Craniocervical Imaging: Traumatic and Nontraumatic

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May 3, 2019
Learning Objectives

1. Understand craniocervical junction (CCJ) anatomy including common variants
2. Understand the mechanics of the CCJ
3. Understand the approach to imaging the cervical spine in trauma
4. Understand various traumatic pathologies at the CCJ
5. Understand special considerations in geriatrics
6. Understand various nontraumatic pathologies at the CCJ
What comprises the CCJ?

1. Occiput
2. Atlas (C1)
3. Axis (C2)
4. Atlanto-occipital joints
5. Atlanto-axial joints
Occiput anatomy

Ligaments of the CCJ

Intrinsic ligaments (3 layers anterior to the dura)

- Odontoid ligament
- Cruciate ligament
- Tectorial membrane

Extrinsic ligaments

- Anterior atlanto-occipital membrane
- Posterior atlanto-occipital membrane
- Nuchal ligament
CCJ Ligaments

CCJ Ligaments

CCJ Ligaments

Mechanical Stabilization

Atlantoaxial joint

Mostly for axial rotation

Transverse Ligaments (allows for axial rotation)

Alar ligaments (restricts excessive rotation and lateral flexion)

Atlanto-occipital joint

Mostly for flexion and extension

Impingement of odontoid on the basion restricts flexion

Tectorial Membrane restricts extension

Disruption of a joint capsule may suggest instability
Approach to CCJ Imaging in Trauma

Workhorse of C-spine imaging is CT at 1.25 mm or thinner with reformations.

CT ideally is reserved to patients that are at high risk per NEXUS criteria or Canadian C-Spine Rule.

Clinical clearance appropriate if patient meets all low risk criteria.

Obtunded or Polytrauma Patient
Obtunded or Polytrauma Patient

ACR Recommends C-Spine CT for patients failing to meet any of the low risk criteria

Article from 2012 showed in blunt trauma patients with GSF of 14 and distracting injuries, 99% sensitivity to clear C-spine on clinical grounds

Closed head injuries increase risk of C-spine injuries by 8.5%

Missed injuries in these patients 10x more likely to produce 2nd neuro compromise

Early discontinuity of C-spine precautions, when cleared is associated with fewer complications, fewer days on ventilator and shorter stay in ICU
Role of MRI in Traumatic C-spine Imaging

- Symptoms suggest spinal cord injury (Myelopathy)
- Pre-surgical planning
- Suspected ligamentous injury
- Patients who cannot be clinically evaluated for more than 48 hours (AMS)
Considerations of MRI in C-spine trauma

Not all ligamentous injuries are picked up

Isolated signal abnormality without bone injury or abnormal alignment is common and of uncertain clinical significance

However, combination of negative CT and MRI has 98.9% NPV for ligamentous injuries and 100% NPV for unstable cervical spine injuries

Recent studies suggest discontinuing C-spine precautions in polytrauma/obtunded patients on CT basis alone (no MRI needed)
Role of CTA in Traumatic C-spine Imaging

Risk factors for blunt cerebrovascular injury

Traumatic Pathology
<table>
<thead>
<tr>
<th>Interval</th>
<th>Ligaments Injured</th>
<th>Radiography Cutoff/Reference</th>
<th>Multidetector CT Cutoff/Reference</th>
</tr>
</thead>
<tbody>
<tr>
<td>Basion-to-dens interval</td>
<td>Alar ligaments, tectorial membrane</td>
<td>12 mm/Harris et al (44)</td>
<td>8.5–9.5 mm/Rojas et al (37), Chang et al (35)</td>
</tr>
<tr>
<td>Basion–axial line interval</td>
<td>Alar ligaments, tectorial membrane</td>
<td>&gt;12 mm anterior or 4 mm posterior to the posterior axillary line/ Harris et al (44)</td>
<td>Difficult to reproduce/Rojas et al (37)</td>
</tr>
<tr>
<td>Atlantodental interval</td>
<td>Transverse ligament, atlanto-occipital and C1-C2 capsules, tectorial membrane, alar ligaments</td>
<td>3 mm (men), 2.5 mm (women)/Hinck and Hopkins (45)</td>
<td>2 mm/Rojas et al (37)</td>
</tr>
<tr>
<td>Atlanto-occipital interval</td>
<td>Atlanto-occipital joint capsules, alar ligaments, tectorial membrane</td>
<td>No data in adults</td>
<td>4.0 mm (summed)/Chang et al (35); 2.5 mm (single atlanto-occipital interval)/Rojas et al (37)</td>
</tr>
<tr>
<td>Atlanstoval interval</td>
<td>C1-C2 joint capsules, alar ligaments, tectorial membrane</td>
<td>No data in adults</td>
<td>Midsagittal, 2.6–4.0 mm/ Gonzalez et al (46), Chaput et al (41); lateral margins, 1.2 mm/Radicliff et al (47); posterior and anterior margins, 1 mm/Gonzalez et al (46)</td>
</tr>
<tr>
<td>Powers ratio</td>
<td>Transverse ligament, atlanto-occipital joint capsules, tectorial membrane, alar ligament</td>
<td>Anteriorly displaced atlanto-occipital distraction indicated by Powers ratio &gt;1/ Powers et al (42)</td>
<td>Anteriorly displaced atlanto-occipital distraction indicated by Powers ratio &gt;1/Dziurzynski et al (43)</td>
</tr>
</tbody>
</table>

