Trauma at the Craniocervical Junction

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The craniocervical junction

- A biomechanical and anatomical unit that extends from the skull base to C2
- Includes the clivus, foramen magnum and contiguous occipital bone, the occipital condyles which articulate with the superior articulating surface of C1, C1 (atlas) and its articulations with the dens and the superior facets of the articulating masses of C2, and C2 (axis).
- The complex joints and ligaments allow a wide range of motion while ensuring stability
The Craniocervical joints..

- **biconvex** occipital condyles articulate with the **biconcave** superior articulating surface of C1
Biconvex joint surfaces at C1-C2

**Biconvex** inferior articulating surface of C1, articulates with **biconvex** superior facets of the articulating masses of C2
• The odontoid peg arises from the cranial aspect of C2, projects through the arch of C1.

• The most anterior ligament is Anterior Longitudinal Ligament (ALL). It inserts in to the antero-inferior corner of the C2 body.
  • Deeper to ALL, apical ligament, tip of the odontoid to basion.

• Anterior atlantoaxial membrane is dense fibrous tissue that extends from the C2 body to the anterior arch of C1.

• Anterior Atlanto-Occipital membrane is the the cephalad extension of ALL, extending rostrally from the anterior tubercle of C1 to the clivus.
**Tectorial membrane** is the cephalad continuation of PLL, connects the dorsal surface of the dens to the ventral surface of the FM
- Laterally, it connects C2 to the occipital condyles

**Transverse ligaments**
- Oriented horizontally dorsal to odontoid, attaches to medial surfaces of the lateral masses of C1
- Extends rostrally to FM and caudally to C2 body

**Alar ligaments** connect the dens to
- Occipital condyles
- The lateral masses of C1

Each alar arises from the lateral margin of the dens, courses laterally, in a near vertical plane, attaching to the ipsilateral occipital condyle and the subadjacent superior margin of the C1 lateral mass. In 30% of people it attaches solely to the condyle.
Fig. 2. Drawing depicting the midsagittal view of the cranio-cervical junction.  A: Apical ligament.  B: Anterior atlantooccipital membrane.  C: Superior crus of the cruciform ligament.  D: Tectorial membrane.
Fig. 1. Drawing showing the posterior view of the craniocervical junction. A: Apical ligament. B: Alar ligament. C: Cruciform ligament (cut ends of the superior crus). D: Tectorial membrane.
• The tectorial membrane and the alar ligaments are the most important in maintaining stability
  • Alar ligaments are strong and prevent excessive rotation of C1 on C2, and lateral bending of the occiput/C1 on C2

• The transverse/cruciate ligaments are next.
• The apical ligament is considered a vestigial structure that offers no significant added stability to the CCJ (Tubbs et al, 2000).
  • Absent in 20% of cadaveric specimens examined

• The Posterior atlanto-occipital membrane connects the posterior margin of the FM to the posterior arch of C1
Figure 2 Macroscopic view of the deep ligaments of the craniocervical junction after removal of the dorsal elements of the spinal canal. Viewed in neutral (0°) position. **AL** Alar Ligament. **CLA** Cruciform Ligament of the Atlas.
Fig. 1.—Normal anatomy in 21-year-old man. Sagittal T1-weighted MR image (TR/TE, 510/25) obtained on 0.3-T scanner shows normal apical ligament (1) and anterior atlantoaxial membrane (2).

Fig. 2.—Normal anatomy in 43-year-old woman. Sagittal T2-weighted MR image (TR/TE, 4500/117) obtained on 0.3-T MR scanner shows normal apical ligament (1), anterior occipitoadlantal membrane (2), anterior atlantoaxial membrane (3), anterior longitudinal ligament (4), tectorial membrane (5), dural reflection (6), posterior occipitoadlantal membrane (7), posterior atlantoaxial membrane (8), nuchal ligament (9), flaval ligaments (10), area of interspinous ligaments (11), and supraspinous ligament (12).

