Cervical Spine Injuries:

Pediatric and Adult considerations

BUT…MAINLY PEDIATRIC

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Disclosures

– NONE

Goals

- Highlight epidemiological, physiological and anatomical nuances of pediatric cervical spine injuries
- Review cervical spine injuries unique to pediatrics
- Illustrate various pediatric cervical spine injury patterns which overlap with adults utilizing pediatric examples

Unique feature of pediatric C-spine injuries

- Evaluation of the cervical spine in children in the setting of trauma is difficult
  - Significant morphological changes occur between infancy and adolescence
    - Numerous developmental variants exist
    - Specific disease processes alter anatomy or predispose to injury
    - Occasionally, specific pediatric injury patterns are encountered
  - Cervical spine injury in children is unusual
    - About 1% incidence of cervical spine fractures in children compared to 5-7% in adults
    - Consequently most radiologists have little experience with pediatric spine imaging and pathology
- Etiology
  - Like adults, motor vehicle accidents and falls are common causes of cervical spine injury in pediatrics
  - Pedestrian and bicycle related motor vehicle injuries, sports injuries and child abuse are also encountered
- Distribution of injuries
  - Craniocervical junction (CCJ) injury is very common in infancy and young children
- Prompt and accurate diagnosis is crucial to optimize patient care

NEXUS/CCSR/PECARN

Due to the low frequency of cervical spine injuries in children, much of the information has been derived from large multi-institutional studies

- National Emergency X-ray Utilization Study
  - Of 3065 blunt trauma patients < 18 years of age, 30 fractures identified
    - 0 fractures < 2 years of age
    - 4 fractures 2-9 years of age
    - 5 fractures 9-13 years of age
    - 21 fractures > 13 years of age
    - 5 spinal cord injuries without fracture
  - No fracture or cord injury in patients with normal mental status and absence of midline tenderness, focal neurological deficit or distracting injury
- Canadian Cervical Spine Rules
  - NEXUS criteria plus dangerous mechanism of injury and patient ability to move neck
- Pediatric Emergency Care Applied Research Network
  - Multi-institution multivariable logistic regression analysis of pediatric trauma patients
  - 8 variables associated with cervical spine injury: altered mental status, focal neurological deficit, neck pain, torticollis, predisposing condition (e.g., syndrome, dysplasia, inflammatory arthritis), substantial injury to torso, high risk motor vehicle accident, and diving
  - Presence of one variable had sensitivity of 98% and specificity of 26% for identifying cervical spine injury

Explanations for differences in pediatric cervical spine injuries compared to adults

- Anatomical
  - Disproportionately large head compared to body
  - Underdeveloped neck muscles
    - Predispose spine to higher torque with acceleration/deceleration injuries
  - Shallow articulations (A-O joints, facets and uncovertebral joints)
  - Vertebral body shape: ovoid in neonates, to anterior wedge children to rectangular in adolescents
- Biomechanical
  - Fulcrum of motion is centered at C2-C3 in children compared to C5-C6 in adults
  - Ligamentous and capsular laxity
    - Z-axis distractibility of the spine exceeds that of the spinal cord and supportive soft tissues
    - Probably accounts for the higher incidence of SCIWORA in children
  - Incompletely ossified vertebrae
- Behavioral
  - Difficult to get reliable history or physical examination
  - Difficult to get high quality imaging

Pediatric C-spine Imaging

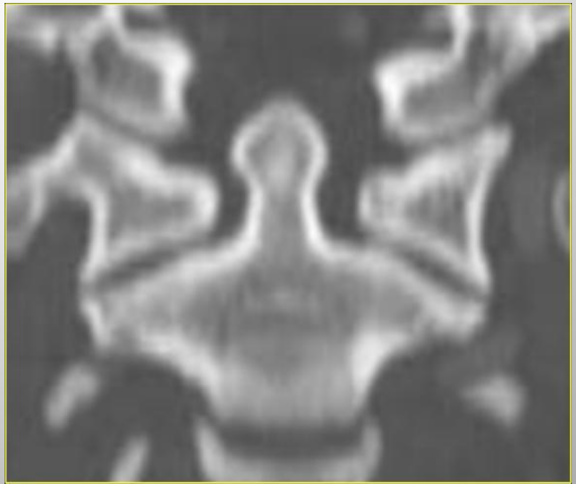
- If imaging is clinically required (HDVCH protocol)
  - Radiography: Low sensitivity for cervical spine injury (43%)
    - Protocol: AP, lateral and odontoid (less than 13 years of age)
      - Bilateral obliques can be added in adolescent patients
    - Generally precautionary in patients some clinical suspicion but no NEXUS, CCR or PECARN risk factors or because of expediency
  - Computed tomography: High sensitivity for cervical spine fracture (98.5%)
    - All patients with risk factors outlined by NEXUS, CCR or PECARN studies or patient getting CT of other body part get CT of cervical spine
    - Protocol: Noncontrast 1.25 mm axial acquisition with sagittal and coronal reformats with bone algorithm; sagittal reformat using standard algorithm
      - CT Angiography rarely alters treatment
      - Although C1-C3 injury associated with vertebral artery injury
  - Magnetic resonance: High sensitivity for soft tissue injury
    - Sagittal fat suppressed T1 and IR, sagittal and axial T1 and T2 and axial T2 MERGE
    - Essential in patients with suspected CCJ injury and unstable injuries by radiography/CT (presurgical assessment, disc herniation, extra-axial hemorrhage, cord status)
    - Also recommended in patients under 2 years of age in conjunction with CT with high risk injuries

Developmental Variations

Pseudosubluxation

- Commonly seen in children under 8 years of age
- Often in upper cervical spine
  - Lateral atlanto-dental interval (coronal plane)
    - **Normal < 3.9 mm** of asymmetry and intact lateral spinal line
  - C2-C3 (sagittal plane)
    - Normal < 3 mm offset between C2 and C3 vertebral body lines and preserved spinolaminar line
- Importantly, pseudosubluxation should only be diagnosed in the absence of fracture or other secondary post-traumatic findings

Pseudosubluxation in 2 year old child who fell off couch. Sagittal reformatted CT image shows anterior subluxation of C2 relative to C3 but intact spinolaminar line.

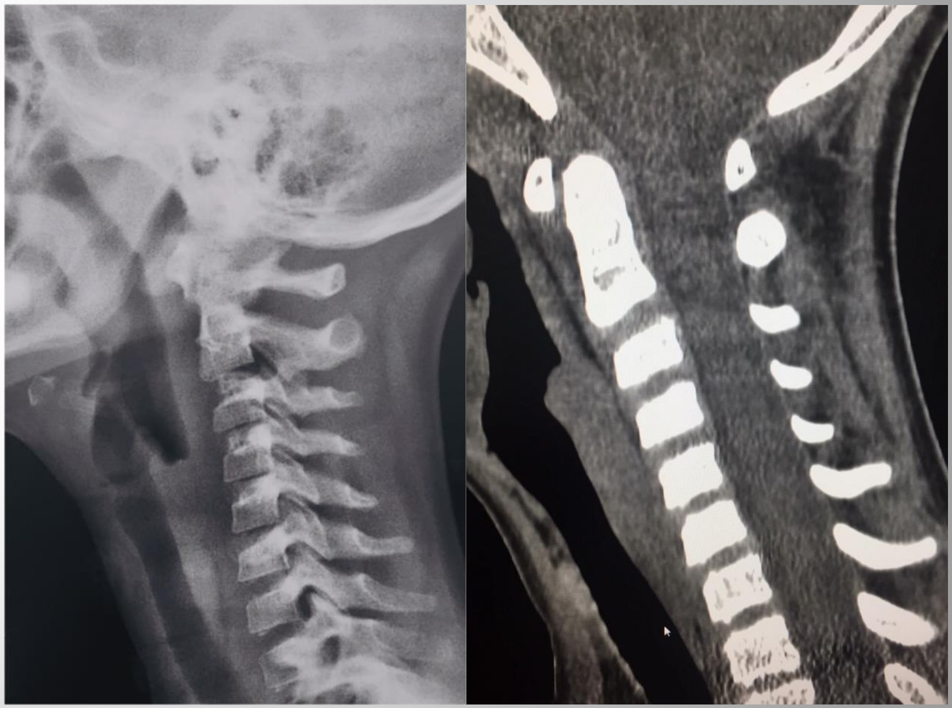


Normal lateral atlantodental asymmetry seen incidentally in a teenager with lymphoma. Note the intact lateral spinal line.

Developmental Variations

Precervical Soft Tissues

- Precervical soft tissue swelling on radiographs is an important indicator of possible bony injury in the context of trauma
  - Swallowing, expiratory phase of imaging and flexion can artifactually increase precervical soft tissues
  - Infectious, congenital (hemangioma, lymphatic malformation, teratoma) and neoplastic (lymphoma, neuroblastoma) etiologies can also increase precervical soft tissues
- Preservation of precervical fat suggests absent edema
- Most predictable measurement of precervical soft tissues is at C2 (lower vertebral body)
  - Lateral radiograph or sagittal reformat CT
    - 0-2 y < 5 mm
    - 3-6 y < 5 mm
    - 7-10 y < 4.6 mm
    - 11-15 y < 4.6
    - > 15 y < 3.7 mm

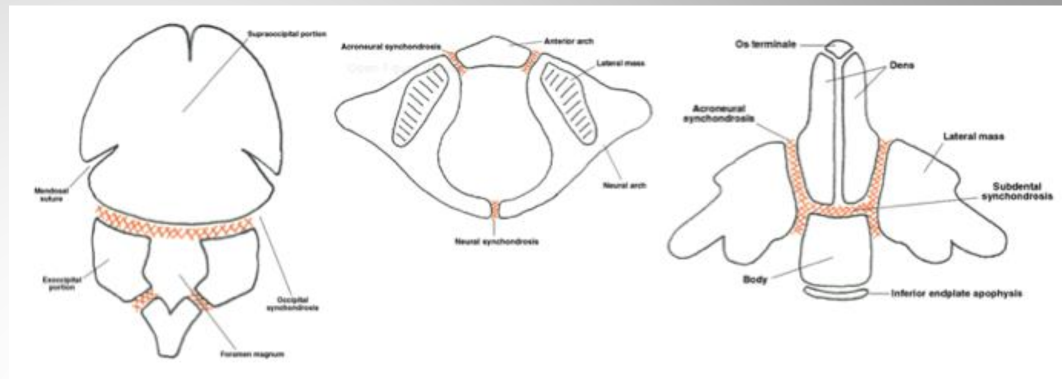


Teenager with neck pain after motor vehicle accident. Radiographs were normal except for increased precervical soft tissues at C2. CT confirms absent osseous injury and shows that the soft tissue prominence was related to redundant mucosa; note that the precervical fat stripe is preserved.