Important Measurements - Basion-dens int.

Normal is less than 8.5-9.5 mm on CT, 12 mm on XR
Important Measurements - Basion-axial int.

Normal is less than 10 mm on CT, less than 12 on XR.
Important Measurements - Atlanto-dens int.

Normal is less than 2 mm on CT, 3 mm (men) and 2.5 mm (women) on XR
Important Measurements - Powers Ratio

Powers Ratio = \( \frac{\text{Distance from basion to anterior C1}}{\text{Distance from opisthion to posterior C1}} \)

Less than 1.0 on CT
Atlanto-occipital dissociation (AOD)

3 types: anterior skull, vertical dissociation, and posterior skull

Grade I: Normal CT, equivocal MRI
Grade II: Abnormal CT or MRI (Treated with internal fixation)

Atlanto-occipital dissociation

- Associated with high impact trauma
- More common and more survivable in pediatric patients
- In one paper 50% that presented were adults, but only 6 of the 22 survivors were adults (27%)
- Early diagnosis is important to try and minimize residual neuro defects
AOD Type 1

AOD Type 1

AOD Type 1

V sign: suggests transverse ligament Injury

V is associated with AOD and isolated C1-C2 distraction is rare

AOD Type 2

AOD Type 3

<table>
<thead>
<tr>
<th>Types of Cranio cervical Injury (Classification System Reference)</th>
<th>Stability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Occipital condyle fractures (Anderson and Montesano [53])</td>
<td></td>
</tr>
<tr>
<td>Type I: axial loading with minimal or no fracture displacement</td>
<td>Stable</td>
</tr>
<tr>
<td>Type II: skull base fracture extending through the condyle</td>
<td>Stable</td>
</tr>
<tr>
<td>Type III: alar ligament avulsion fracture</td>
<td>Unstable</td>
</tr>
<tr>
<td>Atlas fractures (Jefferson, as modified by Gehweiler et al [54])</td>
<td></td>
</tr>
<tr>
<td>Type I: posterior arch</td>
<td>Stable</td>
</tr>
<tr>
<td>Type II: anterior arch</td>
<td>Stable</td>
</tr>
<tr>
<td>Type III: bilateral posterior arch with bilateral or single unilateral anterior arch (“Jefferson burst”)</td>
<td>Depends on integrity of transverse ligament</td>
</tr>
<tr>
<td>Type IV: lateral mass</td>
<td>Stable</td>
</tr>
<tr>
<td>Type V: transversely oriented anterior arch fractures (avulsion of longus colli or atlantoaxial ligament)</td>
<td>Stable</td>
</tr>
<tr>
<td>Odontoid fractures (Anderson and D’Alonzo [55])</td>
<td></td>
</tr>
<tr>
<td>Type I: oblique fracture through the tip of the odontoid, result of alar ligament avulsion</td>
<td>Stable</td>
</tr>
<tr>
<td>Type II: dens-body junction</td>
<td>Unstable*</td>
</tr>
<tr>
<td>Type III: cancellous portion of the axis body</td>
<td>Heals well with immobilization but can cause canal compromise</td>
</tr>
<tr>
<td>Hangman fractures (Effendi et al [56], modified by Levine and Edwards [57])</td>
<td></td>
</tr>
<tr>
<td>Type I: hairline fractures, &lt;2-mm translation</td>
<td>Stable</td>
</tr>
<tr>
<td>Type II: angulation &gt; 11°, &gt;2-mm translation</td>
<td>Variable, external immobilization often used</td>
</tr>
<tr>
<td>Type IIa: severe angulation without translation, intact anterior longitudinal ligament</td>
<td>Angulation can worsen with initial traction</td>
</tr>
<tr>
<td>Type III: bilateral facet dislocation</td>
<td>Unstable</td>
</tr>
<tr>
<td>Atlantoaxial rotatory subluxation and fixation (Fielding and Hawkins [58])</td>
<td>Need for surgery depends on degree of rotation, prognosis improves with early reduction</td>
</tr>
<tr>
<td>Type I: rotatory fixation in normal physiologic range (&lt;48°–52° left or right), dens acts as a pivot, intact alar and transverse ligaments</td>
<td>Unstable</td>
</tr>
<tr>
<td>Type II: transverse ligament injured, center of rotation shifts to lateral mass, anterior displacement of the atlas &lt; 5 mm</td>
<td>Unstable</td>
</tr>
<tr>
<td>Type III: transverse and alar ligaments both deficient, similar to type II but anterior displacement of the atlas &gt; 5 mm</td>
<td>Unstable</td>
</tr>
<tr>
<td>Type IV: deficient odontoid, with posterior displacement of the atlas</td>
<td>Unstable</td>
</tr>
</tbody>
</table>

