Pediatric Fracture Complications

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Disclosures

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Outline

Physeal Injuries and bridge formation

- Incidence
- Mechanism
- Complications
- Pre-treatment Imaging
- Post-Treatment Imaging
Incidence of Physeal Injuries
Incidence of Physeal Injuries

• 15 - 30% of pediatric fractures involve the physis

• Up to 15% of physeal fractures -> growth arrest requiring treatment
Mechanism of Physeal Injuries
Anatomy of the Physis

Anatomy of the Physis

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Bridge Formation After Acute Injury

Two Mechanisms:

Bridge Formation After Acute Injury

Two Mechanisms:

1. Direct physeal injury

Bridge Formation After Acute Injury

Two Mechanisms:

1. Direct physeal injury -> communication of epiphyseal-metaphyseal vessels.

Bridge Formation After Acute Injury

Two Mechanisms:

1. Direct physeal injury -> communication of epiphyseal-metaphyseal vessels.
   - Osteoprogenitor cells deposit bone along vessel

Two Mechanisms:

1. Direct physeal injury -> communication of epiphyseal-metaphyseal vessels.
   - Bone deposited along vessel

2. Disruption of the epiphyseal vessels that supply germinal and proliferative zones of the physis

Risk Factors of Bridge Formation
Risk Factors of Bridge Formation

- Severity of injury
  - Displacement, comminution
Risk Factors of Bridge Formation

• Severity of injury
  – Displacement, comminution
  – Loss of a segment of germinal & proliferative zones

Risk Factors of Bridge Formation

• Severity of injury
  – Displacement, comminution
  – Loss of a segment of germinal & proliferative zones

• Growth potential
  – Younger / less skeletal maturity
Risk Factors of Bridge Formation

• Severity of injury
  – Displacement, comminution
  – Loss of a segment of germinal & proliferative zones

• Growth potential
  – Younger / less skeletal maturity

• Anatomic site
  – Contour of the physis & growth rate
Risk Factors of Bridge Formation

Anatomic site:
Risk Factors of Bridge Formation

Anatomic site:

• Distal radius
Risk Factors of Bridge Formation

Anatomic site:

- Distal radius
Risk Factors of Bridge Formation

Anatomic site:

- Distal radius - smooth, uniplanar physis
Risk Factors of Bridge Formation

Anatomic site:

- Distal radius - smooth, uniplanar physis
  - 45% of all physeal injuries
  - Only 12% of growth disturbances
Risk Factors of Bridge Formation

Anatomic site:

• Distal radius - smooth, uniplanar physis
  - 45% of all physeal injuries
  - Only 12% of growth disturbances

• Distal femur
Risk Factors of Bridge Formation

Anatomic site:

• Distal radius - smooth, uniplanar physis
  – 45% of all physeal injuries
  – Only 12% of growth disturbances

• Distal femur
Risk Factors of Bridge Formation

Anatomic site:

- Distal radius - smooth, uniplanar physis
  - 45% of all physeal injuries
  - Only 12% of growth disturbances

- Distal femur - undulating, multiplanar physis
Risk Factors of Bridge Formation

Anatomic site:

• Distal radius - smooth, uniplanar physis
  – 45% of all physeal injuries
  – Only 12% of growth disturbances

• Distal femur - undulating, multiplanar physis
  – Only 1.4% of physeal injuries
  – 35% incidence of post-traumatic bridges
Risk Factors of Bridge Formation

- **Severity of injury**
  - Displacement, comminution
  - Loss of a segment of germinal & proliferative zones

- **Growth potential**
  - Younger / less skeletal maturity

- **Anatomic site**
  - Contour of the physis & growth rate

- **Type of Fracture**

Risk Factors of Bridge Formation

• Severity of injury
  – Displacement, comminution
  – Loss of a segment of germinal & proliferative zones

• Growth potential
  – Younger / less skeletal maturity

• Anatomic site
  – Contour of the physis & growth rate

• Type of Fracture
  – Longitudinal fractures -> transphyseal vascularity

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  – Younger / less skeletal maturity