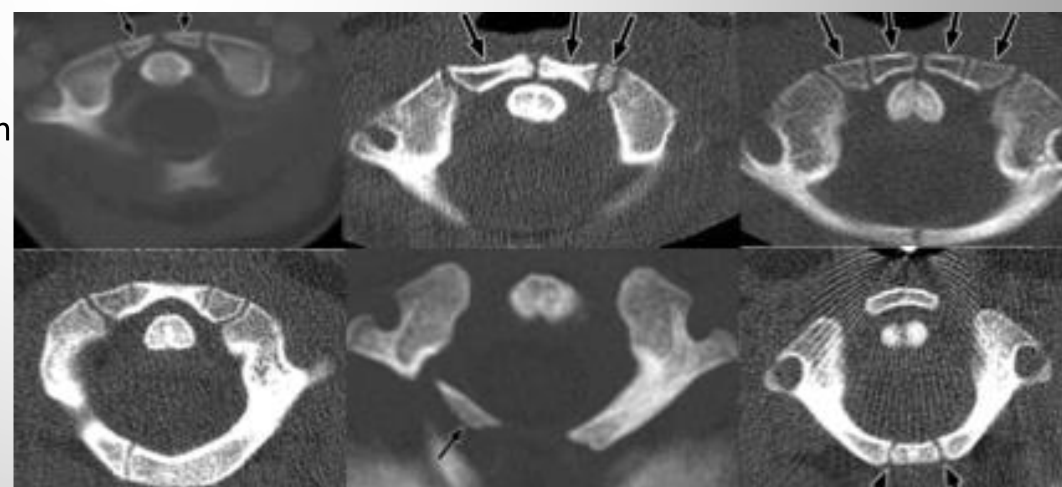
Developmental Variations

Normal Ossification Variants

- Ossification of basi-occiput
  - 4 ossification centers
- Ossification of cervical vertebra
  - Usually 1 for the body and each of the posterior arches
  - C1 quite variable
    - As many as 4 ossifications for the anterior arch and
    - Occasionally asymmetric ossification of the anterior and posterior arches
    - Incomplete fusion of the anterior arch in the midline is common
  - C2 normally has 5 or 6
    - 1 for the body, 2 for the dens, 2 for the posterior arches and 1 for os terminale
- Incomplete fusion of posterior arches in the midline is normal



Normal ossification centers and synchondroses of the craniocervical junction



Selected ossification variants of the anterior and posterior arches of the atlas

Developmental Variations

Bone and Joint Morphology

- A-O joints are shallow in infancy with redundant capsules
  - Joints deepen with age
- Uncovertebral joints (joints of Luschka) are unique to the cervical spine
  - Lips projecting from the lateral aspects of the superior vertebral bodies
  - Uncinate processes limit lateral translation
  - Gradually enlarge with age
- Facets
  - Relatively short and horizontal

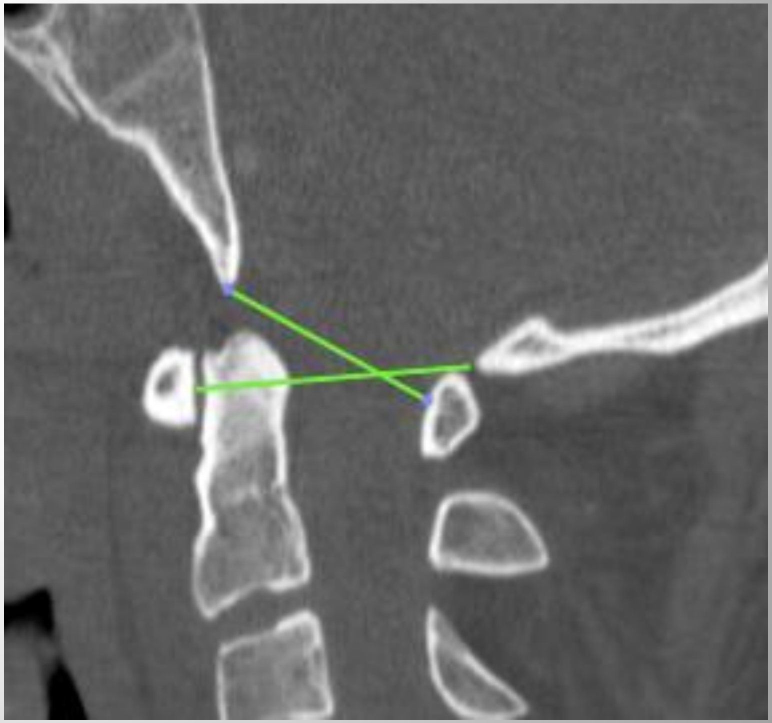
Sagittal and coronal reformatted images from 1 year old male to evaluate for injury. Note the shallow nearly horizontal AO joints and the yet to be developed uncinate processes.

Evaluation of the Craniocervical Junction

CCJ Measurements

- Powers ratio
  - Distance between the basion and posterior arch of C1 divided by distance between the anterior arch of C1 to opisthion
    - < 1 posterior A-O dislocation, odontoid fracture or C1 ring fracture
    - > 1 anterior A-O dislocation
- Basion-axial interval
  - Distance between the basion and a tangent drawn along the posterior cortex of the C2 body
- Basion-dental interval
  - Distance between the basion and tip of the dens
- Atlantodental interval
  - Distance between the posterior cortex of the anterior arch of C1 and the anterior cortex of the dens
- Wackenheim line
  - Line tangential to clivus
  - Should not touch or intersect dens

Powers Ratio



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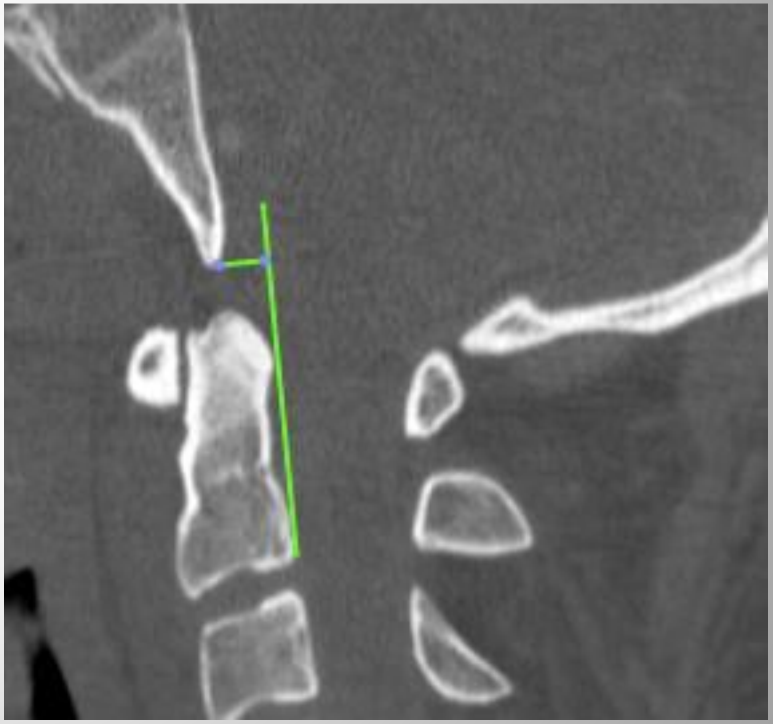
Basion-Axial Interval



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  - Line tangential to clivus
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Basion-Dental Interval

Evaluation of the Craniocervical Junction

CCJ Measurements

- Powers ratio
  - Distance between the basion and posterior arch of C1 divided by distance between the anterior arch of C1 to opisthion
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    - > 1 anterior A-O dislocation
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  - Distance between the basion and tip of the dens
- Atlantodental interval
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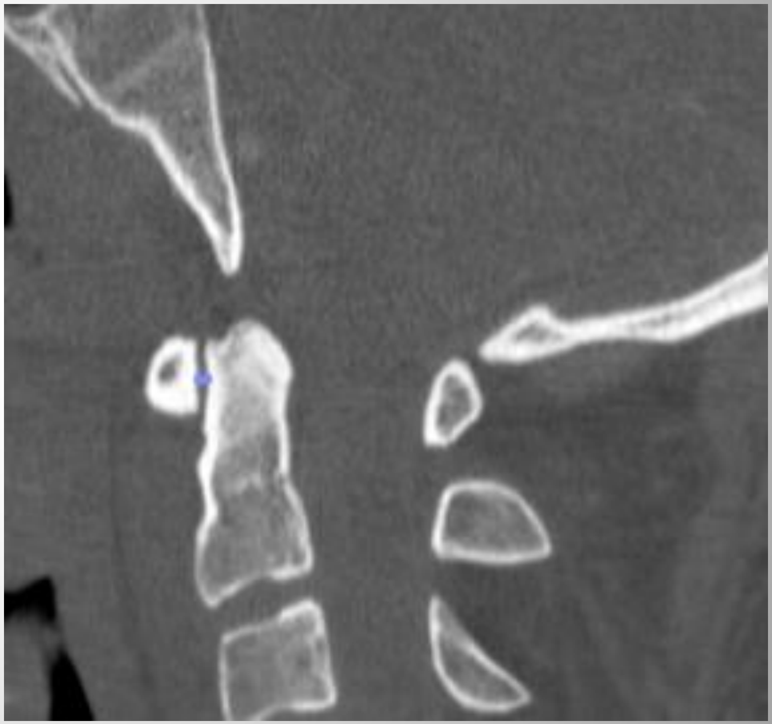
  - Should not touch or intersect dens