Fig. 3.—Normal anatomy in 38-year-old man. Axial gradient-echo or fast low-angle shot MR image (TR/TE, 420/18; flip angle, 30°) obtained on 1.0-T MR scanner shows dens (1), presumed anterior atlantoaxial ligaments (2), alar ligaments (3), transverse ligament (4), and lateral masses of C1 (5).
The range of motion between Atlas and Axis is the greatest between any two vertebrae.

- The **primary movement at C1-C2 is rotation around the vertical axis** of the odontoid peg
- The two convex surfaces resting upon each other also allows vertical translation with the descent of the the skull
- The Bi-convex shape of the atlanto-axial joints and the oblique orientation of the alar ligaments allow a large range of motion but gradually restricts motion at the extremes of axial rotation.
Degrees of motion

- **Flexion**
  - O-C1 is 10°
  - C1-C2 is 5°
- **Extension**
  - O-C1 is 25°
  - C1C2 is 10°
- **Rotation**
  - O-C1 is 0°
  - C1-C2 is 45°
Trauma at the Craniocervical Junction

Fractures and dislocations of the cranio-cervical junction represent 1/3 of all injuries to the cervical spine.

- Isolated ligamentous Injuries
- Isolated Fractures
- Mixed injuries

- Disrupted ligaments are incapable of repair and usually require surgery to restore stability
- Fractures alone can usually heal if reduced and satisfactorily immobilized
- Mixed injuries require surgery
Isolated Ligamentous Injuries

- Atlanto-occipital (AO) dislocation
- Transverse ligament disruptions
  - Ligaments are avulsed and require surgical fixation
- Rotatory C1-C2 dislocations
  - Blood or oedema adjacent to an acute ligamentous tear can be seen on MRI.
  - Secondary evidence of ligamentous injury is displacement of the dens to the contralateral side.
  - Hypermobility at the atlanto-axial joint can reduce blood flow to the contralateral vertebral artery.
    - Hulse et al. 1982, described a “cervical nystagmus as a manifestation of vertebral artery insufficiency due to rotator hypermobility at the occipito-atlanto-axial complex”.
Atlanto-occipital (AO) dislocation..

- They are usually caused by high-energy trauma.
  - Devastating injury- sometimes referred to “internal decapitation”.
  - AOD is the cause of death in an estimated 8–35% of traffic fatalities and 10% of fatal cervical spine injuries.

- Disruption of the vascular supply may caused a haematoma esp.SAH at the craniovertebral junction.
Atlanto-occipital (AO) dislocation

- Pathomechanism
  - flexion and distraction
  - rotation and hyperextension.
  - Rupture of the alar ligaments and the tectorial membrane, as well as the occipito-atlantal joint capsules and membranes, lead to severe C0-C1 instability in a vertical, anterior or posterior direction.
Established criteria for diagnosis of AO dislocation include:

- basion-to-dens interval $>12$ mm, or
- posterior axis line $>12$ mm posterior to basion, or
- posterior axis line $>4$ mm anterior to basion
Power's Ratio
(Powers et al., 1979)

Basion-Post. C1 arch divided by Opisthion-Ant. C1 arch

$< 0.9$ normal (1 s.d. below lowest case of AOD)

$\geq 0.9$ & $< 1.7\%$ normal

$\geq 1$ All AOD
Lateral C-spine XR is recommended for the diagnosis of AOD. Radio-logically three types

- *longitudinal distraction* with axial separation of the occiput,
- *rotational injuries*
- *anterior* or *posterior displacement* of the occiput with respect to the atlas.

Distraction and rotational injuries are difficult to diagnose on plain radiographs, but the prevertebral soft-tissue swelling which is usually present warrants further investigation. CT with reformatted sagittal and coronal images may show widening of the atlanto-occipital joint or dislocation of the occipital condyles.
- Respiratory distress may be secondary to **brainstem compression**, or **lower cranial nerve palsies** causing airway obstruction, **diaphragmatic paralysis**.
- Hypertension can occur owing to bilateral glossopharyngeal nerve (IX) lesions, whereas complete cord transection can cause hypotension.
- **Medullary compression** can lead to bradycardia and apneic spells. Other brainstem signs commonly observed with AOD include rotatory nystagmus, ocular bobbing and decerebrate posturing.
• Improvements in emergency management of the patient in the field, rapid transport, and better recognition have resulted in more survivors of AOD in the past two decades.