Occipital Condylar Fractures

Two classification schemes: Anderson/Montesano and Tuli

Anderson/Montesano Type I

Anderson/Montesano Type II

Anderson/Montesano Type III

Anderson/Montesano Type III

Fractures of the Atlas (C1)

25% of craniocervical injuries / 2-13% of cervical fractures

44% of C1 fractures have associated C2 fractures

Anterior and posterior arches are the weakest points

Jefferson developed the first classification system
This has since been modified

Normally not associated with neuro defects

Are associated with neurovascular injuries
Atlas (C1) Fractures

Type I: Posterior arches (stable)

Type II: anterior arches (stable, but depends on displacement)

Type III: bilateral posterior arches with anterior arch fracture

Jefferson burst

Type IV: lateral mass (stable)

Type V: transverse anterior arch (stable)

Avulsion of longus coli or atlantoaxial ligament
Atlas (C1) Fractures

Type II and III most common

Transverse ligament integrity and anterior arch displacement are the most important determinant for surgery

Dickman further classified transverse ligament injuries

- Type I: Disruption of the ligament substance
- Type II: avulsion of the tubercle at the insertion at the lateral mass
Atlas (C1) Fractures
Atlas (C1) Fractures - Types I and III

Atlas (C1) Fractures - Type IV

Atlas (C1) Fractures - Type III

Atlas (C1) Fractures - Type III (same patient)

Fractures of the Axis (C2) - Dens

17-20% of C-spine fractures involve C2

~60% of C2 fractures are at the dens

Three Types (Anderson and D’Alonzo classification)

Type I: Oblique through the tip of the odontoid (1-3% of dens fractures)

Type II: Dens-body junction of C2 (54-60% of dens fractures)

Type III: Fracture extends through cancellous part of C2 body (39-42% of dens fractures)
Dens Fracture - Type I

Dens Fracture - Type II

Dens Fracture - Type IIa

Dens Fracture - Type III

Fractures of the Axis (C2) - Hangman

First described as bilateral pars interarticularis fractures

Can occur from compression hyperextension and distractive hyperflexion

Can involve laminae, pedicles, or posterior wall of C2 body

22% of axis fractures, 4% of C-spine fractures

26% associated with neurological defects

Treated with immobilization

Minority are associated with other C-spine fractures
Hangman Fracture Classification

Type I: Minimally displaced, <2 mm

Type II: Anterior angulation >11°, >2 mm anterior translation

Type IIa: Severe angulation without translation

Type III: Bilateral facet fracture-dislocation
Hangman Fracture - Type I

Hangman Fracture - Type II

Hangman Fracture - Type IIa

Hangman Fracture - Type III

Fracture of the Axis (C2) - Body

19-23% of axis fractures

Types

- Isolated lateral mass
- Pedicle fracture
- Transverse process fracture
- Can include burst injuries