Atlantodental Interval



Evaluation of the Craniocervical Junction

CCJ Measurements

- Powers ratio
  - Distance between the basion and posterior arch of C1 divided by distance between the anterior arch of C1 to
    - < 1 posterior A-O dislocation, odontoid fracture or C1 ring fracture
    - > 1 anterior A-O dislocation
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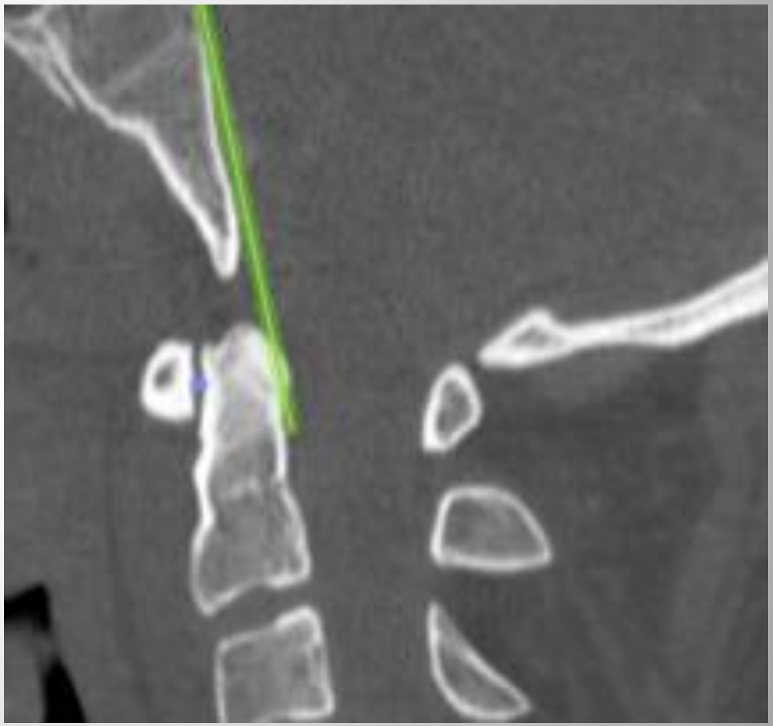
Wackenheim Line



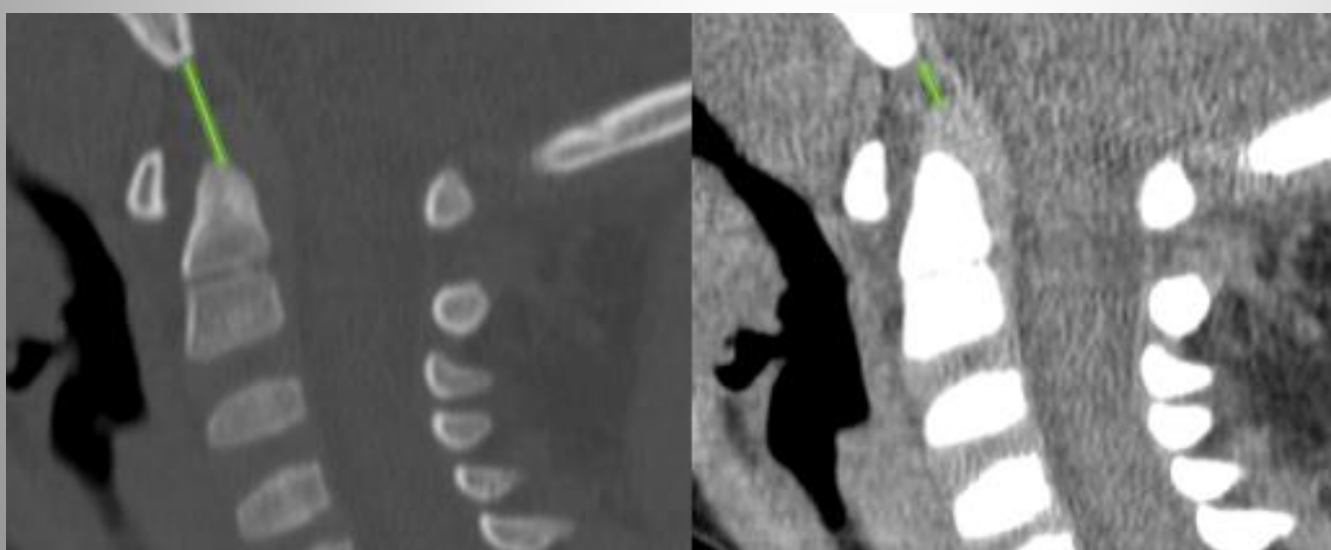
Pediatric CCJ measurements

Inherent Problems

- In children, measurements are sensitive with severe injuries but not as sensitive with less severe injuries
- Standard error related to measurements is larger
- Landmarks used to analyze CCJ may be difficult to ascertain and may confound measurements
  - Ossification variants (especially in the anterior arch of C1 and the dens)
  - Unfused synchondroses(especially the neural synchondrosis of C1)

Normal Values (X-ray, CT)

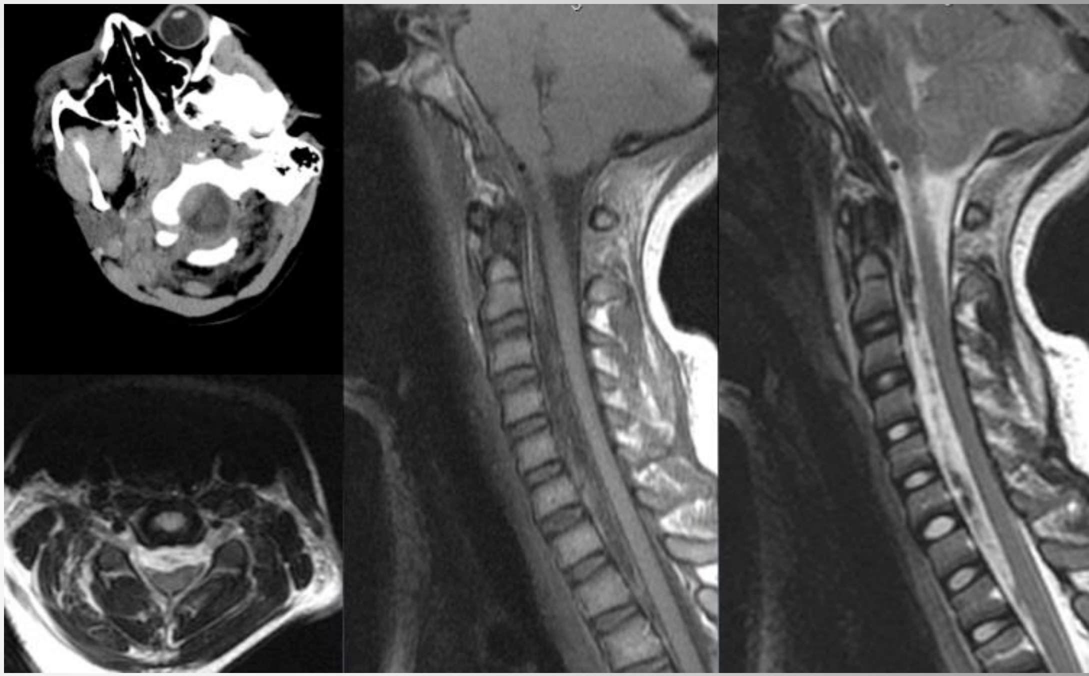
- BAI (< 10 mm, not reliable)
- BDI (< 12.5 mm, not reliable)
- Powers (< 1.0, < 0.9)
- ADI (< 5 mm, < 2.6 mm)
- AO (< 5 mm, < 2.5 mm)



The basion dens interval is one of the most variable measurements at the CCJ; this case illustrates the variability related to the non-ossified cartilage.

Craniocervical Junction Injuries

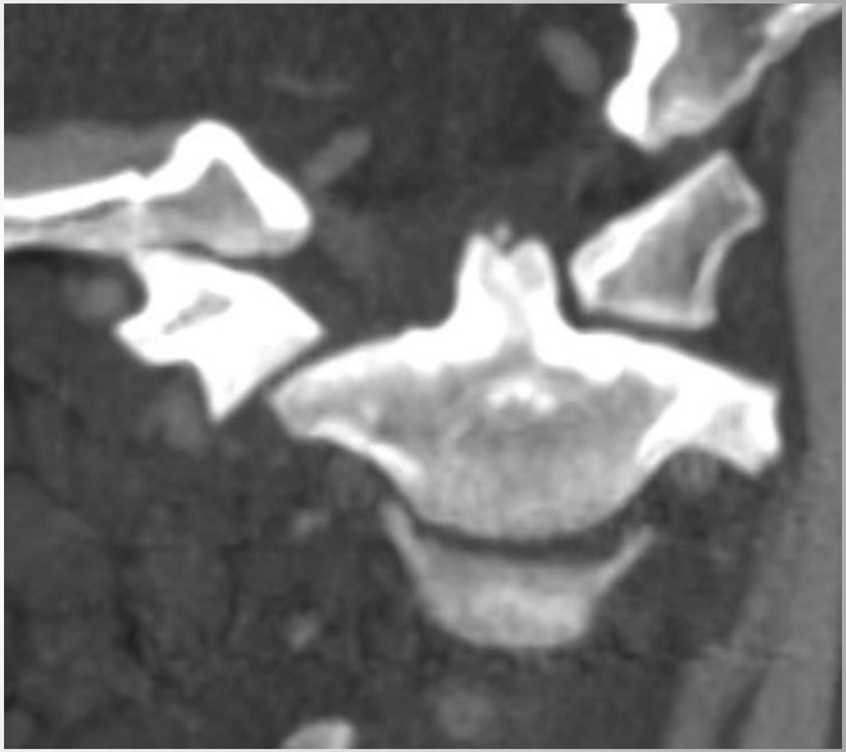
- CCJ is functionally and developmentally distinct
  - Smaller occipital condyles
  - Shallow horizontal A-O joints
  - Capsular and ligamentous laxity
  - Multiple synchondroses
  - CCJ responsible for most of the rotation and flexion of the cervical spine
- CCJ injury in children
  - More common but also more survivable compared to adults
  - Incidence of injury is inversely proportional to age
  - Most often seen in high energy mechanisms
- Radiographic measurements can be difficult to interpret in pediatric imaging
  - MR essential to evaluate for ligamentous and cord injuries



10 year old pedestrian hit by a car. Hematoma anteriorly on the right at the foramen magnum on CT. Precervical and suboccipital edema, apicoclival ligament disruption, posterior stripping of the tectorial membrane and anterior cervical epidural hemorrhage on MR.