• **AOD is 3 times more common in children** - attributed to anatomical differences. The craniovertebral junction in children is inherently less stable because of the relatively small occipital condyles and the horizontal orientation of the articulation between the cranium and the atlas.

• Cranio-cervical fusion with internal fixation is recommended for the treatment of patients with acute traumatic AOD.
Fig. 5.—Occipitoatlantal dislocation in 11-year-old boy who was neurologically intact after motor vehicle crash.

A. Sagittal gradient-echo MR image (TR/TE, 510/35; flip angle, 20°) obtained on 0.3-T MR scanner shows intact (1) and torn (2) portions of anterior occipitoatlantal membrane, anterior arch of C1 (3), intact anterior atlantoaxial membrane (4), prevertebral edema or hemorrhage (5), torn tectorial membrane (6), torn posterior occipitoatlantal membrane (7), torn posterior atlantoaxial membrane (8), intact dural reflection (9), and intact nuchal ligament (10). Before MR imaging, full extent of injury and degree of instability were not appreciated either clinically or from results of radiographs or CT scans. Patient underwent surgical fusion shortly thereafter.

B. Axial gradient-echo MR image (510/35; flip angle, 20°) obtained on 0.3-T MR scanner shows torn right alar ligament (1), displacement of dens (2) to left with respect to lateral masses of C2 (3), and intact transverse ligament (4).
Atlanto-occipital subluxation is radiographically subtle and patients usually survive.

- When flexion occurs without a lateral or rotatory component at the upper cervical level, it can cause an anterior dislocation at the atlantoaxial joint if the transverse ligament is disrupted.
- Since the transverse ligament is the main stabilizing force of the atlantoaxial joint, this injury is unstable.
  - Neurologic injury may occur from cord compression between the odontoid and posterior arch of C1.
C1-C2 Subluxation
AO subluxation

- Radiographically, this injury is suspected if the predental space, ADI, is more than 3.5 mm (5 mm in children);
- These injuries may require fusion of C1 and C2 for definitive management.
- Diagnosis of AO subluxation is based on abnormal; basion-axial interval and/or basion-dental interval. If both are > 12mm, if there is an abnormal cervicocranial prevertebral soft-tissue contour.
- High cervicocranial haematoma associated with AO subluxation makes the contour anteriorly convex.
An abnormal anteriorly convex cervicocranial prevertebral soft-tissue contour due to a high cervicocranial haematoma associated with AO subluxation.

Figure 28. Lateral radiograph shows a grossly abnormal convex cervicocranial prevertebral soft-tissue shadow (arrowheads) associated with anterior-distracted occipitoatlantal subluxation in which the basion (arrow) is more than 12 mm anterior to the posterior axial line (line).
<table>
<thead>
<tr>
<th>Method</th>
<th>Mean</th>
<th>SD</th>
<th>Range</th>
<th>MDCT Normal Value†</th>
<th>Plain Radiograph Normal Value²,⁵,⁶</th>
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<td>BAI</td>
<td>3.4</td>
<td>4.64</td>
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<td>BDI</td>
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<td>0.08</td>
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<td>ADI</td>
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<td>0.5–2.4</td>
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<td>&lt;3.0 men</td>
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<td>AOI</td>
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<td>0.23</td>
<td>0.5–1.8</td>
<td>&lt;1.4</td>
<td>No data in adults</td>
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</table>

**Note:**—MDCT indicates multidetector row CT; BAI, basion-axial interval; BDI, basion-dens interval; ADI, atlantodental interval; AOI, atlanto-occipital interval.

* Results are given in millimeters with the exception of the Powers ratio.