Mostly stable/treated conservatively

Special Considerations in Geriatrics

Can fracture spine in very low trauma mechanisms (fall from standing)

Increased risk of fractures due to:

- Osteoporosis
- DISH
- Ankylosing spondylitis
- DDD & DJD
- Spinal fusion hardware

More prone to fracture C1-C2 than younger patients

Most common: C2 fractures (Dens Type II & III) +/- C1 fracture
Atlantoaxial Distraction and Rotatory Subluxation

Normal rotation is up to 48-52°

Bilatera facet dislocation suggested at 63-64°

Early diagnosis can prevent permanent deformity

Normally related to flexion/rotation

Normally involves an alar ligament tear

Can occur in nontraumatic settings

Vertical distraction is much rarer and deadlier
Atlantoaxial Rotatory Fixation (AARF)

Thought to be caused by joint capsular tear with scarring

Fixation suggested when torticollis persists for 5-7 days

Nontraumatic associations

- Ligamentous Laxity
- Congenital atlantoaxial abnormalities
- Grisel Syndrome
AARF Types

I: Fixation within physiologic range
   - No anterior displacement of C1. Intact alar/transverse ligaments.

II: Anterior displacement of C1 < 5 mm
   - Transverse ligament injured. Alar ligament intact.

III: Anterior displacement of C1 > 5 mm
   - Transverse and alar ligaments injured

IV: Posterior displacement of C1
   - Deficient odontoid
Physiologic Rotation
Non-traumatic Pathology
Spinal Canal Compromise

Most commonly associated with

- Trauma
- Degenerative changes
- Infection
- Metastatic disease

Many less common will now be discussed
Basilar Invagination/Impression (BI)

Congenital or acquired upward shift of the dens cephalad

Invagination implies normal bone and normal foramen, whereas Impression implies soft skull base

Can lead to compression of the cord, medulla, and cause syrinx

Multiple associations

Basilar settling: Special subcategory caused by rheumatoid arthritis

Instability can be imaged with dynamic MR

Managed mostly with decompression
<table>
<thead>
<tr>
<th><strong>Basilar invagination</strong></th>
<th><strong>Basilar impression</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Chiari malformation</strong></td>
<td><strong>Paget disease</strong></td>
</tr>
<tr>
<td><strong>Basioccipital hypoplasia</strong></td>
<td><strong>Osteomalacia</strong></td>
</tr>
<tr>
<td><strong>Atlas hypoplasia</strong></td>
<td><strong>Severe osteoporosis</strong></td>
</tr>
<tr>
<td><strong>Occipital condyle hypoplasia</strong></td>
<td><strong>Osteogenesis imperfecta</strong></td>
</tr>
<tr>
<td><strong>Achondroplasia</strong></td>
<td><strong>Rickets</strong></td>
</tr>
<tr>
<td><strong>Incomplete ring of C1</strong></td>
<td><strong>Hyperparathyroidism</strong></td>
</tr>
<tr>
<td><strong>Atlanto-occipital assimilation</strong></td>
<td><strong>Renal osteodystrophy</strong></td>
</tr>
<tr>
<td><strong>Fused upper vertebrae</strong></td>
<td><strong>Skull base infection</strong></td>
</tr>
<tr>
<td></td>
<td><strong>Hurler syndrome</strong></td>
</tr>
</tbody>
</table>
Lines in evaluating (BI)

- Chamberlain (orange)
- McGregor (green)
- Welcher basal angle (yellow)

Congenital Lesions

- Os Odontoideum
- Hemivertebra
- Diastematomyelia
- Achondroplasia
Os Odontoideum

Round well corticated remnant of the dens not fused to the C2 body

Atlantoaxial instability develops in most patients gradually

Cervical fusion reserved for:

Cervical myelopathy

Instability in flexion and extension

Hemivertebra

Related to failed development of mesoderm chondral centers (lateral) or anterior ossification center (posterior)

Acute scoliosis at that level of a lateral hemivertebrae can cause neural impingement

Direct impingement of the cord can occur from posterior a hemivertebrae

Can be seen in Klippel Feil Syndrome

Congenital fusions of the cervical vertebrae with the patients having a short neck, limitation of the movement of the head or the neck and a low posterior hairline.
Diastematomyelia

Spinal dysraphism with a fibrous or bony spur dividing the spinal canal

Mostly thoracolumbar spine and female predominance (70%)

