Fractures of the Spine in Children

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Objectives

- **Review epidemiology of spine fractures in children**
- **Discuss cervical spine anatomy and injury patterns**
- **Review cervical spine precautions in children**
- **Identify cervical spine clearance protocol in children**
- **Discuss thoracolumbar spine anatomy and injury patterns**
- **Review treatment approaches for spine fracture**

Key Differences in the Pediatric Patient

- Anatomical and Radiographic Differences
- Increased elasticity
- Larger Head-to-Body Ratio
- Physeal/Synchondrosis/Periosteal tube fracture patterns
- Surgery rarely indicated
- Immobilization well tolerated

Epidemiology

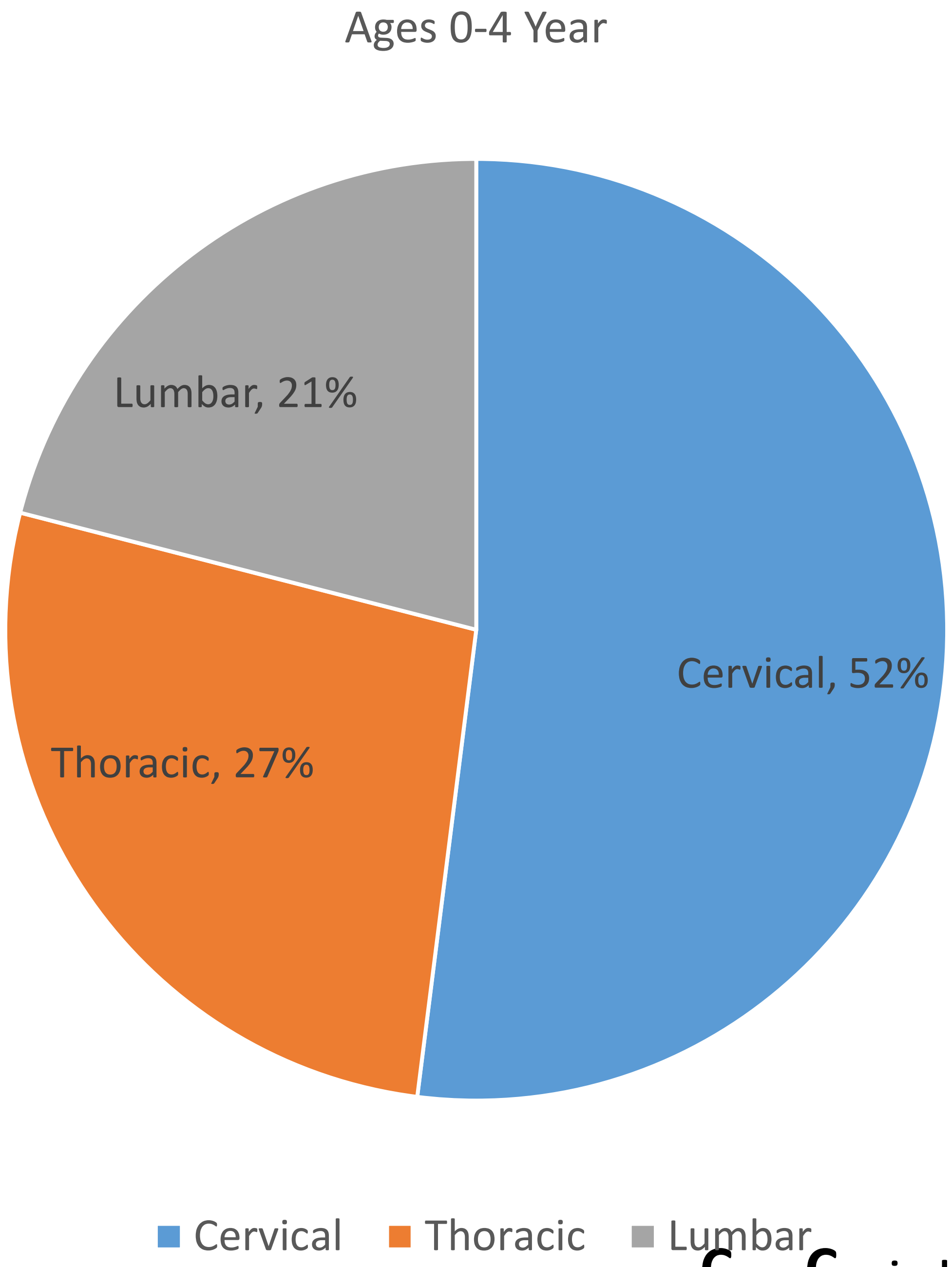
- Spine fractures are rare injuries
  - Potential for devastating complications
- <u>Incidence</u>
  - 93 – 107 per million
  - Annual incidence decreasing since 2000
- <u>Injury Pattern</u>
  - Varies based on patient age
  - <8 years → upper cervical spine injuries
  - Adolescence → thoracolumbar/Sacral fracture

Sagittal MRI demonstrating C2 fracture with spinal cord disruption (R&W 8th ed. Figure 23-8)

Piatt & Imperato. *J Neurosurg Pediatr.* 2018; 21

Epidemiology

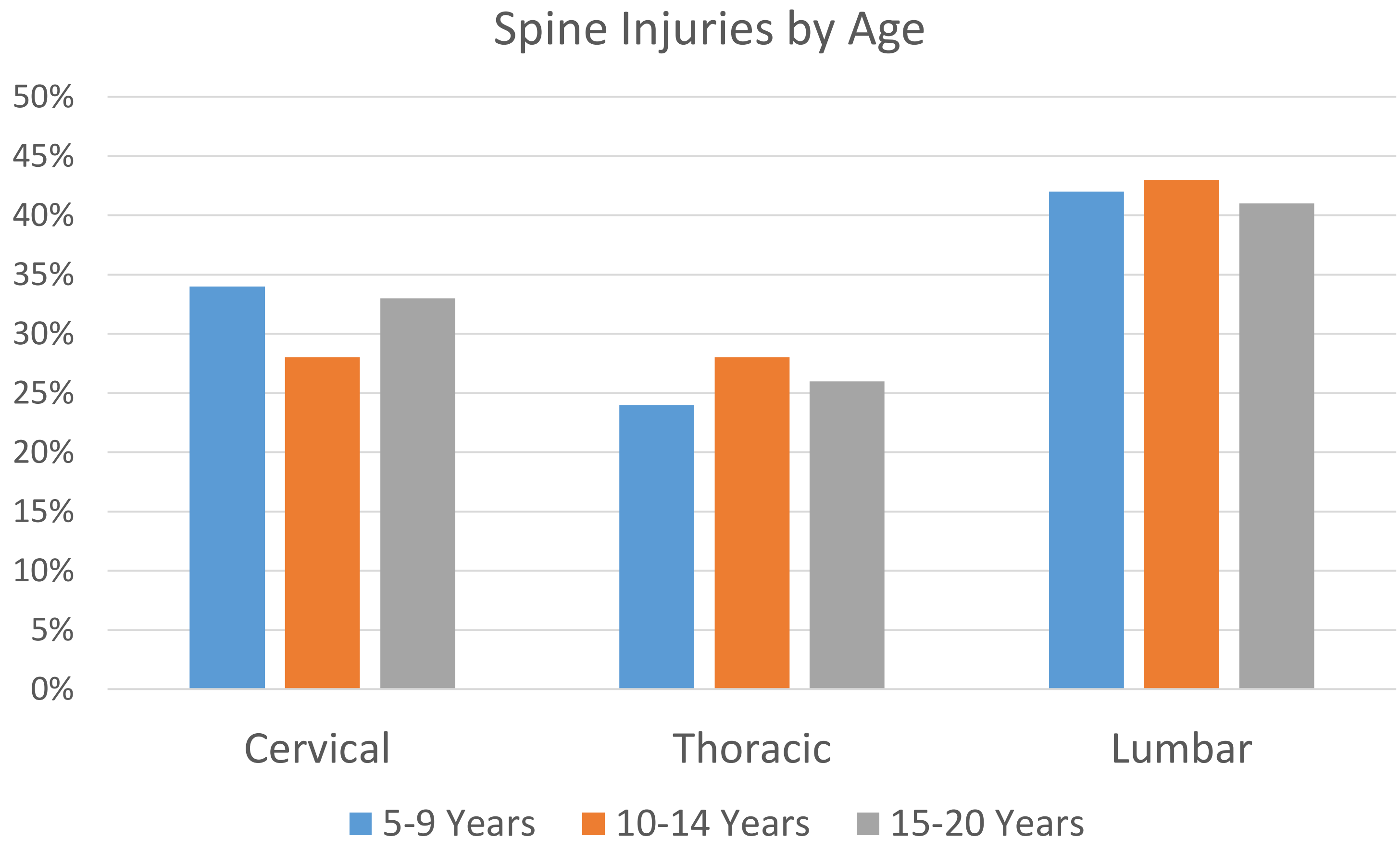
- Cervical Spine most common for age 0-4 years



Mendoza-Lattes et al. *Iowa Orthop J.* 2015; 35

Epidemiology

- Lumbar spine injuries more common for 5-20 years



Mendoza-Lattes et al.
Iowa Orthop J. 2015; 35

Epidemiology

- Motor vehicle accidents (MVAs) account for 52.9% of all injuries
- Cervical spine injuries are much more common in youngest patients
  - 0-3 years → ligamentous injury
  - 4-9 years→ compression fracture
- 25% mortality rate in infants and toddlers
- Neurologic injury occurs in 15% of spine fractures
  - 50% of cervical fractures have neurologic injuries

Knox et al. *J Pediatr Orthop.* 2014; 34(7)
Mendoza-Lattes et al. *Iowa Orthop J.* 2015; 35

Epidemiology

- Mortality
  - Rate of 2.5 – 3.7 per million
  - Mortality rate decreasing per annum
    - Piatt & Imperato. *J Neurosurg Pediatr.* 2018; 21

- Mortality rate related to level of injury and associated injuries
  - Highest mortality rate in upper cervical spine injuries in young children
    - Orenstein et al. *Pediatr Emerg Care.* 1994. 10

Mechanism of Injury

- Non-accidental trauma responsible for up to 19% of spine fractures in infants and toddlers
  - Knox et al. *J Pediatr Orthop.* 2014

- Sports-related trauma increasing in adolescent patients
  - Most common in cycling and contact sports
    - Gupta et al. *J Neurosurg Spine.* 2019

Noncontiguous Spinal Injuries (NCSI)

