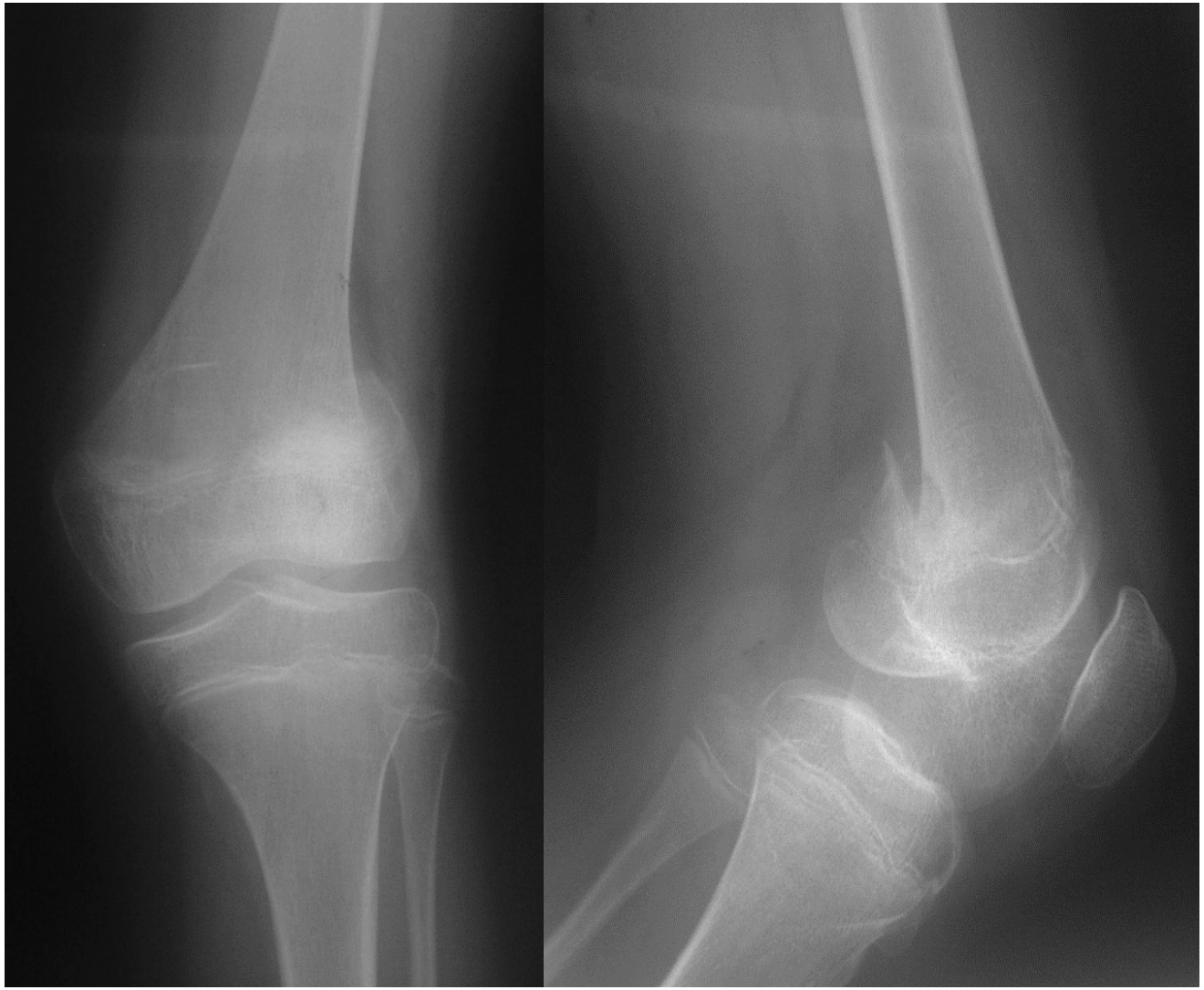
What should the treatment be for this 12 yo girl's distal femoral growth arrest?

- Early diagnosis is best
- Treatment options include:
  - Bar excision
  - Epiphysiodesis
    - Completion of arrest
    - ± contralateral epiphysiodesis
  - Limb Lengthening
  - Limb Shortening

- In this case the family elected to wait until skeletally mature, then the nearly 3cm leg length discrepancy was treated effectively with a using a magnetic internal lengthening nail.

Case 1

What is your diagnosis & treatment plan (10 yr male)?