Associated with tethered cord/myelomeningocele in infants

Older children present with scoliosis or leg weakness

Adults usually present with gradual onset of myelopathy

Treatment is surgical resection of spur
Diastematomyelia

https://www.orthobullets.com/spine/2062/diastematomyelia
Achondroplasia

- Autosomal dominant form of dwarfism
- Short limbs, thoracolumbar kyphosis in infancy, and lordosis in older patients
- Foreshortening of the skull base
- Shortened pedicles
- Posterior body concavity
Arthritides/Enthesopathies

Rheumatoid Arthritis

Ankylosing Spondylitis

Synovial Cyst of the Facet Joint

Deposition Diseases

  Calcium pyrophosphate dihydrate (CPPD) deposition

  Hydroxyapatite deposition disorder (HADD)

Ossification of the Posterior Longitudinal Ligament

Ossification of the Ligamentum Flavum
Rheumatoid arthritis

60-90% of RA patients have cervical involvement

Synovitis causes laxity of the transverse and alar ligaments

Also causes erosions of subjacent bone

Results in atlantoaxial subluxation

Dens erosions seen in \( \frac{2}{3} \) of RA patients

Granulation tissue and pannus contribute to spinal canal stenosis

Laminectomy and fusion is treatment if instability regardless of symptom presence
Rheumatoid arthritis
Ankylosing spondylitis

Normally presents in young adults

“Flowing syndesmophytes”/”Bamboo spine”

Effectively fuse all affected segments

Severe displaced fractures can occur even with minor trauma
Deposition Diseases - CPPD

CPPD at the cervical spine is very common

12% overall, 34% in patients >60, 49% in patients > 80.

Associated with hyperparathyroidism or hemochromatosis in young patients

Deposits are made on PLL, ISL, and ligamentum flavum

Deposits can also be in disc space, which accelerate DDD
Deposition Diseases - CPPD

Calcific tendinitis of longus colli

Courtesy of Drs. Fliszar and Alqahtani
Ossification of PLL/Ligamentum Flavum

- OPPL more common in Japan/China, etiology unclear
- Can be associated with DISH and spondylosis
- OPPL can be segmental or thin/linear along the posterior vertebral body
- OLF can be lateral, diffuse or nodular
- Both can present with focal radiculopathy or myelopathy
- Both require surgical decompression if symptoms
Tumors, Tumorlike Lesions, and Miscellaneous

- Hemangioma
- Aneurysmal Bone Cyst
- Eosinophilic granuloma
- Osteochondroma
- Osteoblastoma
- Paget’s disease
References


Questions
Question 1

1) Which type of dens fracture has the highest chance of healing on its own?

a) Type I
b) Type II

c) Type IIa
d) Type III
1) Which type of dens fracture has the highest chance of healing on its own?

a) **Type I**
   - b) Type II
   - c) Type IIa
   - d) Type III

Type I fractures have near 100% fusion rate. Type II has the highest risk for malunion. Type III requires immobilization, but about 1 in 10 need surgery.
Question 2

1) Which ligament is labeled?

   a) Alar
   b) Apical
   c) Transverse
   d) Nuchal
Question 2

1) Which ligament is labeled?
   a) Alar
   b) Apical
   c) Transverse
   d) Nuchal
Question 3

1) How high above the Chamberlain line must the tip of the odontoid be to qualify for basilar invagination?

   a) 3 mm
   b) 5 mm
   c) 7 mm
   d) 9 mm
Question 3

1) How high above the Chamberlain line must the tip of the odontoid be to qualify for basilar invagination?

   a) 3 mm
   b) 5 mm
   c) **7 mm**
   d) 9 mm
1) Posterior arch fractures of C1 are most commonly seen in which mechanism of injury?

   a) Hyperflexion
   
   b) Hyperextension
   
   c) Axial loading (Burst)
   
   d) Forced atlantoaxial rotation
Question 4

1) Posterior arch fractures of C1 are most commonly seen in which mechanism of injury?

a) Hyperflexion

b) **Hyperextension**

c) Axial loading (Burst)

d) Forced atlantoaxial rotation
Question 5

1. What is the upper limit of normal for the Basion-axial interval (on CT)?

   a. 4 mm
   b. 6 mm
   c. 8 mm
   d. 10 mm
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   a. 4 mm
   b. 6 mm
   c. 8 mm
   d. **10 mm**
Fin.