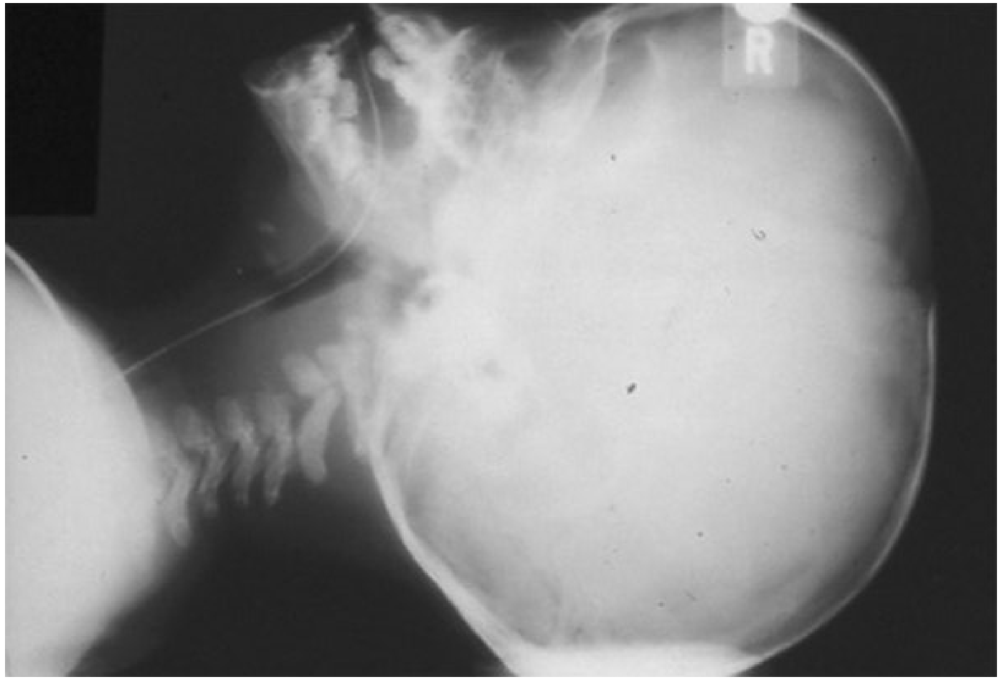
- Occurs in approximately 11.8% of cases
  - Most common is two noncontiguous thoracic spine
- 16% of NCSIs are initially missed
- Higher rates of neurologic injury than single level or contiguous injuries
  - 24% vs 9.7%
- Associated injuries found in 44% of cases
- Recommend imaging to include at least 4 spinal levels above and below

14 year old M with L2 and L5 burst fractures (Image courtesy of Josh Murphy, MD)

Firth GB et al. *Spine.* 37(10):E599-608.

Pediatric C-spine Immobilization

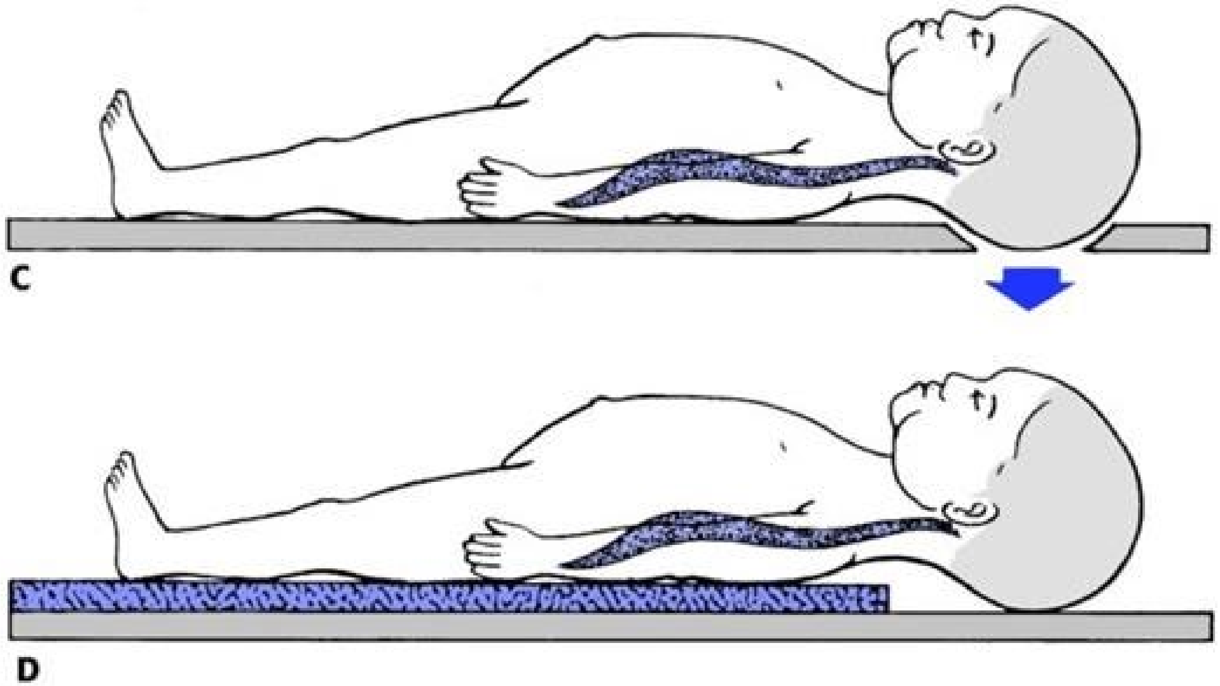
- Requires unique consideration in the pediatric patients
  - Especially true for children < 8 years
- Children have disproportionately larger heads relative to the body
  - Produces a cervical flexion when on a flat surface



Anterior translation of C2 fracture in child placed on spine board. (R&W 8th ed. Image 23-6)

Appropriate Immobilization

- Aim: to align external auditory meatus with shoulders
- Requires either head cut-out or mattress to elevate torso



Proper positioning techniques for cervical spine immobilization in young children. (R&W 8th edition. Figure 23-14, page 854)

Cervical Spine Clearance

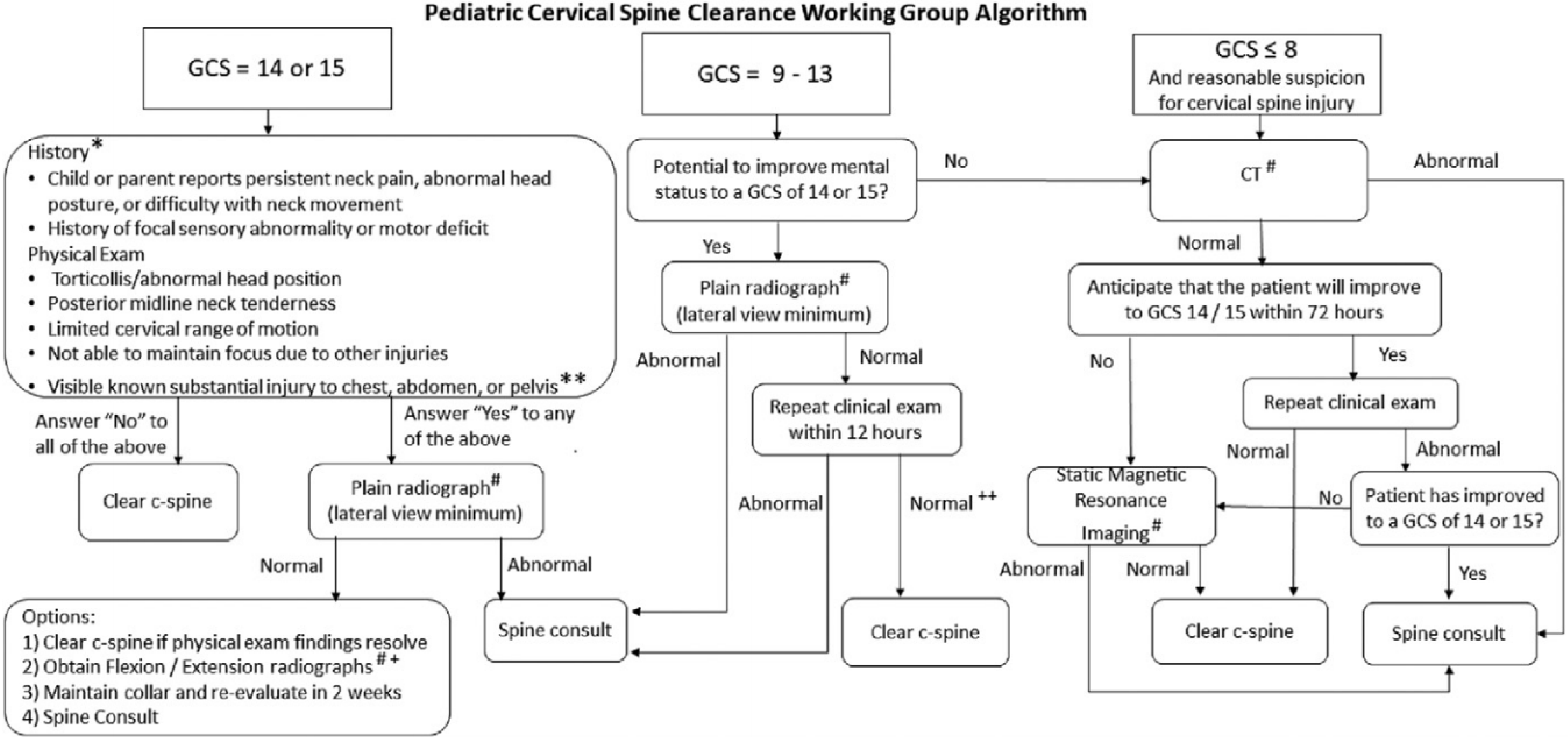
THE ORTHOPAEDIC FORUM

Pediatric Cervical Spine Clearance

A Consensus Statement and Algorithm from the Pediatric Cervical Spine Clearance Working Group

- Clearance protocol is distinctly different from adult protocol
- Pediatric Cervical Spine Clearance Working Group presented new clearance algorithm in 2019
- Approach based upon mental state at presentation, potential for recovery, and radiographic interpretation
  - Subgroups: 1) GSC 14 or 15 2) GSC 9-13 3) GSC ≤ 8
- *Goals: (1) Reduce time to c-collar removal (2) Decrease radiation exposure*

Herman et al. *J Bone Joint Surg Am.* 2019; 101



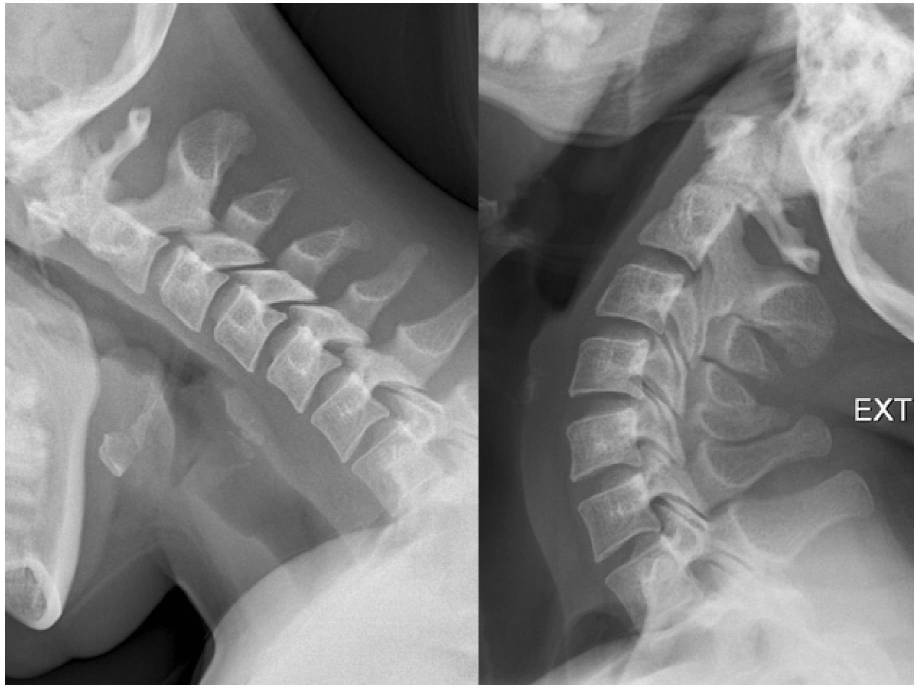
Used with permission from: Herman MJ, et al. Pediatric Cervical Spine Clearance: A Consensus Statement and Algorithm from the Pediatric Cervical Spine Clearance Working Group. J Bone Joint Surg Am. 2019 Jan 2;101(1):e1.

