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
- Incidence
  - 93 – 107 per million
  - Annual incidence decreasing since 2000
- Injury Pattern
  - Varies based on patient age
  - <8 years → upper cervical spine injuries
  - Adolescence → thoracolumbar/Sacral fracture
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

Spine Injuries by Age

- Cervical
- Thoracic
- Lumbar

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

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
Mechanism of Injury

• Non-accidental trauma responsible for up to 19% of spine fractures in infants and toddlers

• 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)
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

• 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

Pediatric Cervical Spine Clearance Working Group Algorithm

GCS = 14 or 15

- History*
  - Child or parent reports persistent neck pain, abnormal head posture, or difficulty with neck movement
  - History of focal sensory abnormality or motor deficit
- Physical Exam
  - Torticollis/abnormal head position
  - Posterior midline neck tenderness
  - Limited cervical range of motion
  - Not able to maintain focus due to other injuries
- Visible known substantial injury to chest, abdomen, or pelvis**

Answer "No" to all of the above

Clear c-spine

Options:
1) Clear c-spine if physical exam findings resolve
2) Obtain Flexion / Extension radiographs #*
3) Maintain collar and re-evaluate in 2 weeks
4) Spine consult

GCS = 9 - 13

Potential to improve mental status to a GCS of 14 or 15?

Yes

- Plain radiograph# (lateral view minimum)

No

- Repeat clinical exam within 12 hours

Abnormal

Repeat clinical exam

Normal

Anticipate that the patient will improve to GCS 14 / 15 within 72 hours

GCS ≤ 8
And reasonable suspicion for cervical spine injury

CT #

Abnormal

Normal

Patient has improved to a GCS of 14 or 15?

Yes

Clear c-spine

No

Repeat clinical exam

Abnormal

Normal

Spine consult

Spine consult

Glasgow 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 synchondrosisis (F) fuses by age 7 years
- Ring reaches adult size by age 4 years
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-occipital 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
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)
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)

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)
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

- 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

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

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 $\rightarrow$ < 6 mm
  - C6 $\rightarrow$ < 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).
**SCIWORA**

*Spinal Cord Injury Without Radiographic Abnormality*

- 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 \( \frac{1}{4} \) 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*

What About High-Dose Steroid Therapy?

• NASCIS trial excluded children < 13 years of age
• Current recommendation against use 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

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

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
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
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


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)
Flexion-Distraction Classification

Bony

Bony and ligamentous

Ligamentous

Lap Belt sign

• High association with intra-abdominal and lumbar spine injuries

• Warrants lumbar spine imaging

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)
Thoracolumbar Injuries

Treatment options

• 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 $\leq 3 \rightarrow$ Non-surgical treatment
  - Score $\geq 5 \rightarrow$ Operative treatment

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

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


References


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