Traumatic Torticollis

- Patients present with neck pain and “cocked robin” appearance of the neck, i.e., tilted, flexed and rotated neck
- Common in older children
  - Often secondary to minor trauma
  - Accentuated by
    - Normal ligamentous laxity
    - Inflammatory processes (infection, arthritis, lymphadenitis)
    - Anatomic predisposition
- Pain and failure to reduce may be related to entrapped soft tissues



Neurologically intact 9 year old female with neck pain after falling out of bed. The asymmetry of the lateral masses of C1 and the lateral atlantodental intervals indicate rotational subluxation.

Avulsion Injuries

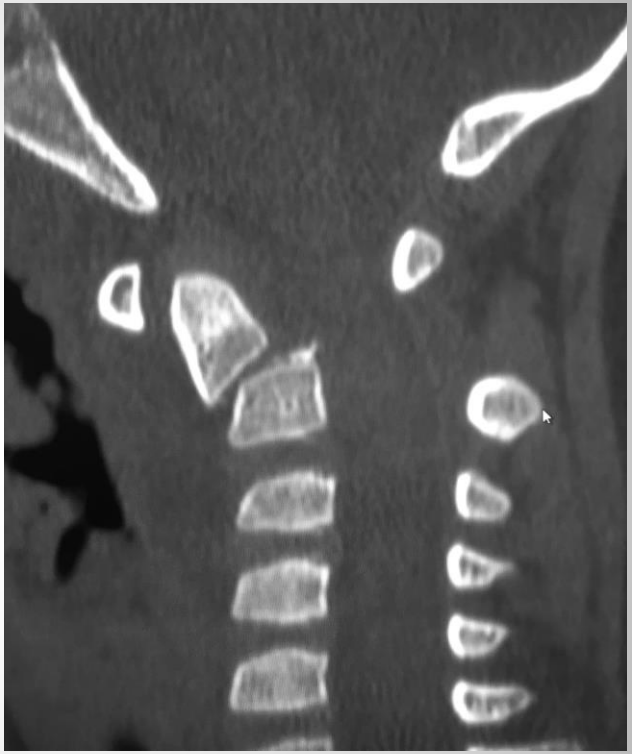
Apophyseal avulsions

- Apophyses appear in adolescence and fuse by young adulthood
  - Endplates
  - Transverse processes
  - Spinous processes
- Serve as ligamentous and muscular attachments
- Common athletic injury
- Mechanically stable

Teenager with neck pain after football injury. Anteriorly displaced inferior endplate apophysis of C3 (blue arrow) on radiography. Precervical edema and marrow edema on sagittal IR MR image related to avulsion of Sharpey's fibers. Hyperextension tends to involve the inferior endplate and hyperflexion the superior endplate.

Synchondrosis Injuries

- A synchondrosis is a connection of bones by cartilage that allows growth
- The basiocciput, atlas and subaxial vertebrae have 3 synchondroses and the axis has 4
  - In general, the neural arch synchondroses fuse by 2-3 years and the neurocentral synchondroses by 3-6 years
- In children, the synchondroses are vulnerable to injury
- In adults, the synchondroses occasionally do not completely fuse
  - Usually not clinically relevant
  - Most often seen in the posterior midline (neural synchondroses)
  - Remnants of the subdental synchondrosis persist into adulthood in 87% and may account for the high incidence of low dens fractures and pseudoarthrosis in the adult population



3 year old male involved in motor vehicle accident. Sagittal CT image shows a transverse fracture through the subdental synchondrosis. The dens is anteriorly displaced with kyphosis, indicating a hyperflexion mechanism.

Child Abuse

- Spine injuries occur in about 0.5% of patients with proven physical abuse but the incidence is likely higher in patients with coexisting head trauma
- Craniocervical junction commonly involved
  - Thoracolumbar junction and other cervical levels can also be seen
  - High association of cervical spine injury with Sudden Infant Death syndrome, intracranial hemorrhage, and HIE
- Precervical edema/hemorrhage, atlanto-occipital joint effusion, extra-axial hemorrhage, ligamentous disruption, and cord edema/contusion may be seen

2 month old shaken infant. Sagittal T1 MR image demonstrates precervical, apicoclival and subtectorial hemorrhage as well as tentorial and retrocerebellar subdural hemorrhage.

Syndromes/Dysplasias/Anomalies

Disorders of skeletal development

- Prone injury because of
  - Anomalous anatomy
  - Poor structural support (osseous and ligamentous)
  - Uneven distribution of forces and altered intersegmental motion

Teenager with trisomy 21 with unstable os odontoideum; note the anterior translation of C1 and the dens relative to C2 between extension and flexion.

9 year old with osteogenesis imperfecta. Sagittal reformatted CT image shows decreased mineralization, platybasia, basilar invagination and healed burst fracture of C7.

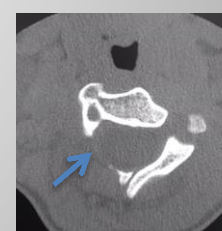
Teenager with thanatophoric dysplasia and stenosis of the foramen magnum and cervical spinal canal. Note cord gliosis.

Congenital

Cervical Spondylolysis

- Congenital
  - Corticated cleft in the articular pillar
  - Associated dysplasia of neural arch
    - Hypoplasia of ipsilateral pedicle
    - Incomplete fusion of neural synchondrosis
- Traumatic
  - Irregular cortical margins
  - Secondary post-traumatic changes
  - Usually hyperextension injury

Hypoplastic neural arch of C6 with corticated cleft (blue arrow) representing congenital spondylolysis in a teenager being evaluated for chronic neck pain.



Teenager with neck pain. Multiplanar CT images reveal a hypoplastic right neural arch of C2 (blue arrows) with incomplete fusion of the neural arches in the posterior midline.

Pediatric-Adult Transitional Fracture

Hyperextension Teardrop

- Usually encountered in older adults with osteoporosis at C2
  - Often from minimal trauma
  - Mechanically stable
  - No neurologic impairment
- When seen in children and young adults, it is in the lower cervical spine
- The triangular fragment of the anterior inferior corner of the vertebral body is similar to flexion teardrop. Radiographic features differentiating from flexion teardrop include
  - The vertical dimension of the fragment is at least equal to its transverse dimension in extension teardrop
  - Neutral or straightened curvature on the lateral projection
  - Often associated with severe trauma
  - Central cord syndrome (as opposed to anterior cord syndrome with flexion teardrop)

17 year old unrestrained driver whose car hit a tree. Sagittal reformatted image demonstrates a triangular fracture fragment (blue arrow) along the anterior inferior corner of C5 vertebral body (soft tissue emphysema is from bronchial injury).

Similarities of Pediatric C-Spine Injuries

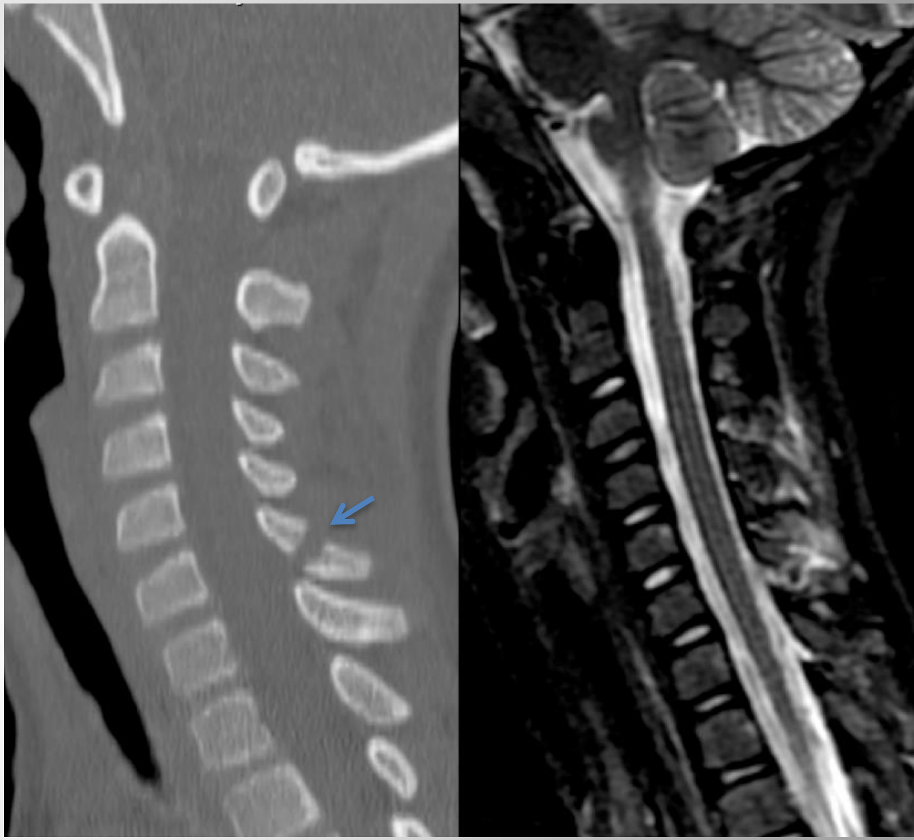
- Incidence of cervical spine injuries
  - 5-10% of adult polytrauma patients
  - <1% of pediatric polytrauma patients
- Epidemiology
  - Mechanism of injury in adult cervical spine injuries is largely secondary to motor vehicle accidents and falls
  - Mechanism of injury in pediatric cervical spine injuries includes the above but also pedestrian inflicted injuries, bicycle accidents, and sport injuries
- Mechanistic models
  - Allen and Ferguson (1976)
    - Injury vector and spine position at determine the injury pattern
    - Mechanisms: Compression Flexion, vertical compression, distractive flexion, compressive extension, distractive extension
  - Harris (1986)
    - Injury dependent upon vector and magnitude of forces
    - Mechanisms: Flexion, flexion rotation, extension rotation, vertical compression, hyperextension and lateral flexion, and complex mechanisms can explain most injuries
    - We will use this model to illustrate various injury patterns