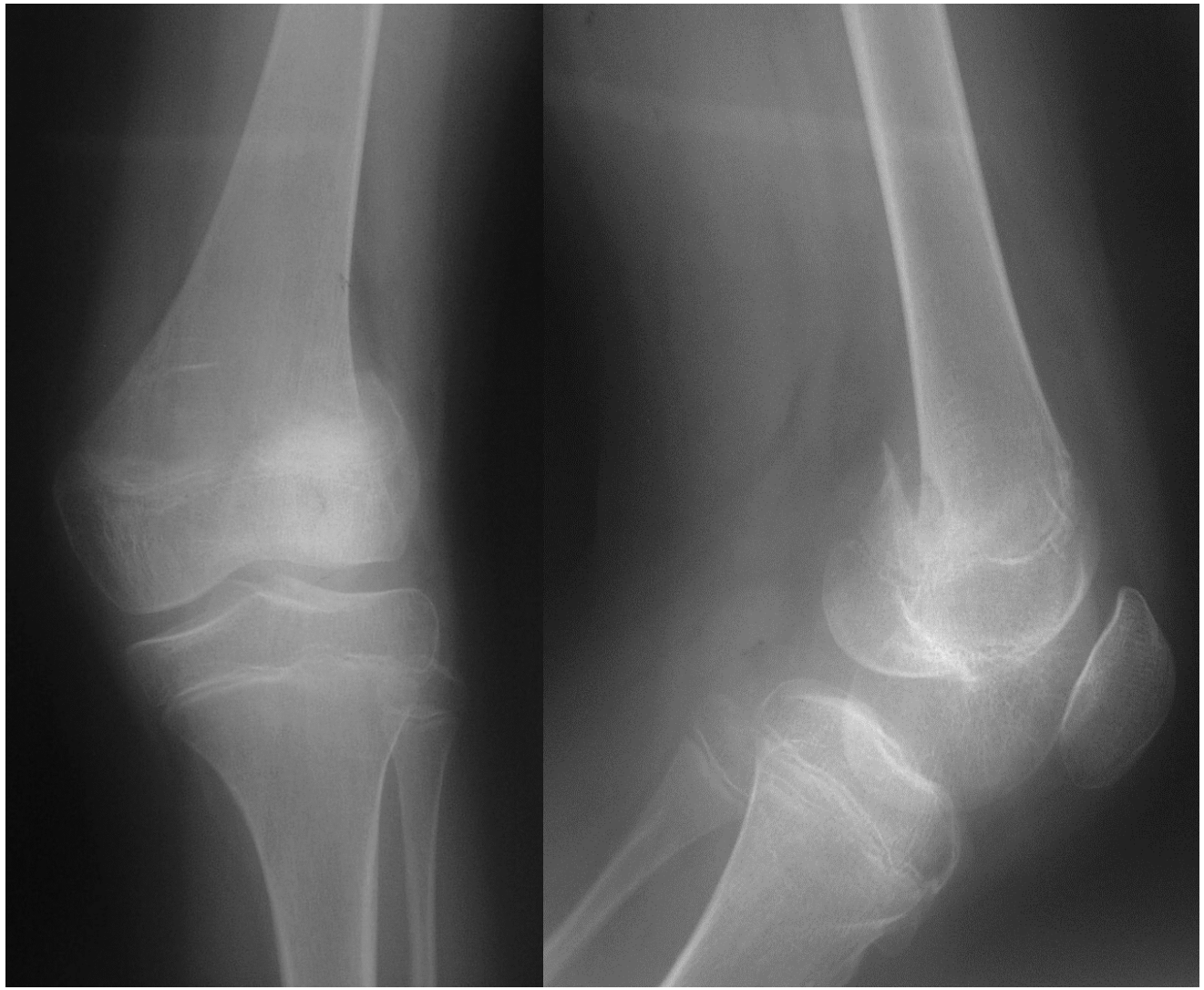


Case 1

What is your diagnosis & treatment plan (10 yo male)?

SH-2 femur fracture as the diagnosis

Treatment Plan?



Case 1

- Treated with closed reduction and percutaneous fixation with smooth Steinmann Pins

- In this case, the pins were actually placed by starting at the epiphysis at a slightly anterior angulation
  - Pins were driven out the thigh
  - Pins are bent and cut outside of the skin proximally

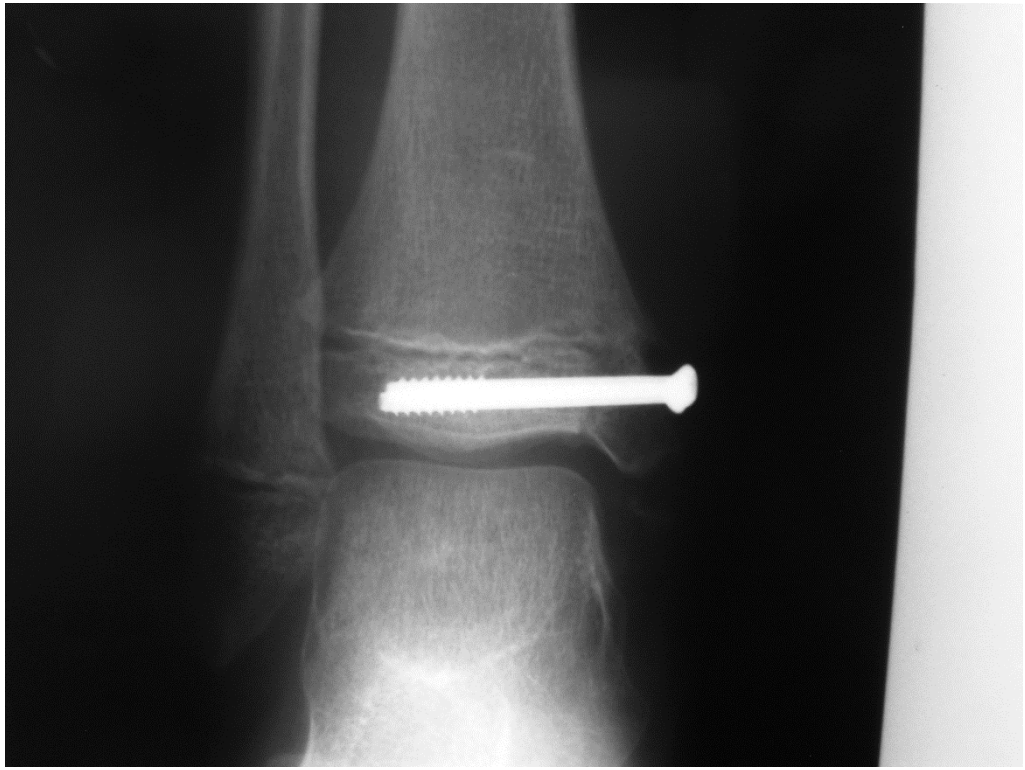
- Pins were removed at 1 month, and the patient was followed for greater than a year to rule out growth arrest