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• Type of Fracture
  – Longitudinal fractures -> transphyseal vascularity
  – Transverse fractures involving germinal/proliferative zones

Risk Factors of Bridge Formation

- **Severity of injury**
  - Displacement, comminution
  - Loss of a segment of germinal & proliferative zones

- **Growth potential**
  - Younger / less skeletal maturity

- **Anatomic site**
  - Contour of the physis & growth rate

- **Type of Fracture**
  - Longitudinal fractures -> transphyseal vascularity
  - Transverse fractures involving germinal/proliferative zones

Risk Factors of Bridge Formation

- Severity of injury
  - Displacement, comminution
  - Loss of a segment of germinal & proliferative zones
- Growth potential
  - Younger / less skeletal maturity
- Anatomic site
  - Contour of the physis & growth rate
- Type of Fracture
  - Longitudinal fractures -> transphyseal vascularity
  - Transverse fractures involving germinal/proliferative zones

Complications of Growth Arrest
Complications of Growth Arrest: Location within Physis
Complications of Growth Arrest: Location within Physis

- Central bridges -> longitudinal growth disturbances
4-year-old girl with history of proximal left tibial fracture
4-year-old girl with history of proximal left tibial fracture
4-year-old girl with history of proximal left tibial fracture
4-year-old girl with history of proximal left tibial fracture
4-year-old girl with history of proximal left tibial fracture
Complications of Growth Arrest: Location within physis

• Central bridges -> longitudinal growth disturbances

• Peripheral bridge -> angular deformities
13-year-old boy with a prior proximal left tibial fracture.
13-year-old boy with a prior proximal left tibial fracture.
13-year-old boy with a prior proximal left tibial fracture.
13-year-old boy with a prior proximal left tibial fracture.
Complications of Growth Arrest: Location within physis

- Central bridges -> longitudinal growth disturbances

- Peripheral bridge -> angular deformities
  - Types of angular deformity – depends on the location of the bridge in the physis.
Complications of Growth Arrest: Location within physis

- Central bridges -> longitudinal growth disturbances

- Peripheral bridge -> angular deformities
  - Types of angular deformity – depends on the location of the bridge in the physis.
    - Anterior -> recurvatum deformity
    - Posterior -> procurvatum deformity
    - Medial -> varus deformity
    - Lateral -> valgus deformity
Complications of Growth Arrest: Location within physis

- Central bridges -> longitudinal growth disturbances

- Peripheral bridge -> angular deformities

- Combination of longitudinal and angular growth disturbances
10 year old girl with a distal right femoral fracture
9 months later
9 months later
9 months later
9 months later
9 months later
9 months later
Complications of Growth Arrest: Anatomic location
Complications of Growth Arrest: Anatomic location

- Lower Extremity
Complications of Growth Arrest: Anatomic location

- Lower Extremity
  - Proximal femur
    - Growth arrest typically due to ischemia not trauma
Complications of Growth Arrest: Anatomic location

• Lower Extremity
  – Proximal femur
    • Growth arrest typically due to ischemia not trauma
  – Distal femur
    • Typically central -> longitudinal growth disturbance
Complications of Growth Arrest: Anatomic location

- Lower Extremity
  - Proximal femur
    - Growth arrest typically due to ischemia not trauma
  - Distal femur
    - Typically central -> longitudinal growth disturbance
  - Proximal tibia
    - Typically central -> longitudinal growth disturbance
    - If at tibial tubercle -> recurvatum
Complications of Growth Arrest: Anatomic location

- Lower Extremity
  - Proximal femur
    - Growth arrest typically due to ischemia not trauma
  - Distal femur
    - Typically central -> longitudinal growth disturbance
  - Proximal tibia
    - Typically central -> longitudinal growth disturbance
    - If at tibial tubercle -> recurvatum
  - Distal tibia
    - Most often anteromedial (Kump’s bump) -> varus deformity
Complications of Growth Arrest: Anatomic location

• Upper Extremity
  – Distal humerus
    • Cubitus varus – common angular deformity after supracondylar fx
Complications of Growth Arrest: Anatomic location