Glascow Coma Score (GCS) of 14-15

- Physical Exam findings are sufficient for clearance
  - *Cannot clear in the setting of:*
    - Torticollis
    - Posterior MIDLINE tenderness
    - Difficulty with neck ROM
    - Distracting injury
- Positive exam finding confirms need for plain radiographs

MIDLINE tenderness with a normal exam?

- Treatment options
  - 1) Place in rigid collar for 1-2 weeks with follow-up repeat examination
  - 2) Lateral flexion/extension radiographs
    - To be cleared, radiographs must confirm:
      - > 30 deg flexion and extension for adequate assessment
      - No subluxation present
  - 3.) Obtain spine consult



Example radiographs demonstrating adequate flexion/extension views of cervical spine.

GCS 9-13

- Initial Work-up:
  - If expected mental status improvement → lateral cervical radiograph
    - If no improvement expected → CT scan
  - If lateral radiograph normal → repeat exam in 12 hours
    - If repeat exam is normal → c-spine can be cleared

- *If suspected abusive head trauma, obtain cervical spine MRI*

- *Stronger consideration for imaging with higher risk mechanisms:*
  - *diving*
  - *axial loading*
  - *clothes-line*
  - *high-risk MVA*

GCS ≤8

- Initial imaging study:
  - Computed Tomography (CT)
  - Obtain MRI if:
    - If initial CT scan is negative and no anticipated mental status improvement within 72 hours
    - If abusive head trauma suspected
  - MRI is sufficient to clear cervical spine

3-year old with complete SCI after C2 fracture sustained during an MVC

Cervical Spine Trauma

Lateral cervical spine radiograph demonstrating C2 Hangman's fracture. (R&W 8th ed. Figure 23-48

Cranio-cervical Junction

- Also referred to as the Atlanto-occipital (AO) junction
- Consists of the articulation between occipital condyle and C1 lateral masses
  - Additional ligamentous component includes the odontoid

- **Articulation between C1 and occipital condyle is more horizontally oriented in young children**
  - *Coupled with a smaller occipital condyle increases vulnerability to injury*

Sagittal CT image demonstrating normal occipital cervical articulation

C1 – Atlas

- Composed of 3 ossification centers
  - Neural arch (x2) and body
- Anterior arch ossification centers appears by 1 year of age
  - Present in 20% of children at birth
- Posterior arches (D) fuse by age 3
- Neurocentral synchondrosis (F) fuses by age 7 years
- Ring reaches adult size by age 4 years

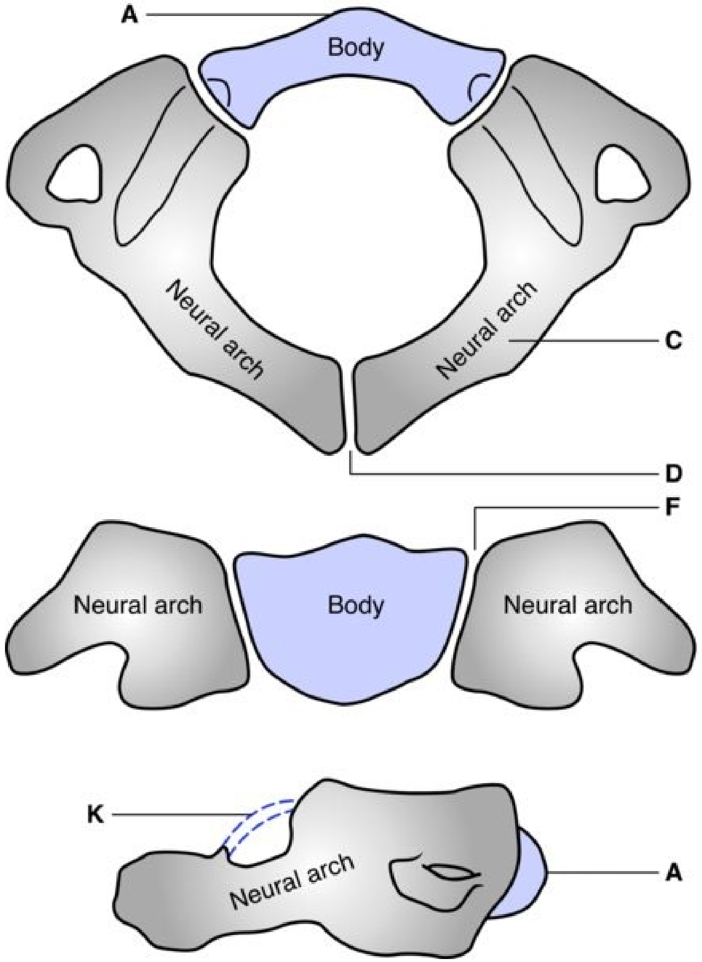


Illustration of C1 ossification centers (R&W 8th ed Figure 23-8)

C2 – Axis

- Consists of 4 ossification centers
  - Dens (odontoid process), body, neural arch (x2)

- Synchondroses
  - Odontoid and Body (Subdental)
    - Fuses by age 7 years
      - *Located below C1-C2 articulation*
  - Neurocentral synchondrosis
    - Formed between neural arch, odontoid and body
    - Fuses at 3-6 years of age
  - Neural Arches
    - Form the posterior arch
    - Fuse at 3-6 years

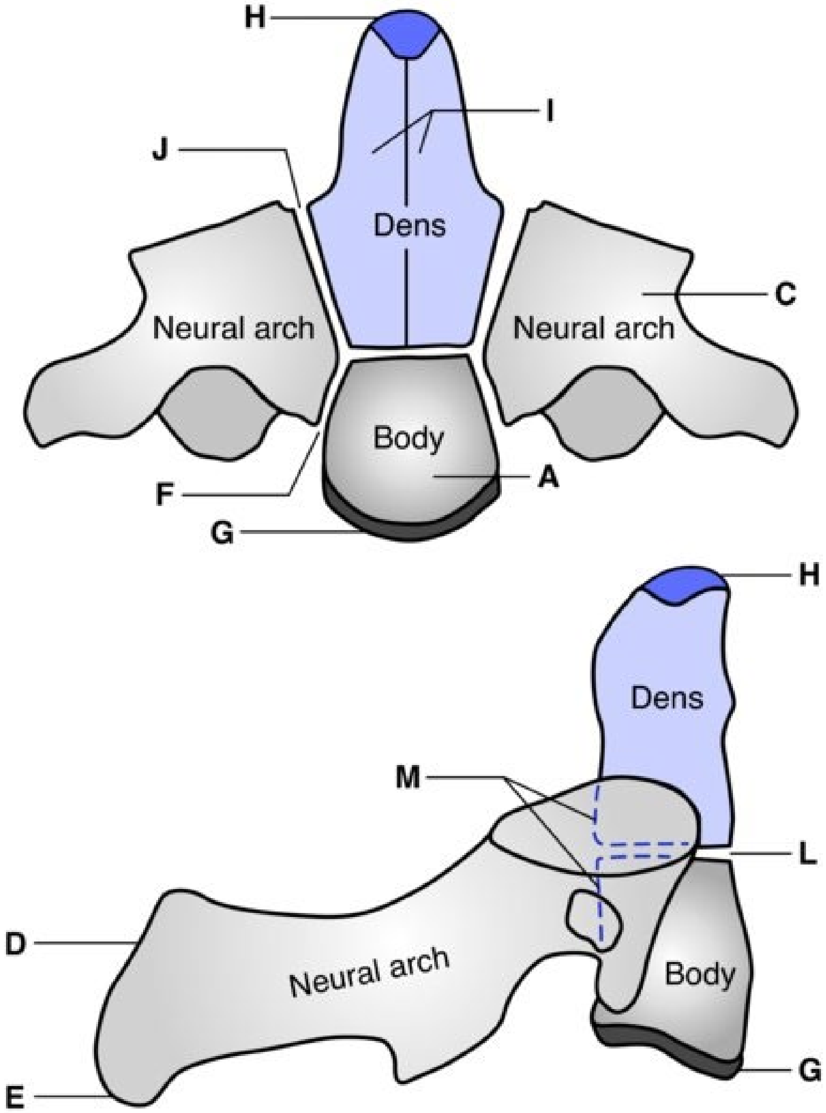
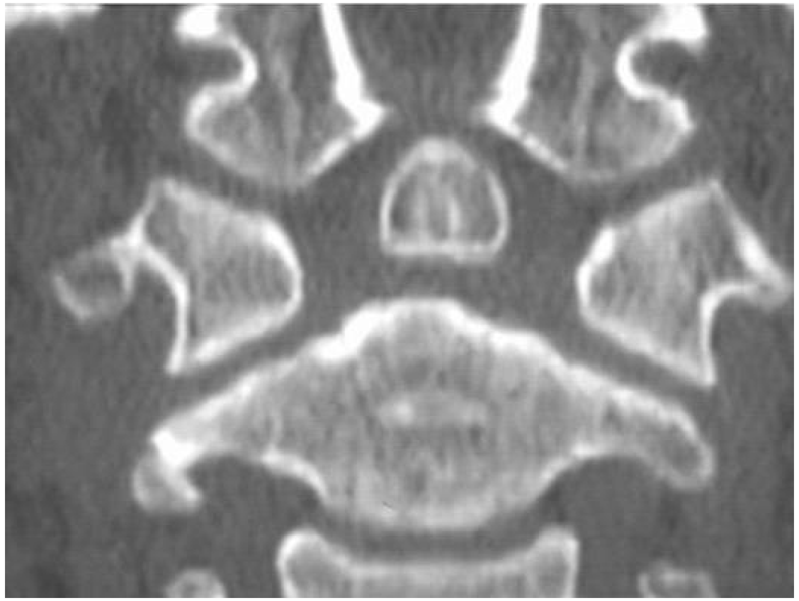