Case 2

8 yo with a Salter-Harris 3 distal tibia fracture

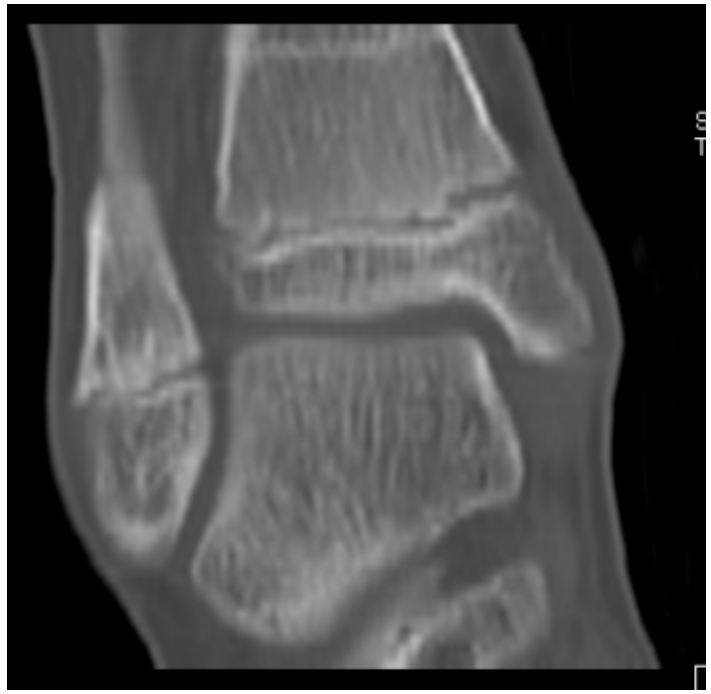
Case 2

Case 2- ORIF was performed



Case 2- growth arrest developed

Case 2- resection completed

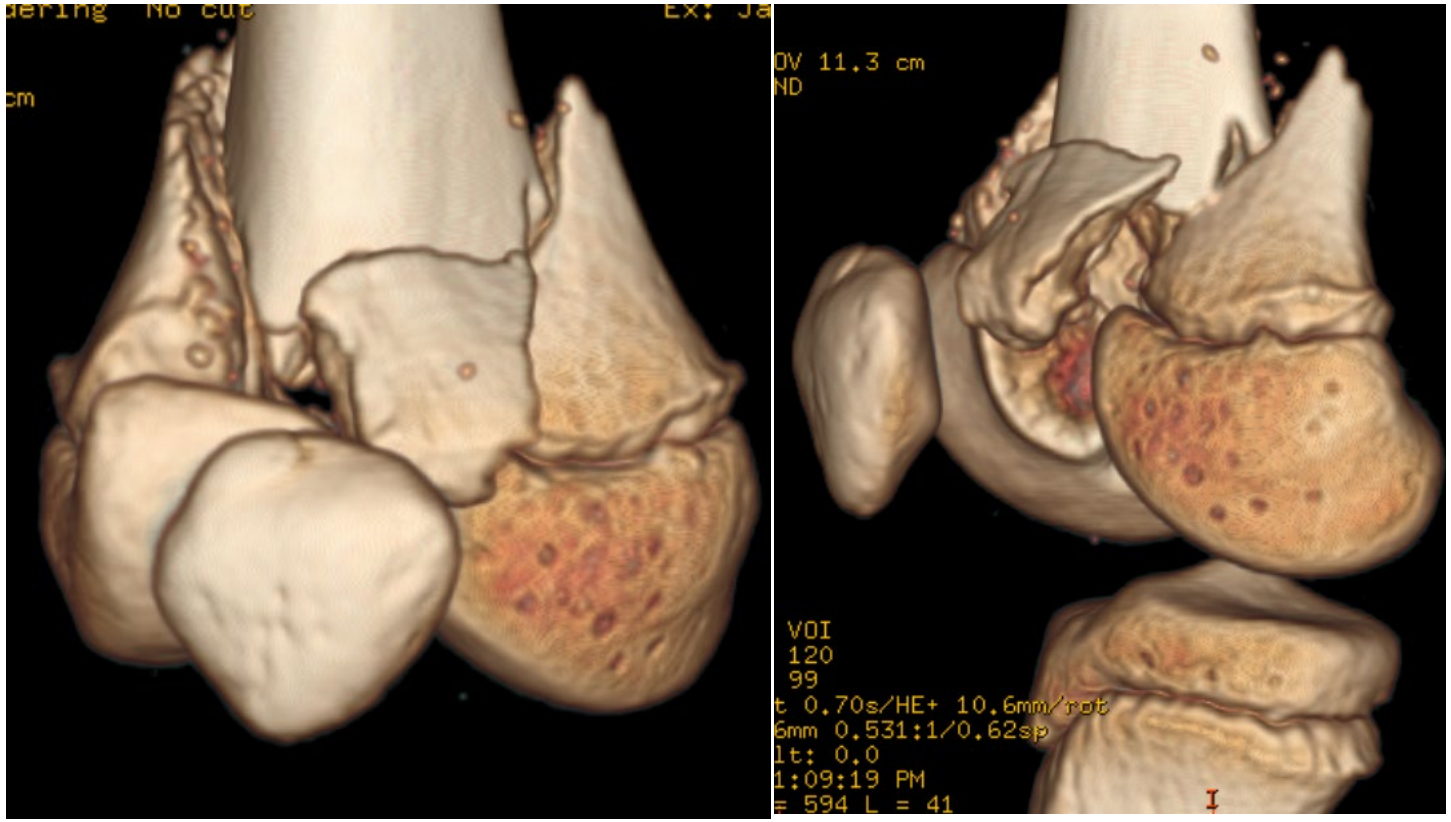


3 year post-op