Hyperflexion Injuries

- Flexion is predominant force
- Severity of injury is related to the magnitude of force
  - Force applied to a flexed neck is more dangerous than the same force applied to the neck in neutral position
- Kyphotic posture of the spine indicates hyperflexion mechanism
- Examples:
  - Clay shoveler's fracture
  - Compression fracture
  - Hyperflexion sprain
  - Bilateral interfacetal subluxation/dislocation
  - Hyperflexion teardrop

Clay Shoveler's Fracture

- Flexion against opposing action of interspinous ligaments and/or trapezius/rhomboid muscles
- Fracture is usually limited to the spinous process but occasionally involves the lamina
  - Most common between C6 and T1
- Patients experience knife-like posterior neck pain
- Spinous process fractures are occasionally part of complex injury patterns



10 year old female restrained passenger in a motor vehicle accident with Glasgow coma score of 15, seatbelt abdominal wall contusion, right clavicle fracture, left pneumothorax and pulmonary contusion, and splenic laceration. Sagittally reformatted CT images show an oblique coronal fracture thorough the spinous process of C6 with minimal separation of the fragments (blue arrow). Axial T2 and sagittal IR MR images show the fracture and adjacent paraspinous and interspinous edema.

Simple Compression Fracture

- Hyperflexion injury with anterior column failure
  - Loss of anterior vertebral body height
  - Superior endplate depression
  - Marrow edema in superior half of vertebral body
  - Subtle buckling of the anterior cortex of the vertebral body
- Posterior distraction may be present
  - Interspinous edema
- Often multiple levels involved
- Mechanically stable

The lateral radiograph is normal. Sagittal IR MR image shows marrow edema in C7 (blue arrow), T1 and T2 with multilevel interspinous ligament sprains.

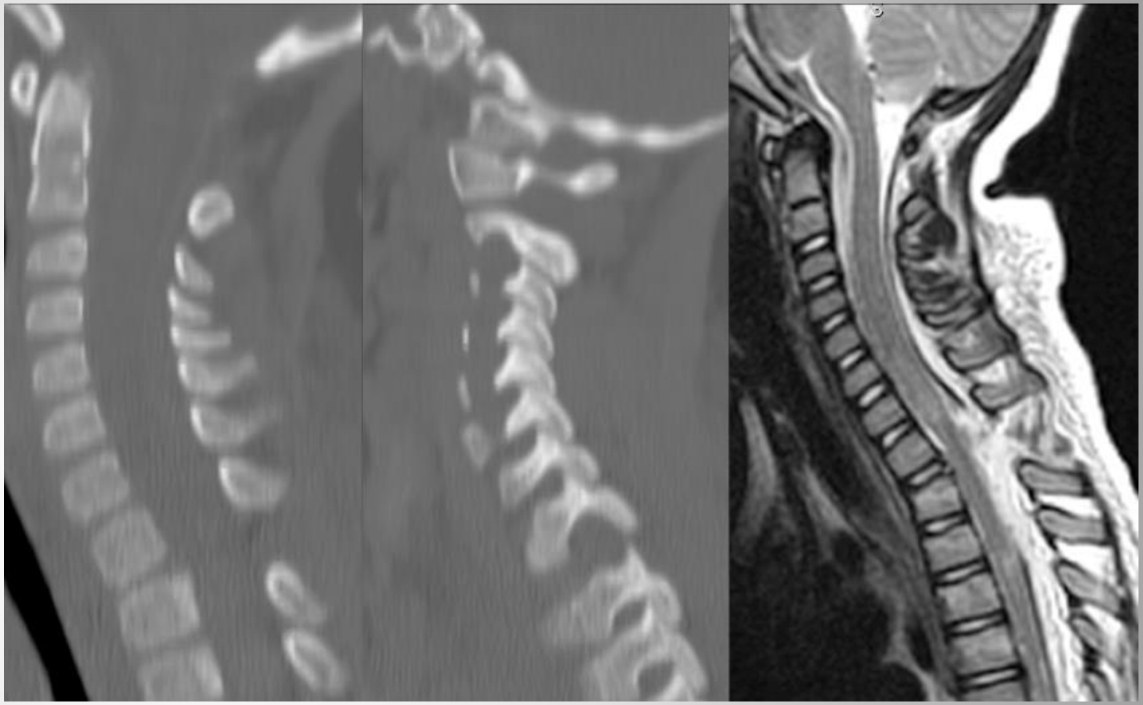
Hyperflexion Sprain

- Hyperflexion injury with posterior column failure
  - Posterior distraction leads to ligamentum flavum, interspinous ligament and/or facets injury
- Diagnosis is easily masked by muscle spasm or supine imaging
  - Upright or flexion lateral radiograph will show kyphosis and widening of the interspinous space
- Relatively high incidence of delayed instability

High school football player with posterior neck pain and swelling. Sagittal reformatted CT image shows widened interlaminar space and tiny osseous avulsion at C5-C6 (blue arrow). Sagittal T2 confirms ligamentum flavum avulsion.

Bilateral Interfacetal Dislocation

- Hyperflexion injury with anterior and posterior and failure
  - Mechanically unstable
  - Anterior and posterior ligamentous disruption
  - Compression fractures of the vertebral bodies
  - Subluxed or dislocated but usually not fractured facets
- Associated injuries
  - Disc herniation
  - Extra-axial hemorrhage
  - Other vertebral fractures
  - Cord injury

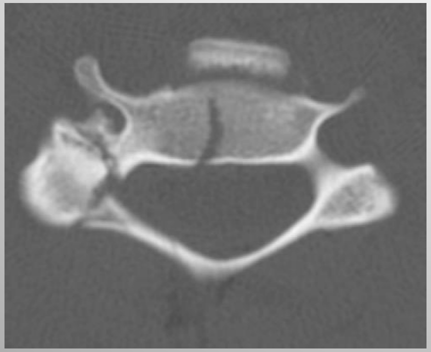


5 year old restrained backseat passenger with upper back pain and extremity paresthesias. Midline and parasagittal reformatted CT images demonstrate widened interspinous space, minimal anterior subluxation of T1 relative to T2 and perched facet. Sagittal T2 demonstrates multilevel ligamenta flava disruption, partial cord dehiscence, anterior disc impression and annulus disruption (PLL) at T1-T2, and multilevel microtrabecular edema.

Hyperflexion Teardrop

- Hyperflexion injury with complete osseous and ligamentous failure
  - Most severe flexion injury
- Mechanically unstable
  - Triangular anterior-inferior vertebral body fragment = teardrop
  - Retropulsed vertebral body → anterior cord syndrome
    - Immediate quadriplegia and loss of pain, temperature and touch sensations but preserved proprioception and vibration
  - Posterior distraction → disruption of posterior ligamentous complex

13 year old found flaccid after fall of 30 feet from tree. Sagittal reconstructed CT image shows reversed lordosis, anterior translation of C4 relative to C5, anterior wedging of C5 vertebral body, teardrop fragment (blue arrow) and fanning of the spinous processes. Axial CT image shows the “classic” sagittal fracture of the vertebral body and right pedicolaminar fractures (“floating pillar”). On sagittal IR MR image, the PLC, ALL and PLL are disrupted with long segment cord edema.

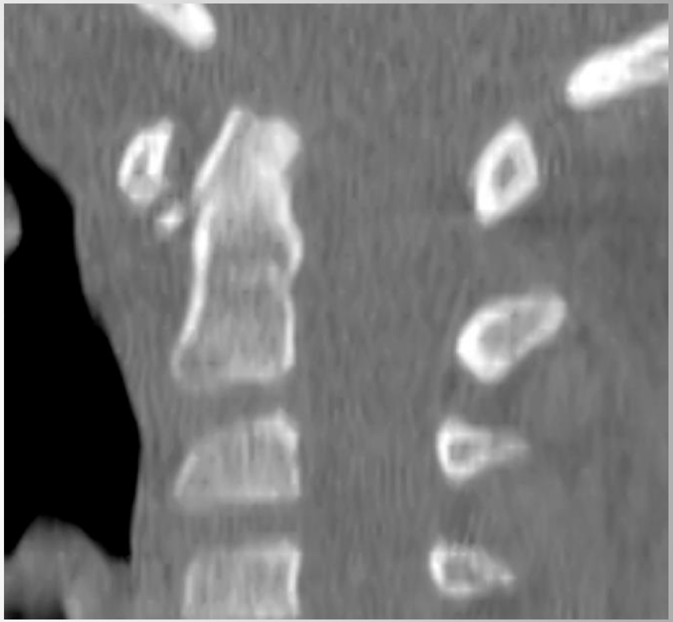


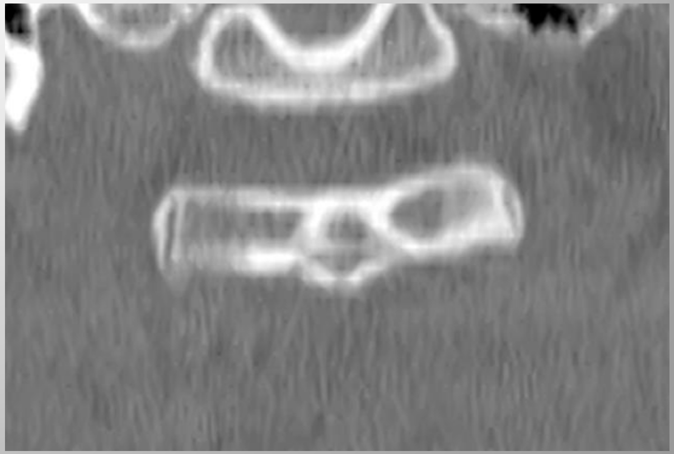
Hyperextension Injuries

- Predominant force is extension
- Associated with facial and anterior cranial injuries
- Neutral or lordotic position of the spine in the sagittal plane is indicative of hyperextension mechanism
- Examples:
  - Anterior atlas avulsion
  - Lamina fracture
  - Hangman's fracture
  - Hyperextension teardrop
  - Hyperextension fracture/dislocation

C1 Anterior Arch Avulsion

- Jefferson Type II fracture
- Hyperextension injury related to avulsion of the anterior atlantodental ligament (deep fibers of the anterior longitudinal ligament) and/or longus colli muscle
- Mechanically and neurologically stable
- Heals without incident





5 year old restrained backseat passenger involved in high-speed head on collision with significant other injuries. Sagittal and coronal reformatted CT images show axial plane fracture of the inferior aspect of the anterior arch of the atlas; note the soft tissue edema inferior to the anterior arch.