Illustration of C2 ossification centers (R&W 8th ed Figure 23-9)

Os Odontoideum

- Corticated ossicle of the odontoid
  - Anatomical variant
- Located well above C1-C2 articulation
- Etiology is debatable
  - Sequelae of trauma vs congenital
- Can be associated with C1-2 instability
  - Management depends on symptomatology and instability



Coronal CT image demonstrating an os odontoideum (R&W 8th ed Figure 23-10)

Subaxial Cervical Spine

- 3 ossification centers
  - Vertebral body and Neural arch (x2)
- Neural arches fuse at 2-3 years
- Neurocentral synchondrosis fuses at 3-6 years
- Vertebral body: wedge-shaped until 7-8 years

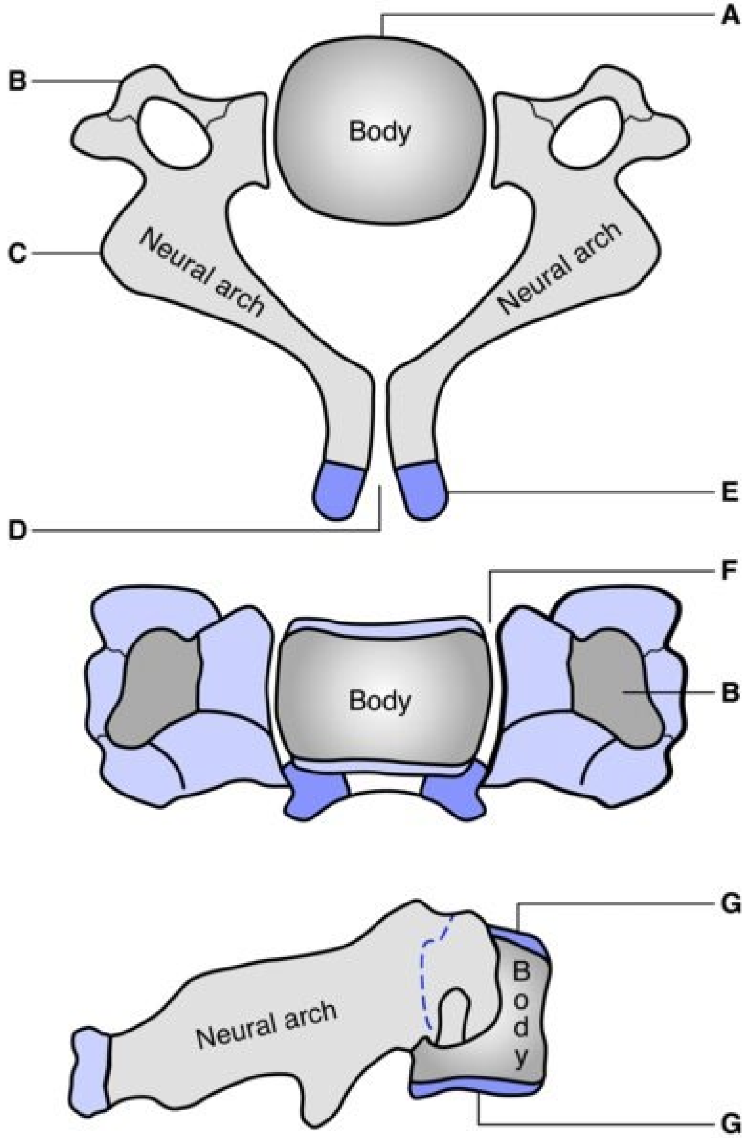
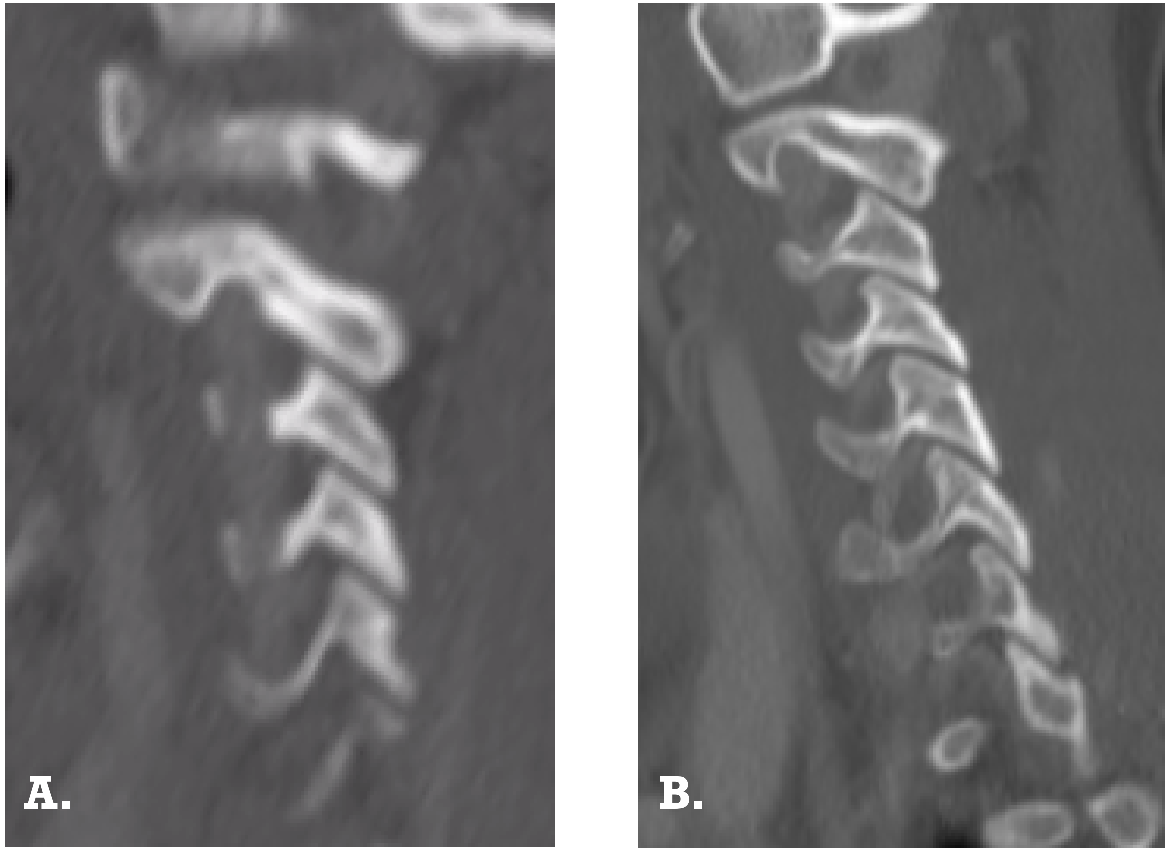


Illustration of subaxial cervical ossification centers (R&W 8th ed. Figure 23-12)

Facet Orientation

- Undergo progressive change in orientation with age
- Initial horizontal orientation may increase susceptibility to injury
- C1 and C2 facet orientation
  - 55 degrees at birth → increases to 70 degrees at maturity
- Subaxial spine orientation
  - 30 degrees at birth → increases to 60-70 degrees at maturity

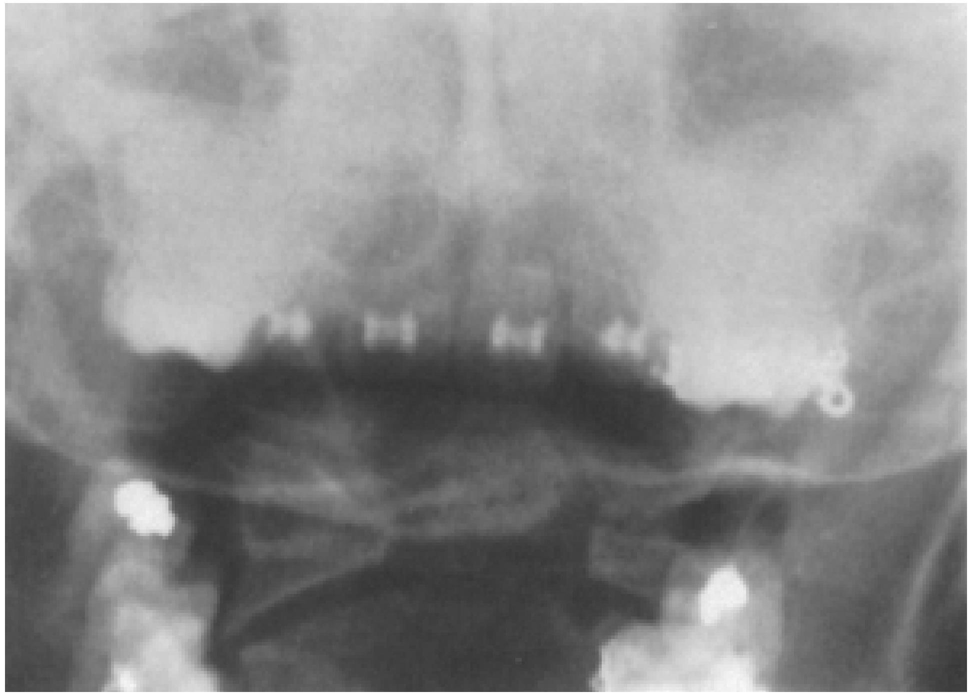


Sagittal CT images demonstrating cervical facet orientation measuring 30 deg in a 3 year old patient (A), and 45 degrees in a 10 year old patient.