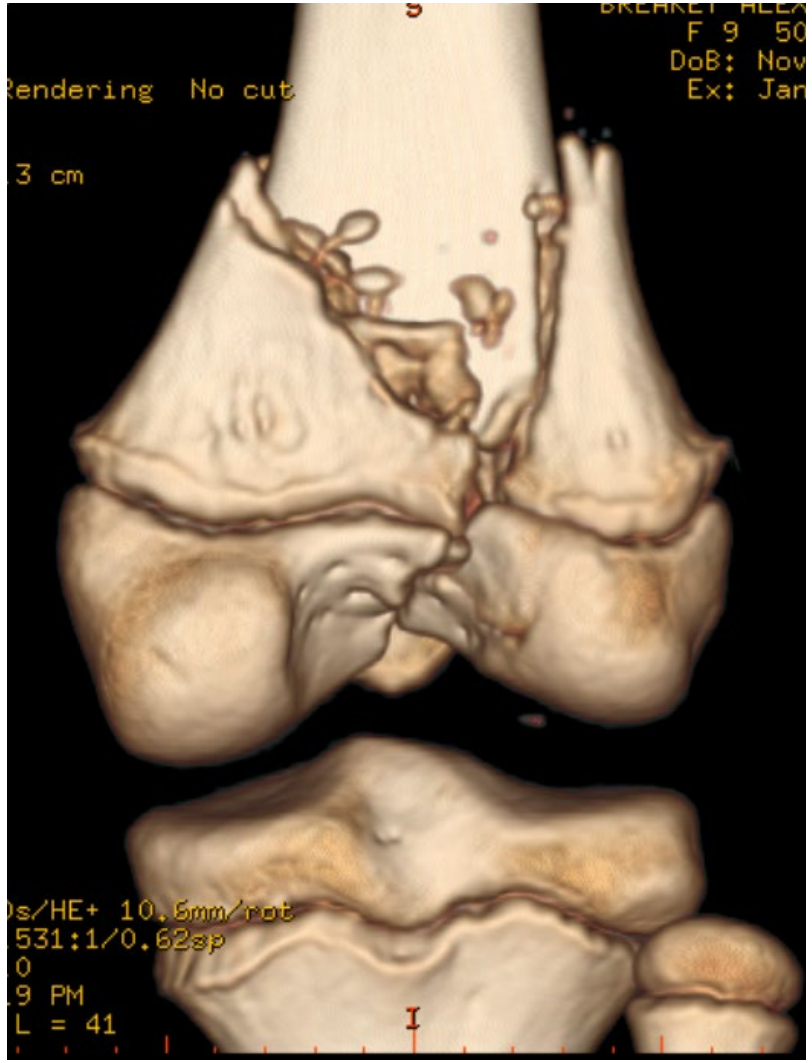
Case 3

10F who last year in January was skiing with her family when she went off-piste and struck a tree at a high rate of speed

She hit the tree with her knee and suffered this complex intra-articular SH-4 distal femur fracture