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  - Distal humerus
    - Cubitus varus – common angular deformity after supracondylar fx
Complications of Growth Arrest: Anatomic location

- Upper Extremity
  - Distal humerus
    - Cubitus varus – common angular deformity after supracondylar fx

Bauman’s angle > 90°
Complications of Growth Arrest: Anatomic location

• Upper Extremity
  – Distal humerus
    • Cubitus varus – common angular deformity after supracondylar fx
Complications of Growth Arrest: Anatomic location

• Upper Extremity
  – Distal humerus
    • Cubitus varus – common angular deformity after supracondylar fx
      – **NOT** typically due to bridge formation
      – Secondary to MALUNION
Complications of Growth Arrest: Anatomic location

- **Upper Extremity**
  - Distal humerus
    - Cubitus varus – common angular deformity after supracondylar fx
      - **NOT** typically due to bridge formation
      - **Secondary to MALUNION**
    - Bridges may occur:
      - S/p pinning of distal humeral fx
      - Lateral condylar fx
      - Usually not clinically significant
Complications of Growth Arrest: Anatomic location

- Upper Extremity
  - Distal humerus
    - Cubitus varus – common angular deformity after supracondylar fx
      - NOT typically due to bridge formation
      - Secondary to Malunion
  - Distal radius
    - High incidence of physeal injuries
    - Low rate of bridge formation
Complications of Growth Arrest: Anatomic location

• Upper Extremity
  – Distal humerus
    • Cubitus varus – common angular deformity after supracondylar fx
      – **NOT** typically due to bridge formation
      – Secondary to Malunion
  – Distal radius
    • High incidence of physeal injuries
    • Low rate of bridge formation
    • When occurs may lead to:
      – Ulnocarpal abutment
Complications of Growth Arrest: Anatomic location

- Upper Extremity
  - Distal humerus
    • Cubitus varus – common angular deformity after supracondylar fx
      - NOT typically due to bridge formation
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  - Distal radius
    • High incidence of physeal injuries
    • Low rate of bridge formation
    • When occurs may lead to:
      - Ulnocarpal abutment

10-year-old with a SH II fracture of the distal left radius
5 years later – returns with left wrist pain
5 years later – returns with left wrist pain

Normal contralateral physis
5 years later – returns with left wrist pain

Normal contralateral physis

Physeal bridge
5 years later – returns with left wrist pain

Normal ulnar variance
(< 2mm of negative variance)
5 years later – returns with left wrist pain

Normal ulnar variance
(< 2mm of negative variance)

Ulnar positive variance
Large Central Bridge
Large Central Bridge

Central Tear of Triangular Fibrocartilage
Imaging Physeal Bridges
Imaging Physeal Bridges

- Bridges may begin forming between 1 and 2 months after injury
Imaging Physeal Bridges

• Bridges may begin forming between 1 and 2 months after injury.

• May not become clinically or radiographically evident until years later during an adolescent growth spurt.
Imaging Physeal Bridges

• Bridges may begin forming between 1 and 2 months after injury

• May not become clinically or radiographically evident until years later during an adolescent growth spurt

• Children at risk for bridge formation should be followed until skeletal maturity
Imaging Physeal Bridges

Radiographs
Imaging Physeal Bridges

Radiographs
- Directly visualized

13-year-old boy with hx of a distal radial fracture
Imaging Physeal Bridges

Radiographs

- Directly visualized
- Indirect evidence
  - Narrowing of the physis

9-year-old boy with hx of left distal tibial fracture
Imaging Physeal Bridges

Radiographs

• Directly visualized

• Indirect evidence
  – Narrowing of the physis

9-year-old boy with hx of left distal tibial fracture
Imaging Physeal Bridges

Radiographs

- Directly visualized
- Indirect evidence
  - Narrowing of the physis
    - Contralateral comparisons helpful
Imaging Physeal Bridges

Radiographs

• Directly visualized
• Indirect evidence
  – Narrowing of the physis
  – Growth recovery lines
Imaging Physeal Bridges