Pesenti et al. *J Bone Joint Surg Am.* 2018; 100(9)

Cervical Spine Imaging

- Initial imaging depends on setting of evaluation
  - For trauma evaluation, follow protocol previously described
- Imaging options include:
  - 3 view plain radiographs
    - AP, lateral, open-mouth odontoid
  - Dynamic radiographs
    - Flexion and extension laterals
  - Computed tomography
    - Static and Dynamic
  - MRI



Open-mouth odontoid radiographs showing os odontoideum (R&W 8th ed. Figure 23-33)

Radiographic Evaluation

- Key relationships to assess for the Craniocervical Junction
  - 1) Occipital condyle – C1 facet distance
    - Should measure < 5 mm, increased distance indicated atlanto-occiptal injury

Lateral cervical spine radiographs showing atlanto-occipital dislocation with increased facet condylar distance (R&W 8th ed. Figure 23-25A)

Radiographic Evaluation

- Key relationships to assess for the Craniocervical Junction
  - 2) Foramen magnum relative to C1
    - Powers Ratio
      - Ratio of distances: BC/AO
        - (Basion-posterior arch)/(anterior arch-opisthion)
        - Normal = 0.7 – 1
        - > 1.0 is abnormal

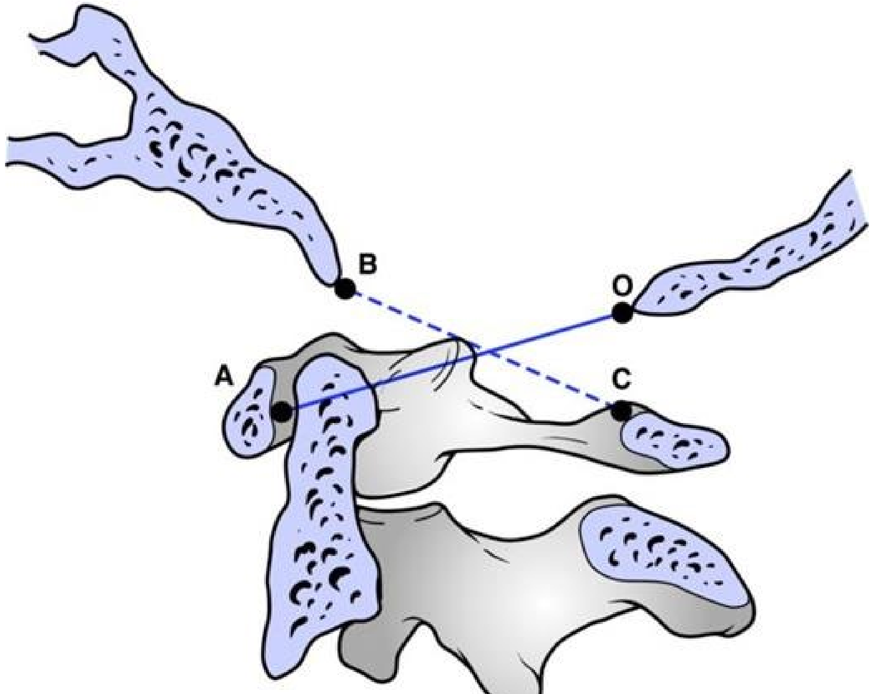


Illustration of Powers Ratio
(R&W 8th ed. Figure 23-1)

Radiographic Evaluation

- Key relationships to assess for the Craniocervical Junction
  - 2) Foramen magnum relative to C1
    - Wackenheim line along clivus
      - 1) Position of odontoid tip relative to line
        - Proximal to line→ basilar invagination
      - 2) angle between line and posterior vertebral body
        - <150 degrees suggests ventral cord compression

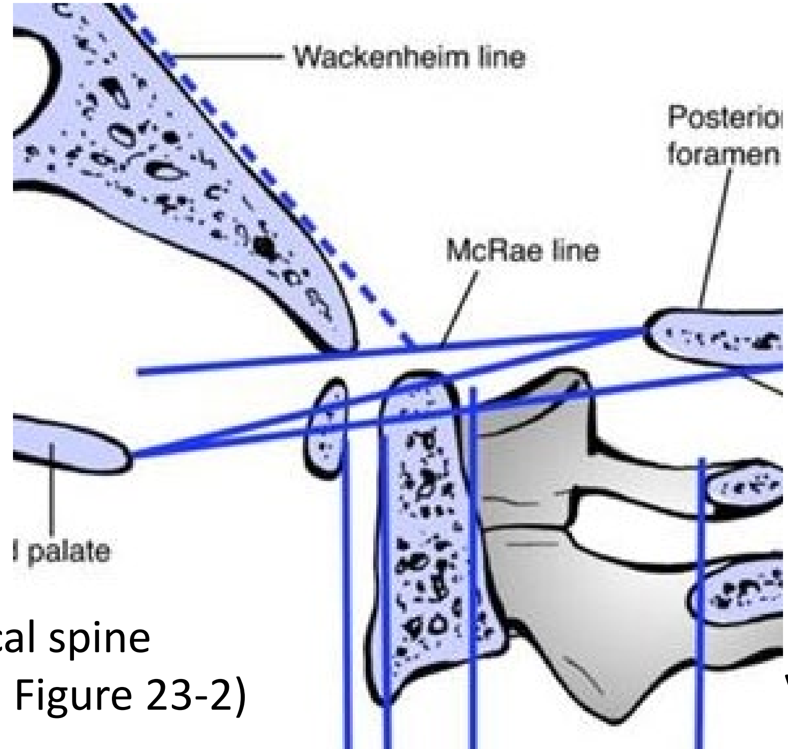


Illustration of upper cervical spine relationships (R&W 8th ed. Figure 23-2)

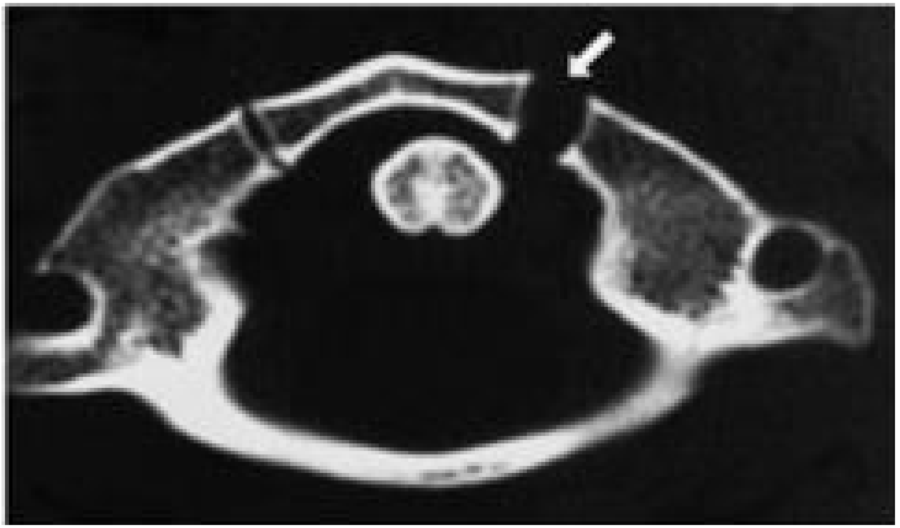
Benke et al. *Am J Orthop*. 2011; 40(10)

V5

Radiographic Evaluation: C1

- Isolated single point ring fractures can occur with patent synchondrosis

- Key relationships:
  - Lateral mass displacement relative to C2
    - Combined displacement >7mm indicative of transverse ligament disruption
      - Results in C1-2 instability



Axial CT image of C1 demonstrating single point ring fracture with patent synchondrosis (R&W 8th ed. Figure 23-30A)

Spence et al. *J Bone Joint Surg*. 1970; 52(3)
Heller et al. *J Spinal Disord*. 1993; 6(5)

Radiographic Evaluation: C1-2

- Most common measurements include:
  - 1) Atlanto-dens interval (ADI)
    - >4.5 mm indicates instability in children
  - Space available for cord (SAC)
    - <13 mm increases risk for spinal cord injury

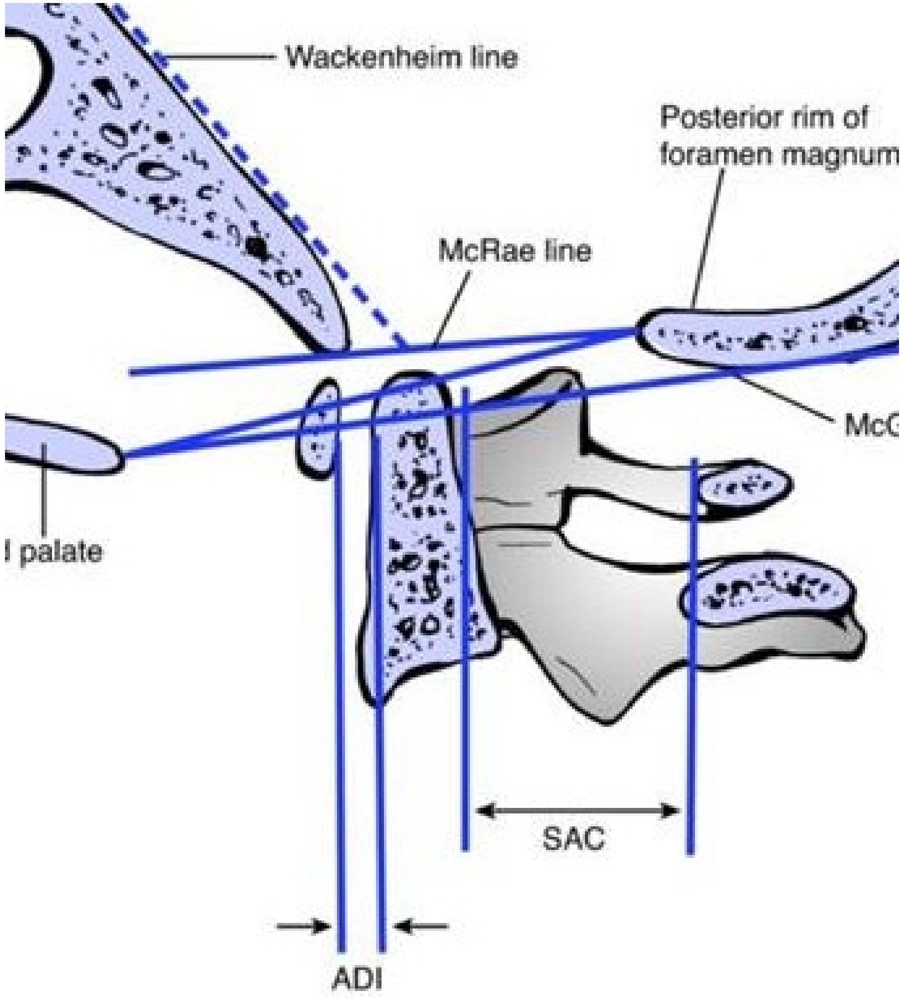


Illustration of upper cervical spine relationships (R&W 8th ed. Figure 23-2)