• **Rotatory C₁-C₂ dislocation**
  - Primarily in young children & adolescents
  - Present in a “cocked-robin” position
    - 20° tilt to one side, with a 20° rotation to the other
  - Rarely locks in rotation
  - Treated with gradually increasing traction and then immobilization
Occipital Condyle Fractures

- Occipital condylar fractures are of three types.

- They may be associated with other cervicocranial fractures, particularly the lateral masses of C1.

- Occipital condyle fractures, alone or in conjunction with C1 lateral mass fractures produce an abnormally concave prevertebral soft-tissue contour superior to the C1 anterior tubercle.
Figure 30. Occipital condylar fracture with ipsilateral fracture of the mass of C1. (a) On the contact lateral radiograph, the cervicocranial prevertebral soft-tissue contour is abnormally convex (arrowheads) rostral to the anterior tubercle of C1. (b) Transverse CT image at the occipitoatlantal level shows the occipital condylar fracture (arrowhead) and fracture of the ipsilateral articular mass and transverse process of C1 (arrow).
Types of condyle fractures

- **Type I**: one or both condyles are split or comminuted by an *axial loading force*
  - Stable
- **Type II**: a fracture of the occipital bone that extends into the condyle
  - Stable
- **Type II**: an avulsion fracture of the medial surface of the condyle at the site of the alar ligament
  - Potentially unstable –
  - due to ligamentous disruption

Anderson et al., *SPINE*, 1988
Tuli et al., *Neurosurgery*, 1997
Fractures of the Atlas

- Four types of atlas fractures (I, II, III, IV) result from impaction of the occipital condyles on the atlas, causing single or multiple fractures around the ring.
- The first 2 types of atlas fracture are stable
  - isolated fractures of the anterior arch of C1
    - Anterior arch fractures usually are avulsion fractures from the anterior portion of the ring and have a low morbidity rate and little clinical significance.
  - isolated fractures of the posterior arch of C1
    - an isolated fracture caused by hyperextension.
Fractures of the Atlas.

- The third type of atlas fracture is a fracture through the lateral mass of C1.
  - Radiographically, asymmetric displacement of the mass from the rest of the vertebra is seen in the odontoid view.
  - low morbidity rate and little clinical significance.

- The fourth type of atlas fracture is the burst fracture of the ring of C1 and also is known as a Jefferson fracture (caused by a Vertical (axial) compression injury).
Jefferson fracture of C1

- Typically caused by an axial-loading force on the occiput of the head
- Fracture variants may include two or three-part fractures
- Usually no associated neurologic deficit as the ring of C1 widens when it fractures limiting cord compression
- 1/3 are associated with a C2 fracture.
- Patients usually complain of upper neck pain.
- Neuro exam usually normal.
Jefferson Burst Fracture (Type IV)
Atlas Fractures - Treatment

Displaced <6.9 mm
- Halo vest for 3 mos

Displaced >6.9 mm
- Halo traction (reduction) * several weeks followed by halo vest
- Immediate halo vest
- Posterior C1-2 fusion (unable to tolerate halo)

After brace treatment complete confirm C1-2 stability
- Flexion/extension films
- C1-2 fusion for ADI > 5mm
Odontoid process fractures

- The 3 types of odontoid process fractures, classified based on the anatomic level of fracture.
- Type I - avulsion of the tip of the dens at the insertion site of the alar ligament.
  - mechanically stable, treated with hard Collar, SOMI, Halo
  - Often seen in association with AO dislocation and AOD must be ruled out.
Type II fractures occur at the base of the dens
- the most common odontoid fractures
- high prevalence of nonunion due to limited vascular supply and small area of cancellous bone.

![CT scan images of the base of the dens with arrows indicating fractures.](image-url)
Treating Type II Odontoid Fractures

- <6mm dens displacement
  - Halo brace

- ≥6mm displacement or comminuted (IIa)
  - ORIF
    - Intact transverse ligament
      - Anterior Odontoid Screw fixation
    - Disrupted transverse ligament
      - C1-2 posterior fusion
        - Transarticular screw fixation
          - Magerl and Steeman Cerv Spine 1987
          - Reilly et al, JSD 2003
        - C1 lateral mass - C2 pars/pedicle screw
        - Posterior wiring

[From Sonntag, Dickman. Treatment of Upper Cervical Spine injuries.]
Fig. 6.—Type II dens fracture in 14-year-old boy who was unrestrained passenger in motor vehicle crash.