Radiographs

• Directly visualized
• Indirect evidence
  – Narrowing of the physis
  – Growth recovery lines

10-year-old girl with history of a distal femur fracture
Imaging Physeal Bridges

Radiographs

• Directly visualized
• Indirect evidence
  – Narrowing of the physis
  – Growth recovery lines

10-year-old girl with history of a distal femur fracture
Imaging Physeal Bridges

Radiographs

- Directly visualized
- Indirect evidence
  - Narrowing of the physis
  - Growth recovery lines
    - Normal - parallel physis

10-year-old girl with history of a distal femur fracture
Imaging Physeal Bridges

Radiographs

• Directly visualized
• Indirect evidence
  – Narrowing of the physis
  – Growth recovery lines
    • Normal - parallel physis
    • Abnormal – Oblique, converge at physeal bridge

10-year-old girl with history of a distal femur fracture
Imaging Physeal Bridges

Radiographs

• Directly visualized
• Indirect evidence
  – Narrowing of the physis
  – Growth recovery lines
    • Normal - parallel physis
    • Abnormal – Oblique, converge at physeal bridge

10-year-old girl with history of a distal femur fracture
Imaging Physeal Bridges

Radiographs

• Directly visualized

• Indirect evidence
  – Narrowing of the physis
  – Growth recovery lines
  – Complications

13-year-old girl hx of radial fracture
Imaging Physeal Bridges

Radiographs
• Directly visualized
• Indirect evidence
  – Narrowing of the physis
  – Growth recovery lines
  – Complications

13-year-old girl hx of radial fracture
Imaging Physeal Bridges

Radiographs

• Directly visualized
• Indirect evidence
  – Narrowing of the physis
  – Growth recovery lines
  – Complications
    • Angular deformity
    • Longitudinal growth restriction
    • Others – site specific
Imaging Physeal Bridges

Radiographs

- Directly visualized
- Indirect evidence
  - Narrowing of the physis
  - Growth recovery lines
- Complications
  - Angular deformity
  - Longitudinal growth restriction
  - Others – site specific
Imaging Physeal Bridges

Radiographs

• Directly visualized
• Indirect evidence
  – Narrowing of the physis
  – Growth recovery lines
  – Complications
    • Angular deformity
    • Longitudinal growth restriction
    • Others – site specific
Imaging Physeal Bridges

CT

• Allows for direct visualization of bridges
• Mostly replaced by MRI due to better visualization of cartilage
Imaging Physeal Bridges

MRI

• T1-weighted images - variable
  – Large bridges – Marrow signal intensity
Imaging Physeal Bridges

MRI

• T1-weighted images - variable
  – Large bridges – Marrow signal intensity
Imaging Physeal Bridges

MRI
- T1-weighted images
  - Large bridges – Marrow signal intensity
  - Small bridges – low signal intensity
Imaging Physeal Bridges

MRI

- T1-weighted images
  - Large bridges – Marrow signal intensity
  - Small bridges – low signal intensity
Imaging Physeal Bridges

MRI
- T1-weighted images - Growth recovery lines
Imaging Physeal Bridges

MRI

- T1-weighted images - Growth recovery lines
**Imaging Physeal Bridges**

**MRI**
- T1-weighted images - Growth recovery lines
Imaging Physeal Bridges

MRI

• T1-weighted images - Growth recovery lines
Imaging Physeal Bridges

MRI
• T1-weighted images - Growth recovery lines
Imaging Physeal Bridges

MRI

• T1-weighted images
  – Large bridges – Marrow signal intensity
  – Small bridges – low signal intensity

• Fluid sensitive sequences
  – Variable depending:
    • +/- edema
Imaging Physeal Bridges

MRI

• T1-weighted images
  – Large bridges – Marrow signal intensity
  – Small bridges – low signal intensity

• Fluid sensitive sequences
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    • +/- edema
Imaging Physeal Bridges

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• T1-weighted images
  – Large bridges – Marrow signal intensity
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Imaging Physeal Bridges