Case 3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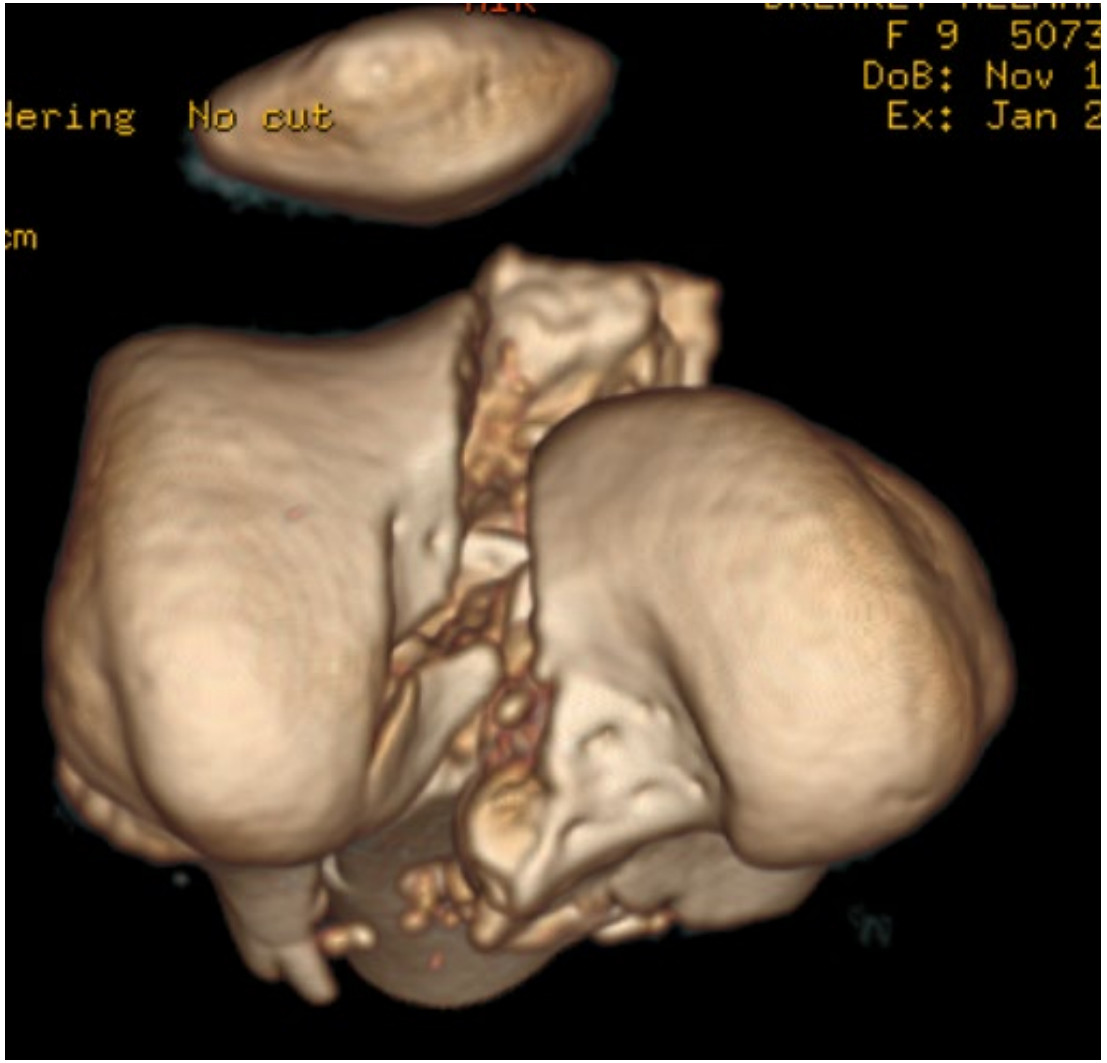
F 9 5073
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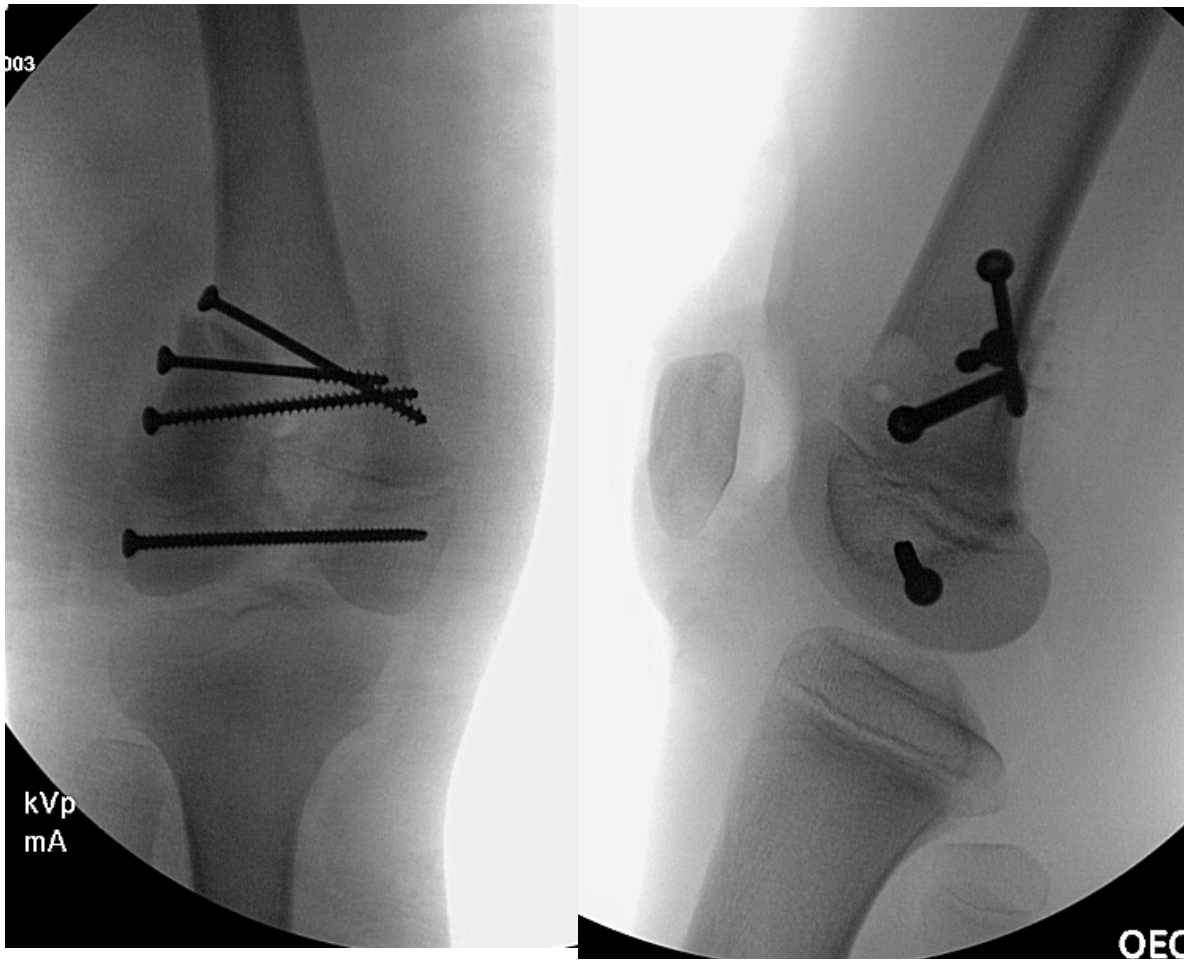
cm