Hyperextension Lamina Fracture

- Hyperextension injury related to impaction of posterior elements in hyperextension
  - Typically this injury occurs in the posterior arch between the lateral mass and spinous process
- Difficult to diagnose on conventional radiographs

Teenager who landed on his face after being thrown from bicycle. Axial CT images show fractures of the C4 and C5 spinous processes. Sagittal fat-suppressed T1 and T2 images show hemorrhage and edema in the interspinous space (blue arrows).

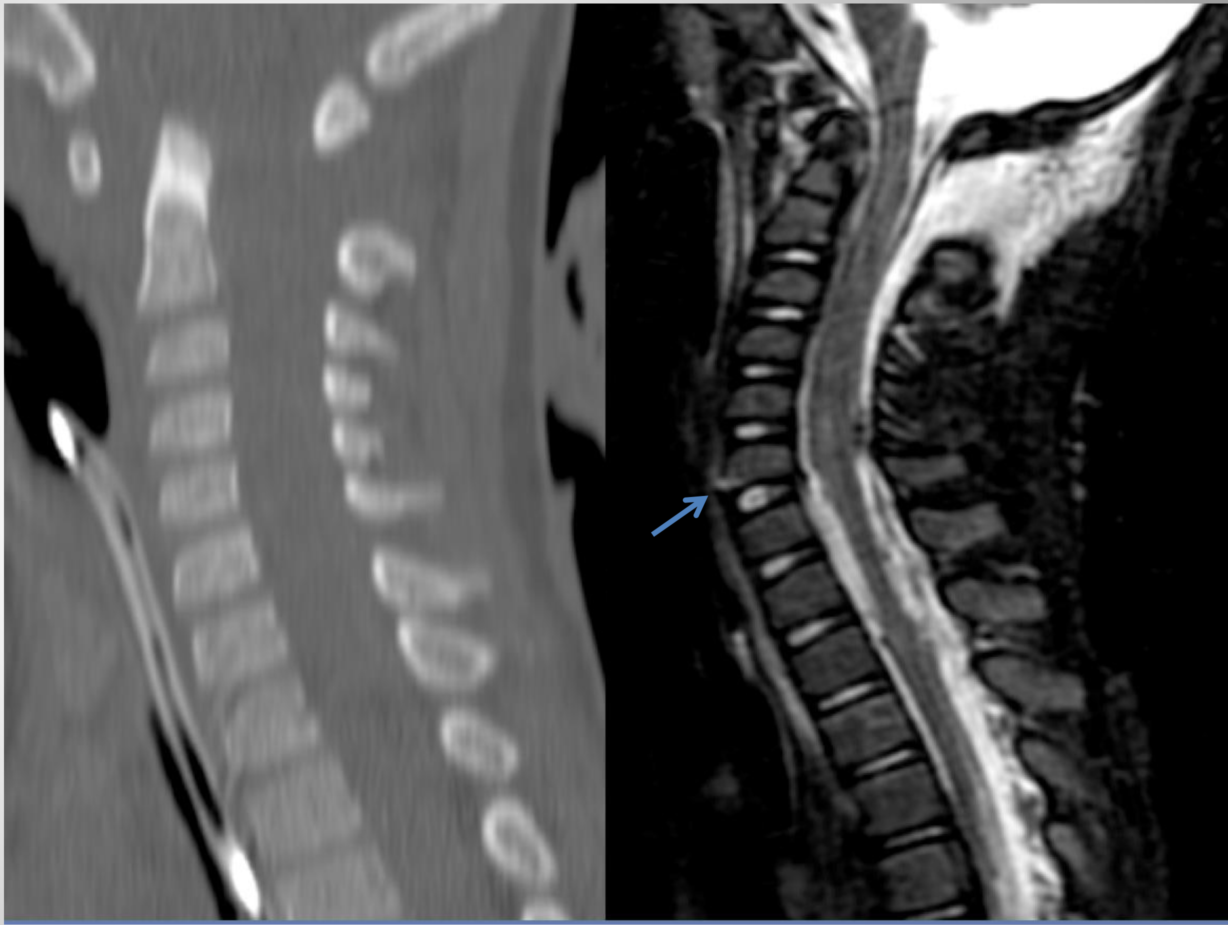
Hangman's Fracture

- Hangman's fracture is usually related to hyperextension
  - "Clothes-line" injury
  - MVA
  - Flexion component is usually secondary but primary flexion injury is possible
- Hyperextension results in traumatic spondylolysis
  - Bilateral fractures, most often involving the pars interarticularis
  - May affect the laminae, facets, or uncovertebral joints
  - Not necessarily symmetric
- Accounts for approximately 20% of cervical spine fractures
  - High incidence of other cervical fractures and vertebral artery injury

16 year old male after motor vehicle accident. Lateral radiograph demonstrates a mildly diastatic fracture of the pars interarticularis of the axis (blue arrow) but preserved anterior and posterior longitudinal lines and C2-C3 disc space.

Hyperextension Dislocation

- Most severe hyperextension injury
  - Posterior column acts as a fulcrum resulting in anterior distraction
- Hyperextension dislocation is notoriously subtle on radiographs
  - Spontaneous reduction after injury is common
- Neurologically devastating
  - Associated with anterior and posterior cord disruption



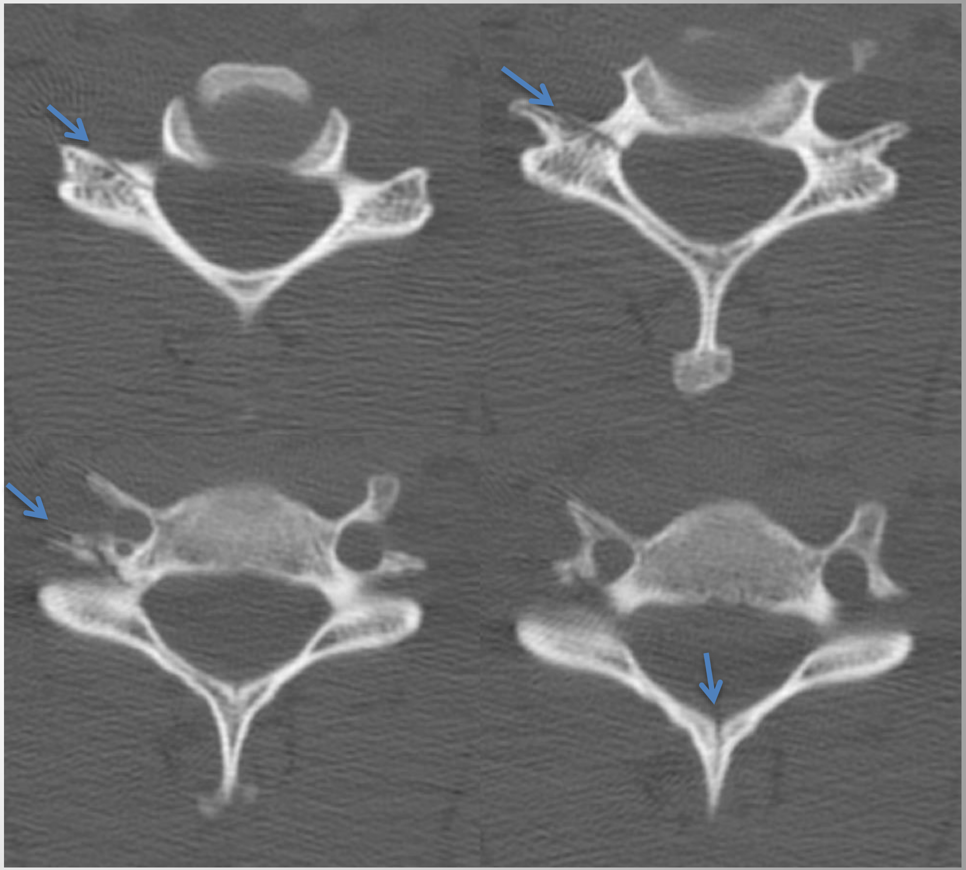
Unresponsive 3 year old restrained backseat passenger involved in a high-speed head on collision. CT indicates a craniocervical injury (abnormal predental space and Power's ratio) but normal lower cervical spine. Sagittal inversion recovery image confirms CCJ injury but also precervical edema, fracture of the inferior endplate of C6 (blue arrow), disrupted ALL and PLL and cord dehiscence.