MRI

- T1-weighted images
  - Large bridges – Marrow signal intensity
  - Small bridges – low signal intensity
- Fluid sensitive sequences
  - Variable depending:
    - +/- edema
Imaging Physeal Bridges

MRI

- 3D fat-suppressed spoiled gradient echo (SPGR)
  - < 1mm to allow for reformatting
Imaging Physeal Bridges

MRI

- 3D fat-suppressed spoiled gradient echo (SPGR)
  - < 1mm to allow for reformatting
  - Bridge is dark SI across bright physeal cartilage
Imaging Physeal Bridges

MRI

- 3D fat-suppressed spoiled gradient echo (SPGR)
  - < 1mm to allow for reformatting
  - Bridge is dark SI across bright physeal cartilage
Imaging Physeal Bridges

MRI

- 3D fat-suppressed spoiled gradient echo (SPGR)
  - < 1mm to allow for reformatting
  - Bridge is dark SI across bright physeal cartilage
Imaging Physeal Bridges

MRI

- Physeal Map – Maximum Intensity Projection (MIP) reformatted axial images centered at the physis
- Typically 5 – 10 mm thick
Imaging Physeal Bridges

MRI

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SPGR
Imaging Physeal Bridges

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Imaging Physeal Bridges
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Total Area of Physis
Imaging Physeal Bridges

Total Area of Physis
Imaging Physeal Bridges

Total Area of Physis

Area of Bridge
Imaging Physeal Bridges

\[
\text{Area of Bridge} \div \text{Total Area of physis} = \% \text{ of Physis Occupied by Bridge}
\]
Treatment
Treatment of Physeal Bridges

- Resection considered if:
Treatment of Physeal Bridges

• Resection considered if:
  – Existing or developing deformity
Treatment of Physeal Bridges

• Resection considered if:
  – Existing or developing deformity
  – > 2 years or 2 cm of remaining growth
Treatment of Physeal Bridges

- Resection considered if:
  - Existing or developing deformity
  - > 2 years or 2 cm of remaining growth
  - Bridge occupies < 50% of the physeal area
Treatment of Physeal Bridges

• Resection considered if:
  – Existing or developing deformity
  – > 2 years or 2 cm of remaining growth
  – Bridge occupies < 50% of the physeal area

• Very small bridges may not disrupt growth
Treatment of Physeal Bridges

• Resection considered if:
  – Existing or developing deformity
  – > 2 years or 2 cm of remaining growth
  – Bridge occupies < 50% of the physeal area

• Very small bridges may not disrupt growth
  – Animal model:
    • 7% physis destroyed -> growth disturbance
    • 3% physis destroyed -> no growth disturbance
Treatment of Physeal Bridges

• Resection considered if:
  – Existing or developing deformity
  – $> 2$ years or $2$ cm of remaining growth
  – Bridge occupies $< 50\%$ of the physeal area

• Very small bridges may not disrupt growth
  – Animal model:
    • $7\%$ physis destroyed $\rightarrow$ growth disturbance
    • $3\%$ physis destroyed $\rightarrow$ no growth disturbance
  – No definite percentage exists
Physeal Bridge

• Treatment options:
  – Bridge resection
  • Approach:
    – Direct - peripheral
    – Metaphyseal - central
Physeal Bridge

• Treatment options:
  – Bridge resection
    • Approach:
      – Direct - peripheral
      – Metaphyseal - central
Physeal Bridge

• Treatment options:
  – Bridge resection
    • Approach:
      – Direct - peripheral
      – Metaphyseal - central
        » Window
Physeal Bridge

• Treatment options:
  – Bridge resection
  • Approach:
    – Direct - peripheral
    – Metaphyseal - central
      » Window
      » Partial osteotomy

Physeal Bridge

• Treatment options:
  – Bridge resection
  • Approach:
    – Direct - peripheral
    – Metaphyseal - central
      » Window
      » Partial osteotomy
      » Complete osteotomy

Physeal Bridge

• Treatment options:
  – Bridge resection
    • Approach:
      – Direct - peripheral
      – Metaphyseal - central
        » Window
        » Partial osteotomy
        » Complete ostotomy
  • Interposition:
    – Fat, methylmethacrylate, Cranioplast, Silastic, bone wax, cartilage, etc.
Physeal Bridge Treatment