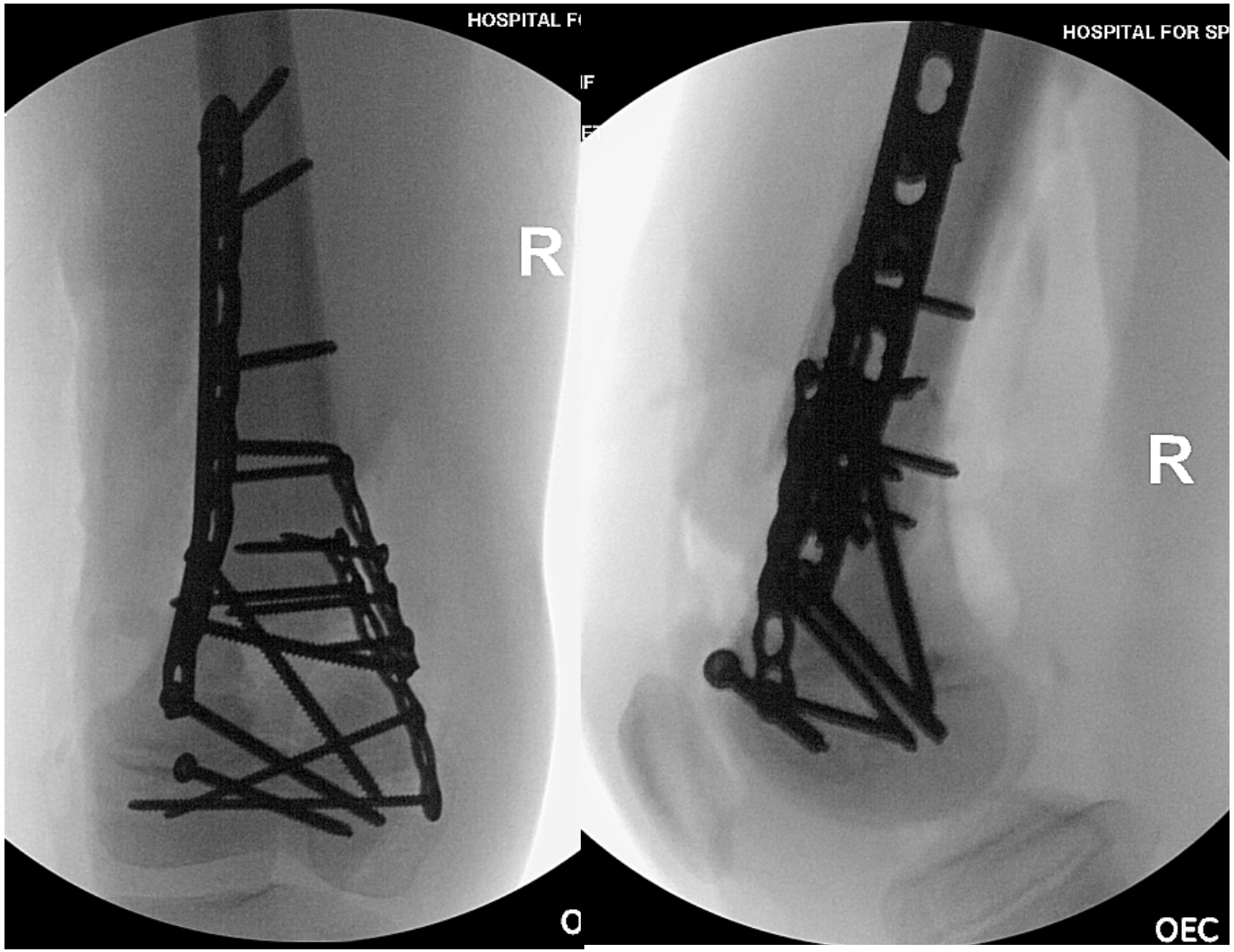
Case 3: Fixation attempt #1



Case 3: ORIF

- Open approach with anatomic reduction. Fixation achieved via multiple plates

- Of note, the growth plate was sacrificed due to the severe comminution and the need to span the growth plate to obtain stability of the fracture



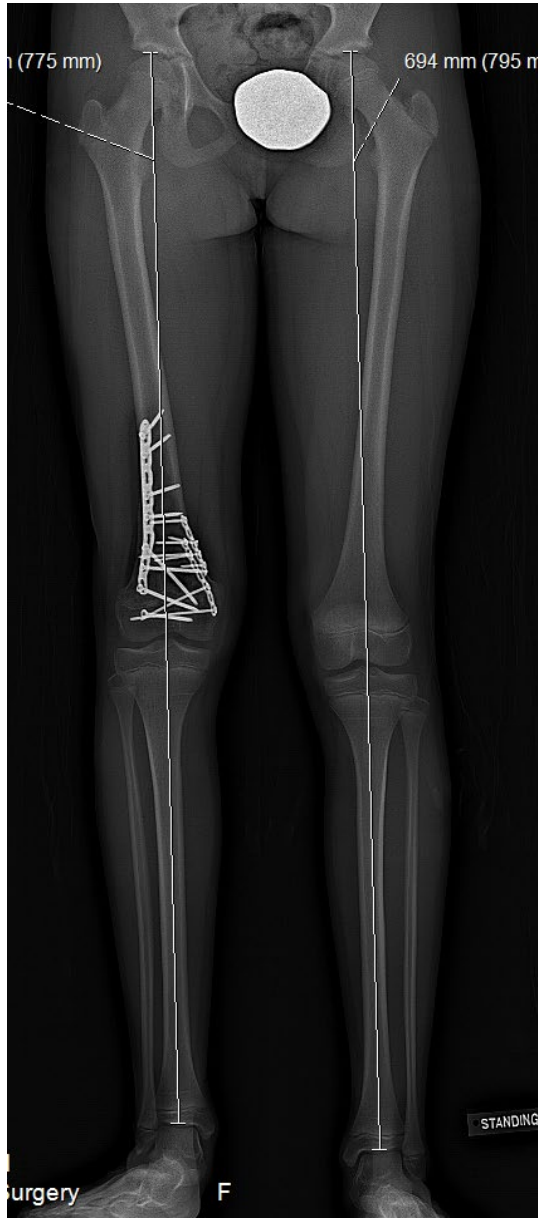
Case 3- 1 year post op:

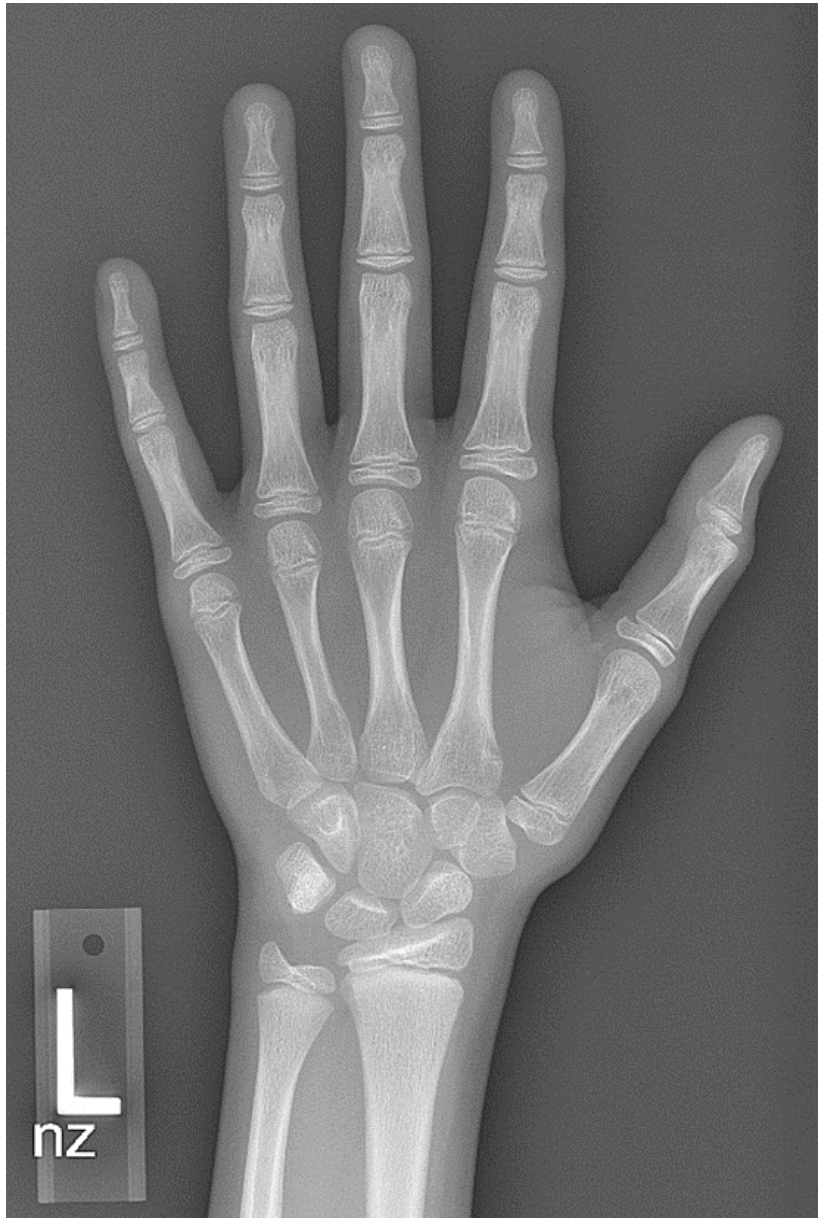
What are the treatment options for the leg length discrepancy?

Approximately 1.5y postop with a 17mm LLD

Bone Age is 11yrs old

Predicted leg length discrepancy at skeletal maturity would be 4.7cm





Case 3- 1 year post op:

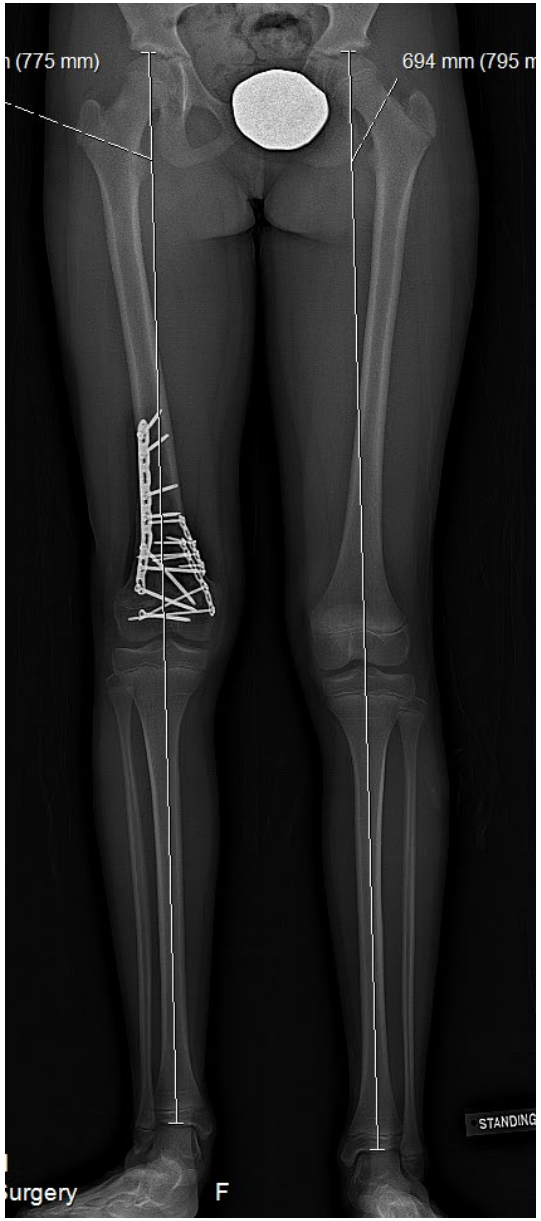
What are the treatment options for the leg length discrepancy?

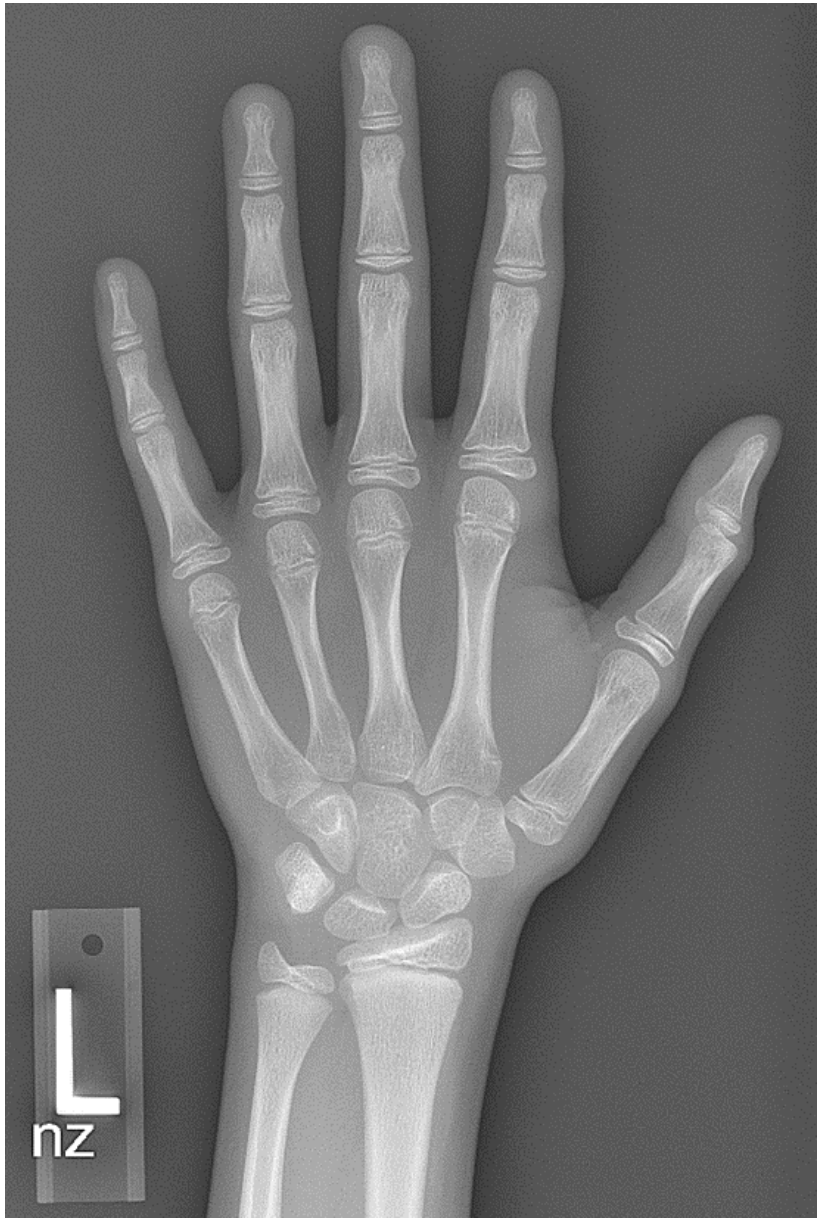
-Contralateral epiphysiodesis

-Delayed limb lengthening in adolescence

Joint decision with surgeon, patient, and family

**Physeal bar resection is not a treatment option as this is a complete arrest*





Summary

- Physeal fractures are common injuries
  - Most heal and growth resumes uneventfully
    - Principles of treatment must be adhered to
- Certain physes have a propensity for growth disturbances
  - Distal femur, proximal tibia, distal tibia
- Treatment of growth disturbances require consideration of
  - Patient age
  - Current and predicted deformity
  - Characteristics of the arrest
    - Location, size, etiology

Image courtesy of Chris Souder, MD

References

- Adapted from work by Jennifer Beck, MD, Joshua Klatt, MD and Steven I. Rabin, MD
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