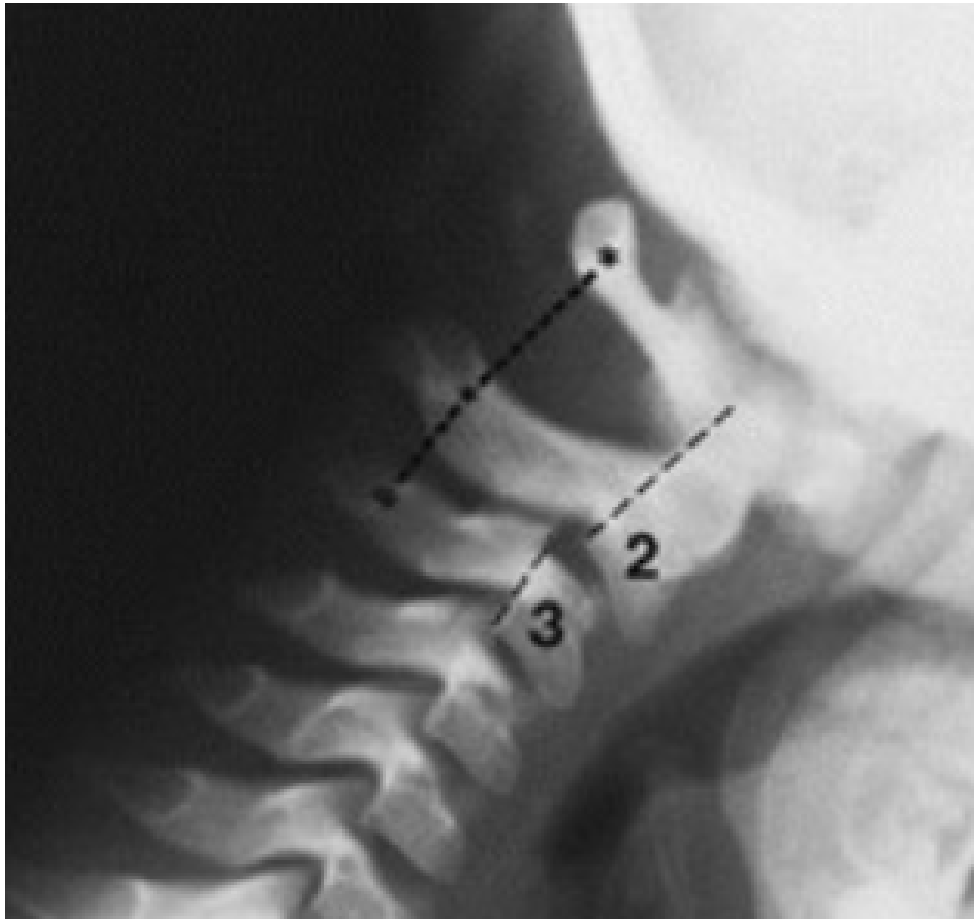
Spierings & Braakman. *J Bone Joint Surg Br.* 1982; 64(4)
Copley & Dormans. *J Am Acad Orthop Surg.* 1998; 6(4)

Radiographic Evaluation: C2

- Children < 6 years: fractures commonly occur through synchondrosis
  - Can be difficult to visualize
- Older children: resemble more adult fracture characteristics
  - Transverse fracture at level of articular surfaces

Lateral cervical radiograph and sagittal CT image demonstrate C2 fracture through the synchondrosis (R&W 8th ed. Figure 23-32)

Pseudosubluxation of C2-3



Lateral cervical radiographs demonstrating pseudosubluxation of C2-3 (R&W 8 ed. Figure 23-4)

- Apparent anterior translation of C2 on C3 on flexion views
  - Reduces with extension
- Translation < 3 mm
- **Line of Swischuk remains intact**
  - Line along anterior spinous process of C1 – C3
- True injury also presents with significant pre-vertebral swelling

Radiographic Evaluation: Subaxial Spine

- Relationship of adjacent vertebral bodies relative to one another
  - Anterior and posterior vertebral body lines
  - Spinolaminar and spinous process lines
  - *Identifies translational abnormalities*
    - *Loss of lordosis may be normal but no significant translation*

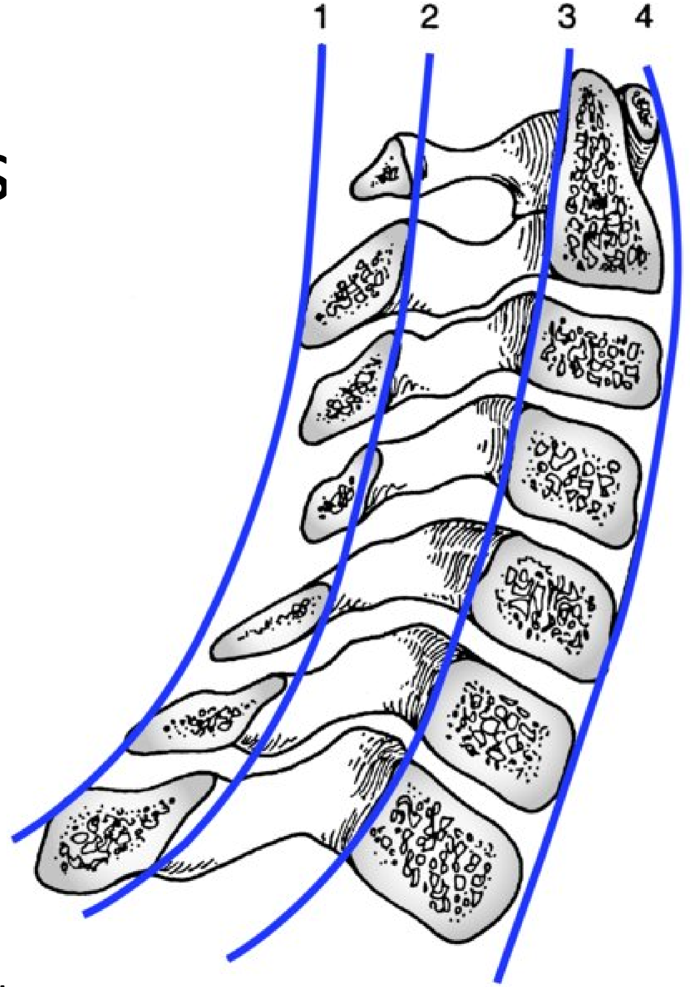


Illustration demonstrating various vertebral relationships (R&W 8th ed. Figure 23-5)

Cattell & Filtzer. *J Bone Joint Surg Am.* 1965; 47(7)

Do Forget the Soft Tissues!

- Pediatric spinal fractures can be difficult to visualize
  - Soft tissue swelling can be an indicator of injury
  - Retropharyngeal soft tissue space:
    - C2→ < 6 mm
    - C6→ < 14 mm

3 year old male with C2 fracture and increased retropharyngeal soft tissue swelling > 6 mm at C2

Spinal Cord Injury

- Rare in children
  - Improved prognosis compared to adults
- Incomplete injuries are 3x more common
- Mechanisms:
  - Child abuse
  - MVC
    - Association with forward-facing car seat in infants and toddlers
  - Breech delivery

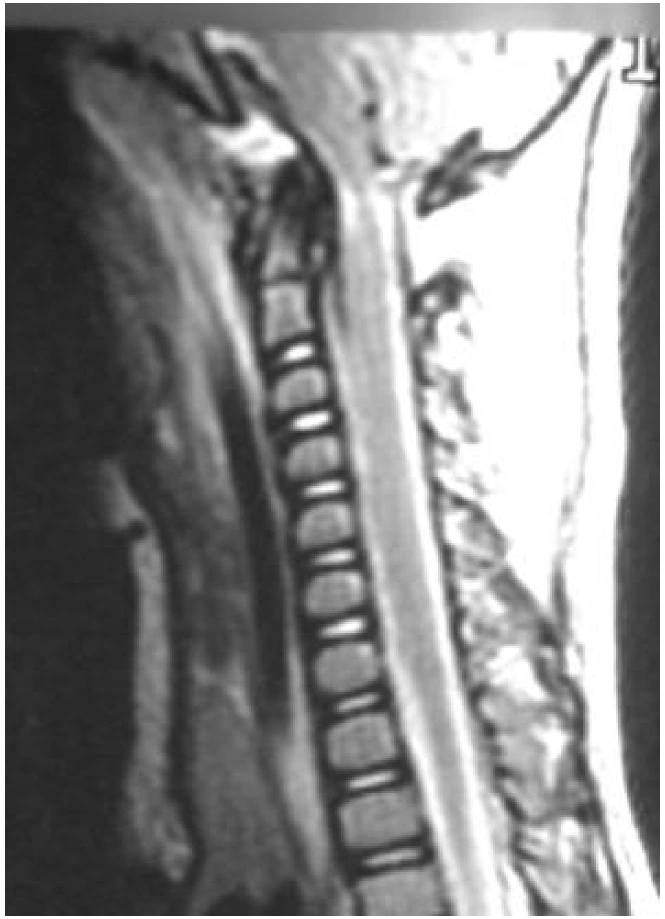
3-year old with complete SCI after C2 fracture in MVC

Reilly CW. *J Bone Joint Surg Am.* 2007; 89(S1).
Ranjith et al. *J Pediatr Orthop B.* 2002; 11.

SCIWORA

<u>*Spinal Cord Injury Without Radiographic Abnormality*</u>

- Distraction injury that is unique to children
- Spinal column is more elastic than spinal cord
  - *Spinal column can elongate 2 inches without disruption whereas spinal cord ruptures with ¼ inch elongation*
- Most common in upper cervical spine injuries and in children <8 years
  - 50% complete injuries
- Delayed onset of neurologic symptoms common in up to 52%
- ***High Suspicion in GCS 3 w/ normal CT head***
  - ***May be upper cervical spinal cord injury***



Sagittal MRI demonstrating atlanto-occipital injury in child with SCIWORA

Pang & Wilberger. *J Neurosurg.* 1982; 57:114-129.
Parent. S et al. *J Neurotrauma.* 2011;28:1515.

What About High-Dose Steroid Therapy?