- Treatment options:
  - Bridge resection
Physeal Bridge Treatment

- Treatment options:
  - Bridge resection
Physeal Bridge

• Treatment options:
  – Bridge resection
  – Osteotomy to correct angular deformities
Physeal Bridge

• Treatment options:
  – Bridge resection
  – Osteotomy to correct angular deformities
  – Contralateral epiphysiodesis
Physeal Bridge

• Treatment options:
  – Bridge resection
  – Osteotomy to correct angular deformities
  – Contralateral epiphysiodesis
Physeal Bridge

• Treatment options:
  – Bridge resection
  – Osteotomy to correct angular deformities
  – Contralateral epiphysiodasis
Physeal Bridge

- Treatment options:
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Physeal Bridge

- Treatment options:
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  - Osteotomy to correct angular deformities
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Physeal Bridge

- Treatment options:
  - Bridge resection
  - Osteotomy to correct angular deformities
  - Contralateral epiphysiodesis
Physeal Bridge

- Treatment options:
  - Bridge resection
  - Osteotomy to correct angular deformities
  - Contralateral epiphysiodesis
Physeal Bridge

- Treatment options:
  - Bridge resection
  - Osteotomy to correct angular deformities
  - Contralateral epiphysiodesis
  - Limb lengthening
Physeal Bridge

• Treatment options:
  – Bridge resection
  – Osteotomy to correct angular deformities
  – Contralateral epiphysiodesis
  – Limb lengthening
  – Ipsilateral completion epiphysiodesis
    • Large bridge -> prevent angular deformity
Post bridge resection
Post Bridge Resection

- Follow up radiographs
  - Evaluation of growth and complications
Post Bridge Resection

• Follow up radiographs
  – Evaluation of growth and complications

• Complications
  – Recurrence of bridge - 18%
  – Infection – 3% (which can also lead to bridge recurrence)
  – Fractures – 2%

Peripheral Bridge - Resection
Peripheral Bridge - Resection
Peripheral Bridge - Resection
10-month Follow-up
10-month Follow-up
10-month Follow-up
10-month Follow-up
1.5-year Follow-up
1.5-year Follow-up
1.5-year Follow-up
1.5-year Follow-up
Interposition material predominately on epiphyseal

Interposition material predominately on epiphyseal

Interposition material predominately on epiphyseal

Interposition material predominately on epiphyseal

Interposition material predominately metaphyseal

Interposition material predominately on epiphyseal

Interposition material predominately metaphyseal

6-year-old girl with hx of distal femoral fx
6-year-old girl with hx of distal femoral fx
Follow-up s/p Bridge Resection
Follow-up s/p Bridge Resection
Follow-up s/p Bridge Resection
Follow-up s/p Bridge Resection
Summary
Key Points: Physeal Bridges

- Risk Factors
  - Severity of injury
Key Points: Physeal Bridges

- Risk Factors
  - Severity of injury
  - Younger patients
Key Points: Physeal Bridges

- **Risk Factors**
  - Severity of injury
  - Younger patients
  - Anatomic site (physeal contour)
Key Points: Physeal Bridges

• Risk Factors
  – Severity of injury
  – Younger patients
  – Anatomic site (physeal contour)

• Complications
  • Central -> longitudinal growth disturbance
Key Points: Physeal Bridges

- Risk Factors
  - Severity of injury
  - Younger patients
  - Anatomic site (physeal contour)

- Complications
  - Central -> longitudinal growth disturbance
  - Peripheral -> angular deformities
Key Points: Physeal Bridges

• Risk Factors
  – Severity of injury
  – Younger patients
  – Anatomic site (physeal contour)

• Complications
  • Central -> longitudinal growth disturbance
  • Peripheral -> angular deformities

• Resection considered if:
  – Existing or developing deformity
  – > 2 years or 2 cm of remaining growth
  – Bridge occupies < 50% of the physeal area
References