A, Sagittal gradient-echo MR image (TR/TE, 500/9; flip angle, 15°) obtained on 1.5-T MR scanner shows intact occipitocervical membrane (1), anterior dislocation of fractured dens (2), anterior arch of C1 (3), partial tear of anterior atlantoaxial membrane (4), cord contusion (5), intact dura (6), medullary contusion or edema (7), torn tectorial membrane (8), intact posterior occipitocervical membrane (9), posterior arch of C1 (10), torn or attenuated posterior atlantoaxial membrane (11), intact dura (12), and intact flaval ligaments (13).

B, Axial gradient-echo MR image (250/15; flip angle, 15°) obtained on 1.5-T MR scanner shows right lateral mass of C1 (1), anteriorly dislocated dens (2), body of C2 at fracture site (3), compressed and contused spinal cord (4), anterior arch of C1 (5), intact alar ligaments (6), and intact transverse ligament (7).
Type III odontoid fracture occurs when the fracture line extends into the body of the axis.

- Nonunion is not usually a problem because of a good blood supply and the greater amount of cancellous bone.
• With Odontoid Type II and III fractures, the fractured segment may be displaced anteriorly, laterally, or posteriorly.
• Since posterior displacement of segment is more common in type III, the prevalence of spinal cord injury is as high as 10% with these fractures.
**Hangman fracture (traumatic spondylolisthesis of C2)**

- Bilateral fractures through the pedicles of C2 due to hyperextension
  - 2nd most common C2 fracture (25%)
  - The typical fracture that occurs after judicial hangings
    - Hyperextension & distraction
  - Commonly is caused by MVA /blows to the head
    - Hyperextension & axial compression

- Radiographically, a fracture line should be evident extending through the pedicles of C2 along with obvious disruption of the spinolaminar contour line

- A common sign is a constricted pupil on the ipsilateral side due to loss of sympathetic innervation to the eye due to damage to the sympathetic trunk in the neck
Type III Treatment Options

**Posterior**
- Open reduction and C1-C3 fusion
- Direct pars repair and C2-C3 fusion

**Anterior**
- C2/C3 ACDF with instrumentation
• Although considered an unstable fracture, it seldom is associated with spinal injury, since
  • the anteroposterior diameter of the spinal canal is greatest at this level
  • the fractured pedicles allow decompression.
• When associated with unilateral or bilateral facet dislocation at the level of C2, this particular type of hangman fracture is unstable and has a high rate of neurologic complications that require immediate cervical traction to reduce the facet dislocation.
Other C2 Fractures

- do not involve the odontoid process or the pars interarticularis of C2

- Fractures of C2 body, laminae, facets and spinous process

- Most heal satisfactorily with C-collar or SOMI orthosis

- Displaced or extensive fractures treated with a Halo
Traumatic spondylolisthesis of C2 (Hangman’s)

- Usually affects a younger age group (Avg 38 yrs)
- Neurologic injury seen in only 5-10% (acutely decompresses canal)
- Traditional treatment has been Halo-vest
- Collar adequate if < 6 mm displaced

[Coric et al. JNS. 1996]
C1-C2 combination fractures are common

- 44% of all C1 and 16% of all C2 fractures (Dickman et al, 1989)
- Higher rate of neurological injury
- Higher rate of non-operative treatment failure
Summary

- Of the entire spine, the CCJ is most difficult to evaluate radiographically and treat because of its complex anatomy, physiologic motions and normal variants.
- Treatment is based on injuries to bone and ligaments responsible for maintaining spinal stability.
- Isolated ligament injuries tend to be highly unstable and don’t heal with non-operative management.
- Minimally displaced or non-displaced bony injuries tend to heal satisfactorily with an orthosis.
- Combination, comminuted and displaced injuries tend to require internal fixation to restore stability.