- NASCIS trial excluded children < 13 years of age
- Current recommendation against us of high-dose steroid in adult SCI
- Initial NASCIS results were extrapolated to pediatric patients but there is no evidence to support improved neurologic outcome
- High rate of complication
  - Hyperglycemia
  - GI complications

Parent. S et al. *J Neurotrauma.* 2011;28:1515.
Caruso MC et al. *J Neurosurg Pediatr.* 2017; 20(6)
Cage JM et al. *J Pediatr Orthop.* 2015; 35(7)

Cervical Spine Treatment Options

- Varying based upon underlying injury and stability

- Options:
  - Cervical Orthosis
  - Halo Fixator
  - Posterior Arthrodesis

Halo vest immobilization for upper cervical spine fracture

Thoracolumbar Injuries

- Account for 1-2% of all pediatric fractures
- MVCs are most common mechanism
- Age difference in injury pattern
  - <8 years less likely to have thoracolumbar injuries
- Modes of failure:
  - Distraction → Chance type injuries
  - Compression → Compression fracture, burst fracture

Sagittal CT image of an L1 bony Chance fracture (R&W 9th ed. Figure 21-6)

Anatomy

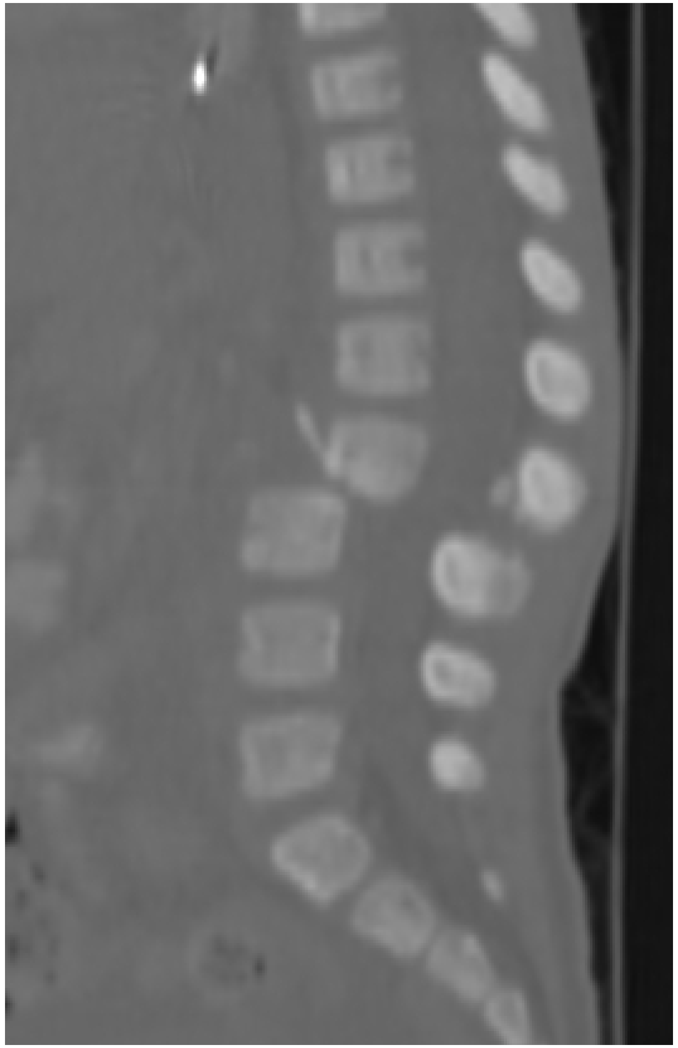
- 3 primary ossification centers
  - Vertebral body, Neural arch (x2)
- 5 secondary ossification centers
  - Spinous process, transverse process (x2), superior and inferior endplates (ring apophyses)
- Additional rigidity of thoracic spine due to rib attachment

Sagittal CT image of T9-11 in a 13 year old male demonstration presence of apophyseal rings (arrow)

Bick EM & Copel JW. The ring apophysis of the human vertebra. Contributions to human osteogeny II. *J Bone Joint Surg Am.* 1951; 33(3): 783-7.

Radiographic Evaluation

- Biplanar radiographs
- CT useful to evaluating fracture displacement, spinal canal encroachment
  - Not recommended for initial screening
  - Must balance with radiation exposure risk
- MRI favored when neurologic deficit present or concern for ligamentous injury



Sagittal CT Image of 2 yo with L2-3 fracture dislocation with canal compromise

Daniels AH et al. *J Am Acad Orthop Surg.* 2013; 21(12)

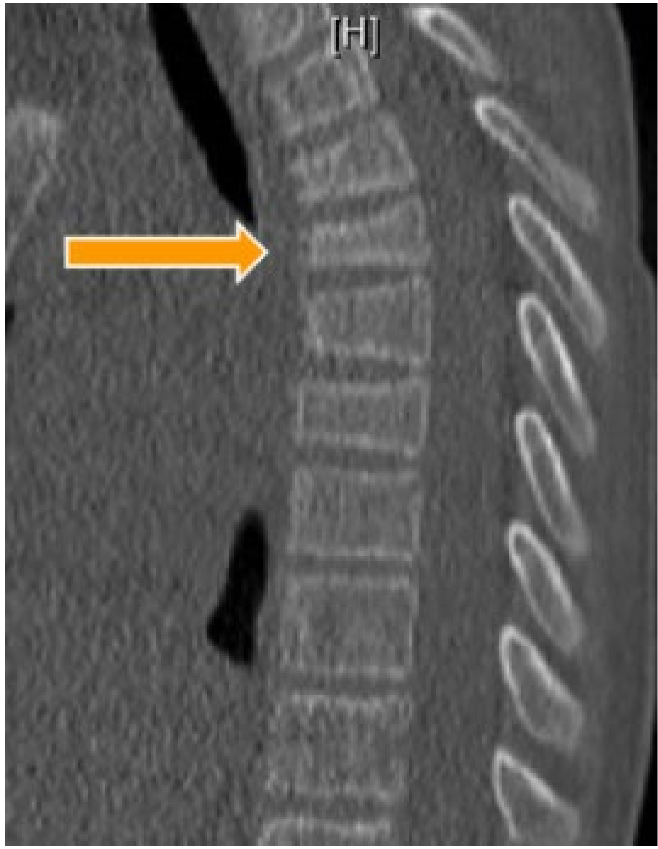
Injury Patterns

- Compression fracture
- Burst
- Flexion-distraction
- Fracture-dislocation
- Ring apophyseal fracture

Lateral radiographs demonstrating an L2 burst fracture (R&W 8th ed. Figure 24-10B)

Compression Fracture

- Most prevalent pediatric spinal fracture pattern
- Most commonly affect the thoracolumbar spine
- Low-energy mechanisms common
- Stability is maintained if posterior elements/ ligamentous structures are intact
  - *Anterior height loss >50% should raise concern for posterior injury and MRI is recommended*



11 year old M with contiguous T4-5 compression fractures after motocross accident

Daniels AH et al. *J Am Acad Orthop Surg.* 2013; 21(12)

Burst Fracture

- Axial compression mechanism
  - Involves anterior and middle column
- More common in older adolescents
- Retropulsion of bone can result in neurologic injury and/or dural tear
- Signs of Instability:
  - Posterior ligamentous complex involvement
    - 3 column injury
  - Focal Kyphosis
  - Retropulsion >50%
  - Lamina fracture
  - Facet subluxation

Daniels AH et al. *J Am Acad Orthop Surg.* 2013; 21(12)

14 year old M with L2 and L5 burst fractures after a fall from 60 feet (Image courtesy of Josh Murphy, MD)

Flexion-Distraction

- Occur secondary to a flexion moment over a fulcrum (i.e. seat belt)
- Tension forces in the posterior elements
  - Failure of posterior elements is propagated anteriorly
- Injuries can be bony, ligamentous, or both
- *Concomitant intra-abdominal and head injuries occur in 40% of patients*

Flexion-distraction injury at T12-1 evident by spinous process widening and anterior fracture (R&W 9th ed Figure 21-15)

Daniels AH et al. *J Am Acad Orthop Surg.* 2013; 21:707-16.

Flexion-Distraction Classification

Bony

Bony and ligamentous

Ligamentous

Daniels AH, Sobel AD, Eberson CP. *J Am Acad Orthop Surg.* 2013; 21:707-16.

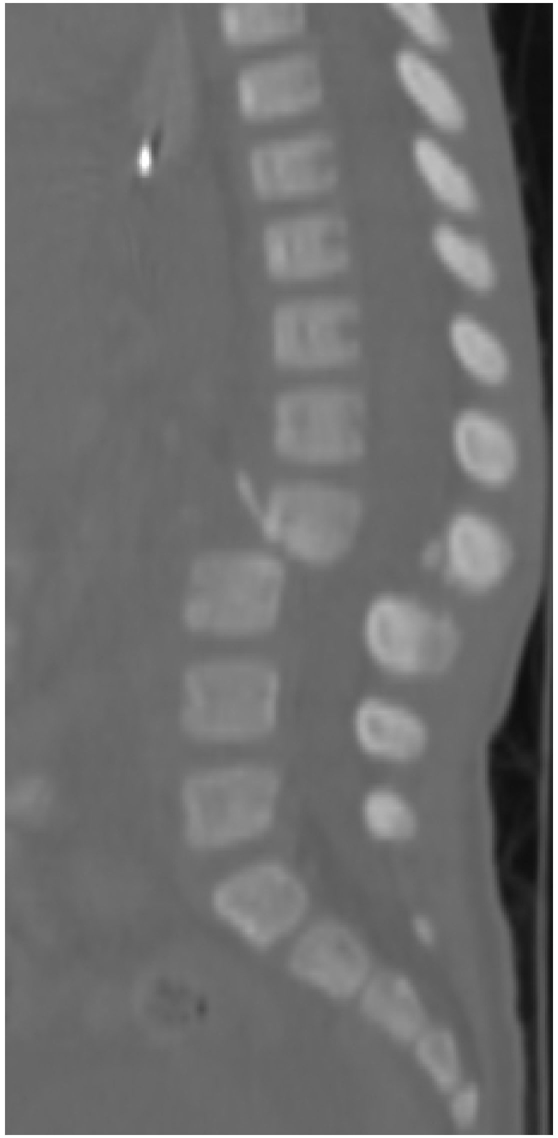
Lap Belt sign

- High association with intra-abdominal and lumbar spine injuries
- Warrants lumbar spine imaging

Arkader et al. Pediatric chance fractures: a multicenter perspective. *J Pediatr Orthop*. 2011;31:741.

Fracture-Dislocation

- Extremely high-energy mechanism
- Often associated with neurologic injury
- Treatment requires reduction and stabilization
- Instrumentation principles:
  - 2 levels above and below
  - If age < 10 years with complete SCI → expect paralytic scoliosis and can consider longer fusion constructs



2 year old with L2-3 fracture dislocation from non-accidental trauma.