Rotation

- Injury primarily related to rotation of the spine with flexion or extension
- Associated with vertebral artery injury
- Examples:
  - Pedicolaminar fracture
  - Pillar fracture
  - Unilateral facet fracture/dislocation

Pedicolaminar Fracture

- Unilateral pedicolaminar fractures are usually related to hyperextension and rotation
  - The pedicle and lamina may also be involved in complex fracture patterns (e.g., teardrop and burst fractures)
  - Unilateral separation of the pedicle and lamina → "floating pillar" (Hyperflexion Teardrop for illustration)
- Fracture often extends to the spinous process
- Most common in the lower cervical spine
- Patients often have radiculopathy



Sequential axial CT images show a minimally separated fracture (blue arrows) of the right pedicle of C5 and sagittal splitting of the spinous process. The right transverse foramen is not directly involved.

Unilateral Interfacetal Dislocation

- Hyperflexion and distraction with rotation
- Easily missed diagnosis on conventional radiographs
- Ipsilateral facet fracture (superior facet) and capsular disruption
  - Posterior longitudinal ligament avulsion and disc herniation are common
- Mechanically stable
- Neurological deficit ranges from unilateral radiculopathy to cord injury

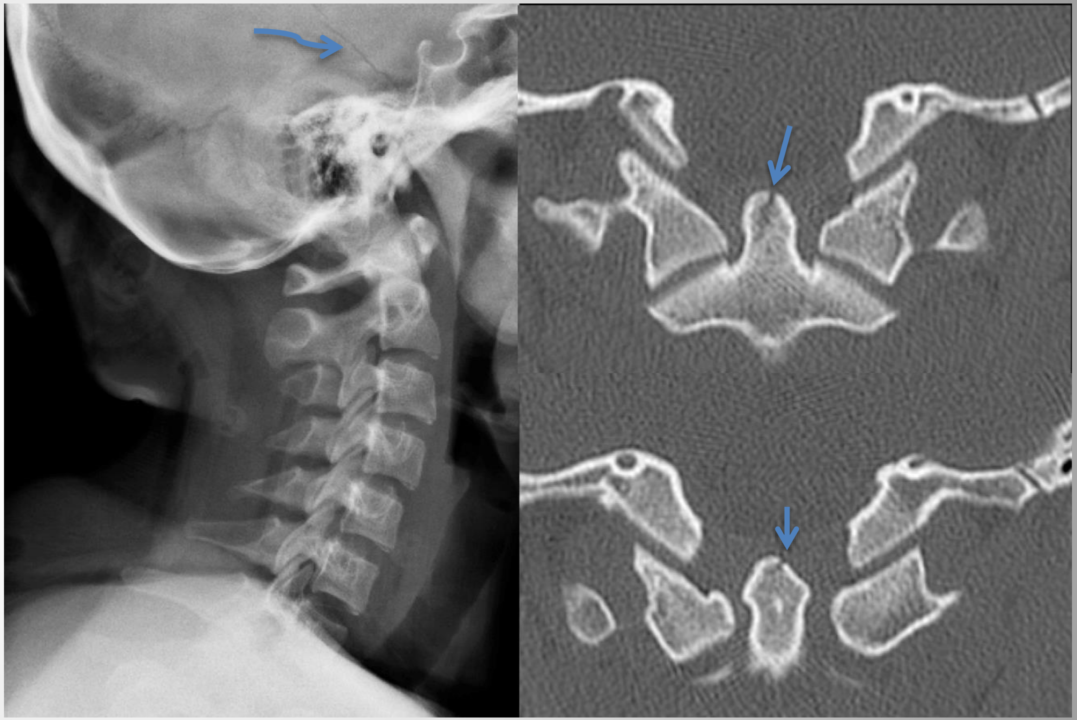
Sagittal reformatted CT images demonstrate unilateral locked facet on the right at C3-C4 (“bow-tie” sign), right facet fracture, anterior translation of C3 relative to C4, avulsion of the posterior longitudinal ligament at C3 and relatively normal left-sided facets.

Compression/Axial Loading

- Vertical compression applied to neutral spine
- Centrifugal dispersion of fracture fragments (Jefferson and burst fractures)
- Neutral sagittal plane cervical curvature
- Examples
  - Vertical dens fracture
  - Jefferson fracture
  - Burst fracture

Vertical Dens Fracture

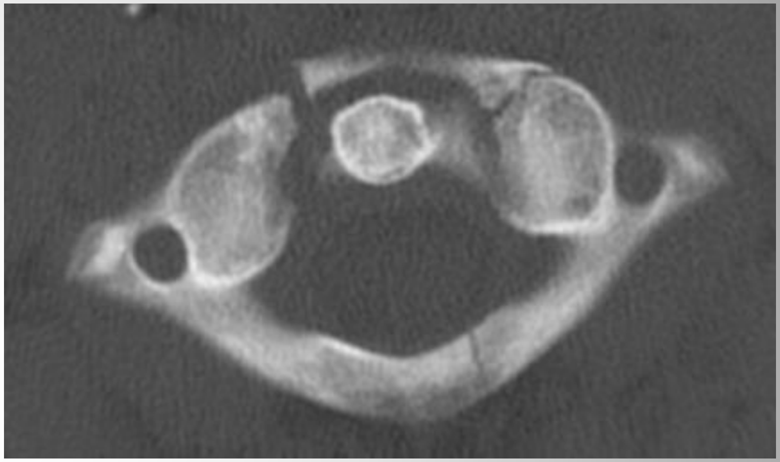
- Pure vertical fractures of the dens may be related to axial loading of the anterior lip of the foramen magnum on the dens
  - Vertical shear stress
    - Clivus acts as a chisel or wedge against the dens
  - A similar fracture of the dens can be seen with alar ligament avulsion but this is not related to axial loading
    - Usually related to rotation or lateral flexion)



13 year old male involved in a motor vehicle collision with intracranial hemorrhage and skull base fracture. Lateral radiograph shows precervical soft tissue swelling but no fracture or malalignment of the cervical spine (note a linear temporal bone fracture – curved blue arrow). Coronal reformatted CT images reveal a nondisplaced vertical fracture of the dens (blue arrow).

Jefferson Fracture

- Mechanism of injury - axial loading of occipital condyles against the lateral masses of C1
- Most injuries result in radial displacement of fragments
  - Often mechanically unstable
  - No neurological deficit
- Jefferson fractures are at risk for vertebral artery spasm/dissection/thrombosis
  - Additional fracture of the axis in many
- Jefferson Classification
  - Type I – fracture of the posterior arch
  - Type II – fracture of the anterior arch only
  - Type III – fracture of both anterior and posterior arches with centrifugal dispersion of fragments
  - Type IV – fracture involves the lateral mass(es)



10 year old with osteopetrosis who was injured on a trampoline. CT demonstrating Type 3 Jefferson fracture. Right synchondrosis fracture is mildly diastatic and anteriorly rotated; the left sided fracture extends to the lateral mass; the posterior arch fracture is nondisplaced.

Burst Fracture

- Axial loading with the neck in neutral → multilevel dispersion of force through discs
- Complex vertebral fracture
  - Fracture involves the posterior vertebral body cortex with retropulsed fragment
  - Sagittal vertebral body fracture is similar to hyperflexion teardrop fracture
  - Posterior element involvement contributes to mechanically instability

Neurological deficit is dependent on the degree of retropulsion

- Deficit is generally less severe than hyperflexion teardrop

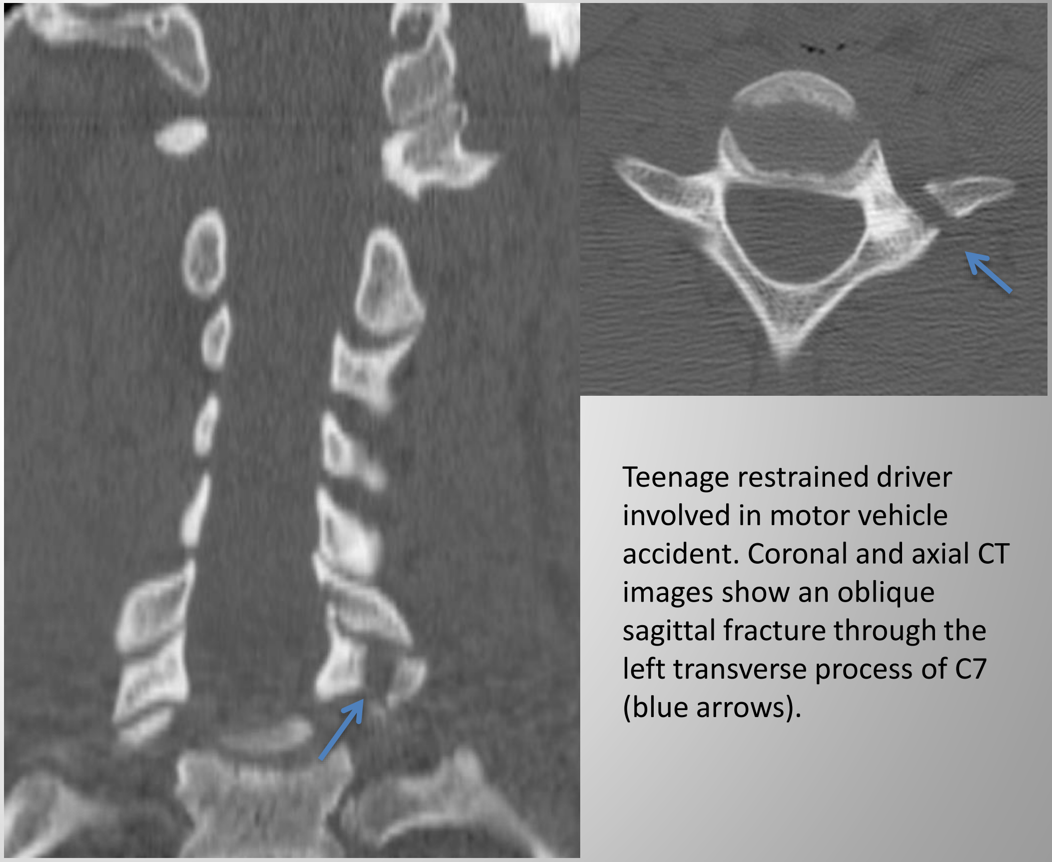
Teenager with comminuted fracture of the C6 vertebral body; note the sagittal component of the fracture and retropulsion of the posterior superior fragment. The left lamina is also fractured. The neutral attitude of the cervical spine indicates that this is a pure axial loading injury rather than flexion injury.

Lateral Flexion Injury

- Pure lateral flexion injuries are unusual in the cervical spine because the oblique orientation of facets converts the vector force to rotation
- Ipsilateral impaction produces fracture
- Examples
  - Uncinate process fracture
  - Transverse process fracture
  - Occipital condyle fracture
  - Certain odontoid fractures

Transverse Process Fracture

- Transverse process fractures are likely to be related to lateral flexion
  - Shoulder harness restraints may contribute
- Mechanically stable injury
- Most common at the cervicothoracic junction (C7)
  - Associated with cervical radiculopathy or contralateral distraction brachial plexus injury in 10%
  - Fractures often extend into the transverse foramen
- Other spinal fractures may be present



Teenage restrained driver involved in motor vehicle accident. Coronal and axial CT images show an oblique sagittal fracture through the left transverse process of C7 (blue arrows).

Occipital Condyle Fracture

- Usually related to high energy mechanism of injury
  - High association with other cervical spine injuries
- Lateral bending injuries of the occipital condyles related to avulsion of the alar ligament or impaction
  - CCJ may be unstable
  - Blood may be present at the foramen magnum
- Painful injury without neurological deficit

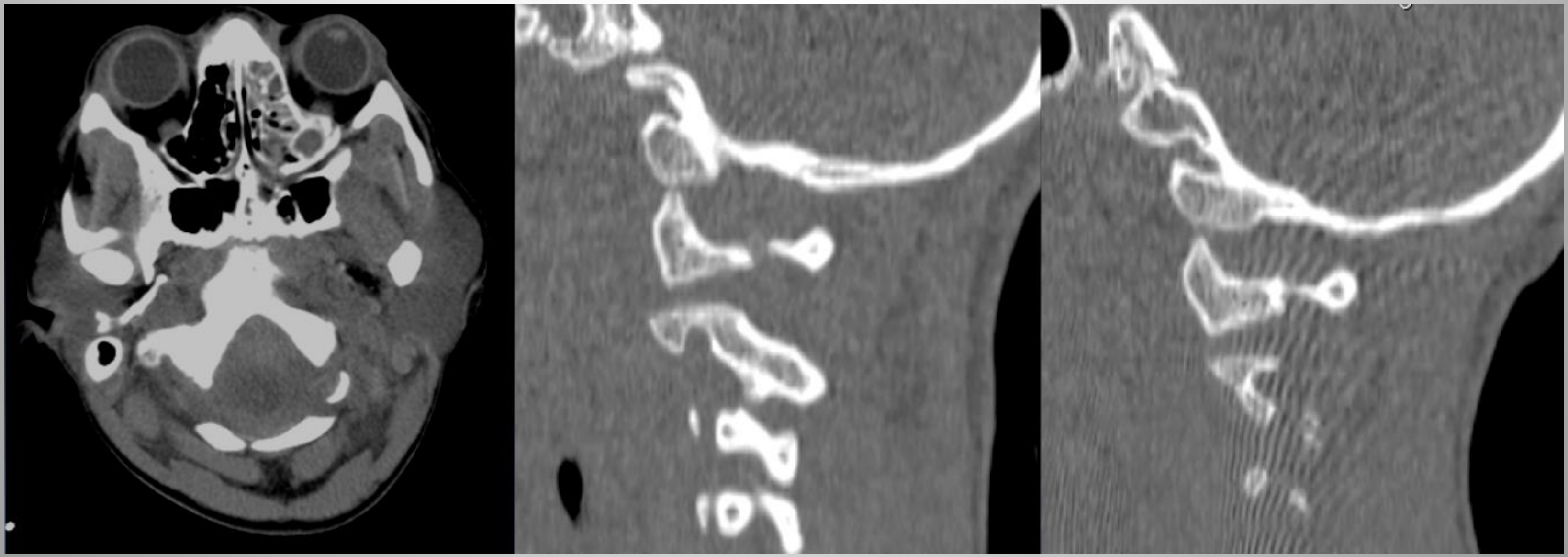
Teenager with neck pain after motor vehicle accident but no neurological deficit. Coronal reformatted images demonstrate a horizontally oriented right occipital condyle fracture (straight blue arrow)with distraction of the left occipito-atlantal joint (curved blue arrow). Blood is often evident at the foramen magnum.

Complex Pattern

- Simple mechanistic explanations fail
  - Forces are often sequential or simultaneous
  - Anatomic and physiologic variability contribute
- Most injuries occur at the craniocervical junction
- Examples:
  - Traumatic torticollis
  - Atlanto-occipital dissociation
  - Transverse atlanto-axial ligament rupture
  - Various odontoid fractures

Atlanto-occipital Dislocation

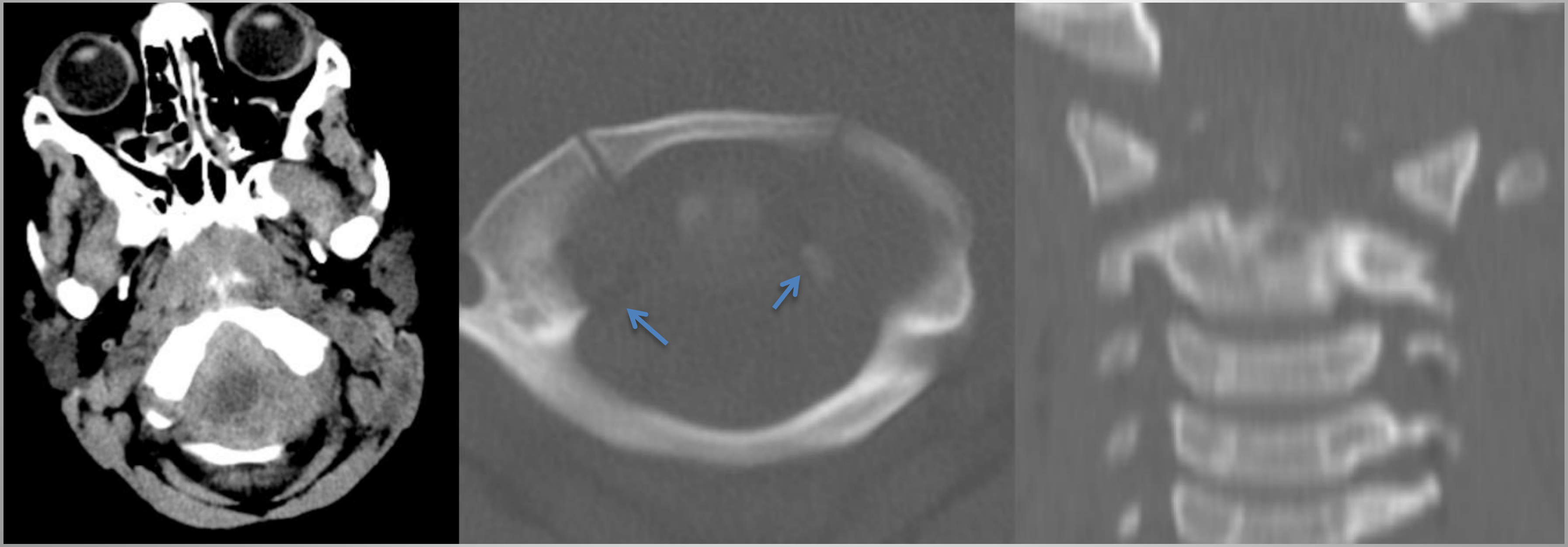
- Atlanto-occipital dislocation is a potentially catastrophic injury, often causing immediate cardiopulmonary arrest
  - 5 times more common in children
  - However, the injury is more survivable in children and adolescents than in adults
- Integrity of the craniocervical junction is largely related to ligaments and the paired atlanto-occipital joints.
- CT provides the best assessment of the atlanto-occipital joint structure and avulsion injuries; MRI offers the best assessment of ligamentous injury to the craniocervical junction.



12 year old male restrained back seat passenger in a car hit by a snowplow. CT of the brain discloses hemorrhage at foramen magnum. CT of the cervical spine illustrates bilateral atlanto-occipital dislocation.

Transverse Atlantal Avulsion

- TAL is the primary stabilizer of atlanto-axial joint
- TAL avulsion is a common whiplash type injury
- TAL injury should be suspected with anterior atlantodental interval of > 3 mm and an intact atlas
  - Severity varies from intrasubstance injury to complete disruption
- TAL avulsion may be the result of flexion, lateral flexion and/or compression.



4 year old male in a MVA. CT of the brain shows blood at the foramen magnum. Axial CT at the level of C1 shows widened predental space. The tubercles are avulsed bilaterally (blue arrows).

Odontoid Fractures

- Dens fractures account for 10-15% of all cervical fractures
- Usually complex mechanism of injury
  - Anteriorly displaced, usually secondary to hyperflexion
  - Posteriorly displaced, usually secondary to hyperextension
- Pitfalls in children
  - Os secundum can be confused with Type I fractures
- Classification of odontoid fractures
  - Type I – oblique fracture of tip of dens; usually due to alar ligament avulsion
  - Type II – transverse fracture of the base of the dens, through the subdental synchondrosis
    - High rate of nonunion (33%) because of remnant synchondrosis, angular deformity > 10 degrees, displacement > 6 mm or impaired blood supply
  - Type III – fracture extends from the C1-C2 articulation into the body of C2

Neurologically intact teenager after a motor vehicle accident. CT images show an anteriorly tilted fracture of the base of the dens which extends into the anterior body of the axis (Type III).

Conclusion

- Spine fractures in children are rare compared to adults
- While certain injury patterns in children are unique, mechanistic similarities to adults exist, especially in adolescents
- Recognition of spine injuries will improve patient care by directing advanced imaging and facilitating prompt intervention

THANK YOU!