Ring Apophyseal Fractures

- Affects children most commonly 10 - 14 years
- Ring apophysis separates from the vertebral spongiosa layer, usually of Inferior apophysis
- Classic symptom: radicular pain following strenuous activity
- Fractures can spontaneously reduce and may be difficult to visualize
    - MRI recommended for suspected injuries
- In absence of neurologic symptoms, non-surgical intervention recommended
- Surgery recommended if cauda equina compression present

16 year old with L5 apophyseal fracture involving the inferior end plate

Ring Apophyseal Variant

- Normal variant anatomy can mimic acute fracture
- Vertebral Body Shape
  - Vertebral body progresses from convex to concave morphology
- Apophyseal Ring ossification
  - Apophyseal appears between 6-13 years and ossifies at the end of growth
  - Ossification can mimic an apophyseal fracture

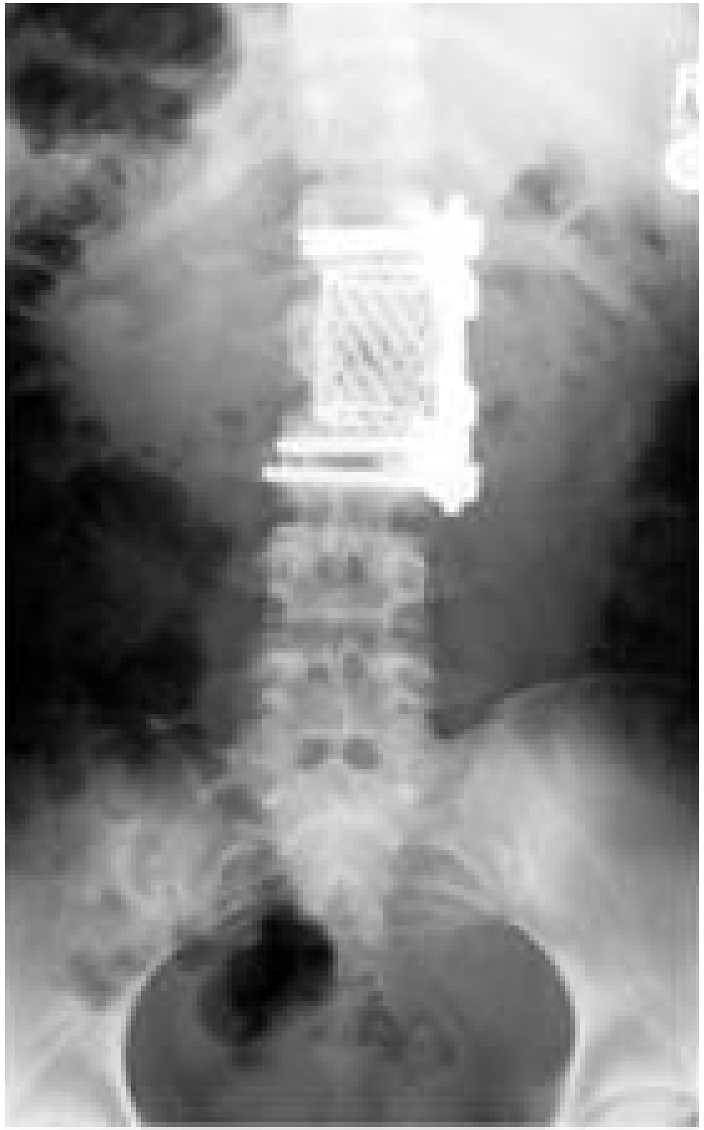
Akhaddar A et al. *J Neurosurg Spine.* 2011; 14(4)
Jaremko JL et al. *Pediatr Radiol.* 2015; 45(4).

Thoracolumbar Injuries

<u>Treatment options</u>

- Non-surgical:
  - Observation
  - Orthotic/Casting
- Operative treatment:
  - Decompression
  - Instrumentation
    (with or without arthrodesis)

- How do we decide when to operate?



AP radiograph after L2 corpectomy with anterior reconstruction and lateral instrumented fusion. (R&W 9th ed. Figure 21-14E)

Thoracolumbar Injury Classification and Severity (TLICS) Score

- Classifies injuries on three characteristics:
  - Fracture morphology
  - Integrity of the posterior ligamentous complex
  - Neurologic status
- Injuries are given a numeric score 1- 10
- Treatment recommendation is determined by score
  - Score ≤ 3 → Non-surgical treatment
  - Score ≥ 5→ Operative treatment

Vaccaro AR, Lehmann RA, Hurlbert JR et al. *Spine.* 2005; 30(20): 2325-33.

TLICS in Pediatric Patients?

- TLICS is applicable in pediatric spine trauma
- High inter-rater reliability and sensitivity
- High levels of agreement between treatment recommendation based on TLICS scores and actual treatment provided

Savage JW et al. *Spine.* 2015; 400(18): E1014-8.
Dawkins RL et al. *Neurosurgery.* 2019; 84(6): E362-7.

Take Home Points

- Cervical spine immobilization requires particular attention in younger children < 8 years
- Age and mechanism of injury influence spine injury patterns
- Proper knowledge of ossification patterns will aid in fracture recognition
- Treatment differs by age and injury location/pattern
- TLICS classification can be used to guide treatment in pediatric patients

References

1. Arkader A, Warner WC, Jr., Tolo VT, Sponseller PD, Skaggs DL. Pediatric Chance fractures: a multicenter perspective. J Pediatr Orthop. 2011;31(7):741-4.
2. Benke M, Yu WD, Peden SC, O'Brien JR. Occipitocervical junction: imaging, pathology, instrumentation. Am J Orthop (Belle Mead NJ). 2011;40(10):E205-15.
3. BICK EM, COPEL JW. THE RING APOPHYSIS OF THE HUMAN VERTEBRA: Contribution to Human Osteogeny. II. JBJS. 1951;33(3):783-7.
4. Cage JM, Knox JB, Wimberly RL, Shaha S, Jo C, Riccio AI. Complications Associated With High-dose Corticosteroid Administration in Children With Spinal Cord Injury. J Pediatr Orthop. 2015;35(7):687-92.
5. Caruso MC, Daugherty MC, Moody SM, Falcone RA, Bierbrauer KS, Geis GL. Lessons learned from administration of high-dose methylprednisolone sodium succinate for acute pediatric spinal cord injuries. J Neurosurg Pediatr. 2017;20(6):567-74.
6. Cattell HS, Filtzer DL. Pseudosubluxation and other normal variations in the cervical spine in children. A study of one hundred and sixty children. J Bone Joint Surg Am. 1965;47(7):1295-309.
7. Copley LA, Dormans JP. Cervical Spine Disorders in Infants and Children. JAAOS - Journal of the American Academy of Orthopaedic Surgeons. 1998;6(4):204-14.
8. Daniels AH, Sobel AD, Eberson CP. Pediatric Thoracolumbar Spine Trauma. JAAOS - Journal of the American Academy of Orthopaedic Surgeons. 2013;21(12):707-16.
9. Dawkins RL, Miller JH, Menacho ST, Ramadan OI, Lysek MC, Kuhn EN, et al. Thoracolumbar Injury Classification and Severity Score in Children: A Validity Study. Neurosurgery. 2019;84(6):E362-e7.
10. Firth GB, Kingwell SP, Moroz PJ. Pediatric noncontiguous spinal injuries: the 15-year experience at a level 1 trauma center. Spine (Phila Pa 1976). 2012;37(10):E599-608.
11. Gupta S, Hauser BM, Zaki MM, Xu E, Cote DJ, Lu Y, et al. Morbidity after traumatic spinal injury in pediatric and adolescent sports-related trauma. J Neurosurg Spine. 2019:1-7.
12. Hedequist DJ, Mo AZ. Os Odontoideum in Children. JAAOS - Journal of the American Academy of Orthopaedic Surgeons. 2020;28(3):e100-e7.
13. Heller JG, Viroslav S, Hudson T. Jefferson fractures: the role of magnification artifact in assessing transverse ligament integrity. J Spinal Disord. 1993;6(5):392-6.
14. Herman MJ, Brown KO, Sponseller PD, Phillips JH, Petrucelli PM, Parikh DJ, et al. Pediatric Cervical Spine Clearance: A Consensus Statement and Algorithm from the Pediatric Cervical Spine Clearance Working Group. J Bone Joint Surg Am. 2019;101(1):e1.
15. Herzenberg JE, Hensinger RN, Dedrick DK, Phillips WA. Emergency transport and positioning of young children who have an injury of the cervical spine. The standard backboard may be hazardous. J Bone Joint Surg Am. 1989;71(1):15-22.

References

16. Knox JB, Schneider JE, Cage JM, Wimberly RL, Riccio AI. Spine trauma in very young children: a retrospective study of 206 patients presenting to a level 1 pediatric trauma center. J Pediatr Orthop. 2014;34(7):698-702.

17. Mendoza-Lattes S, Besomi J, O'Sullivan C, Ries Z, Gnanapradeep G, Nash R, et al. Pediatric Spine Trauma in the United States--Analysis of the HCUP Kid'S Inpatient Database (KID) 1997-2009. Iowa Orthop J. 2015;35:135-9.

18. Orenstein JB, Klein BL, Gotschall CS, Ochsenschlager DW, Klatzko MD, Eichelberger MR. Age and outcome in pediatric cervical spine injury: 11-year experience. Pediatr Emerg Care. 1994;10(3):132-7.

19. Pang D, Wilberger JE, Jr. Spinal cord injury without radiographic abnormalities in children. J Neurosurg. 1982;57(1):114-29.

20. Parent S, Mac-Thiong JM, Roy-Beaudry M, Sosa JF, Labelle H. Spinal cord injury in the pediatric population: a systematic review of the literature. J Neurotrauma. 2011;28(8):1515-24.

21. Piatt J, Imperato N. Epidemiology of spinal injury in childhood and adolescence in the United States: 1997-2012. J Neurosurg Pediatr. 2018;21(5):441-8.

22. Ranjith RK, Mullett JH, Burke TE. Hangman's fracture caused by suspected child abuse. A case report. J Pediatr Orthop B. 2002;11(4):329-32.

23. Reilly CW. Pediatric spine trauma. J Bone Joint Surg Am. 2007;89 Suppl 1:98-107.

24. Savage JW, Moore TA, Arnold PM, Thakur N, Hsu WK, Patel AA, et al. The Reliability and Validity of the Thoracolumbar Injury Classification System in Pediatric Spine Trauma. Spine (Phila Pa 1976). 2015;40(18):E1014-8.

25. Spence KF, Jr., Decker S, Sell KW. Bursting atlantal fracture associated with rupture of the transverse ligament. J Bone Joint Surg Am. 1970;52(3):543-9.

26. Spierings EL, Braakman R. The management of os odontoideum. Analysis of 37 cases. J Bone Joint Surg Br. 1982;64(4):422-8.

27. Takata K, Inoue S, Takahashi K, Ohtsuka Y. Fracture of the posterior margin of a lumbar vertebral body. J Bone Joint Surg Am. 1988;70(4):589-94.

28. Vaccaro AR, Lehman RAJ, Hurlbert RJ, Anderson PA, Harris M, Hedlund R, et al. A New Classification of Thoracolumbar Injuries: The Importance of Injury Morphology, the Integrity of the Posterior Ligamentous Complex, and Neurologic Status. Spine. 2005;30(20):2325-33.

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- Warner WC & Hedequist DJ. Cervical Spine Injuries in Children. In: Waters PM, Skaggs DL, & Flynn JM eds. Rockwood and Wilkins Fractures in Children, 9e. Philadelphia, PA. Wolters Kluwer Health, Inc. 2019.
- Newton PO & Luhmann J. Thoracolumbar Spine Fractures. In: Flynn JM, Skaggs DL, & Waters PM eds. Rockwood and Wilkins Fractures in Children, 8e. Philadelphia, PA. Wolters Kluwer Health, Inc. 2015.
- Newton PO & Upasani VV. Thoracolumbar Spine Fractures. In: Waters PM, Skaggs DL, & Flynn JM eds. Rockwood and Wilkins Fractures in Children, 9e. Philadelphia, PA. Wolters Kluwer Health, Inc. 2019.