

# Radiologic Spectrum of Craniocervical Distraction Injuries<sup>1</sup>

## CME FEATURE

See accompanying test at [http://www.rsna.org/education/lrg\\_cme.html](http://www.rsna.org/education/lrg_cme.html)

## LEARNING OBJECTIVES FOR TEST 6

After reading this article and taking the test, the reader will be able to:

- Describe the osseous and ligamentous anatomy of the craniocervical junction.
- Evaluate for craniocervical integrity using normative measurements of bone relationships at the upper cervical spine.
- Discuss the roles of conventional radiography, CT, and MR imaging in the evaluation of the upper cervical spine.

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Injuries to the atlanto-occipital region, which range from complete atlanto-occipital or atlantoaxial dislocation to nondisplaced occipital condyle avulsion fractures, are usually of critical clinical importance. At initial cross-table lateral radiography, measurement of the basion-dens and basion-posterior axial line intervals and comparison with normal measurements may help detect injury. Computed tomography (CT) with sagittal and coronal reformatted images permits optimal detection and evaluation of fracture and luxation. CT findings that may suggest atlanto-occipital injury include joint incongruity, focal hematomas, vertebral artery injury, capsular swelling, and, rarely, fractures through cranial nerve canals. Magnetic resonance (MR) imaging of the cervical spine with fat-suppressed gradient-echo T2-weighted or short-inversion-time inversion recovery sequences can demonstrate increased signal intensity in the atlantoaxial and atlanto-occipital joints, craniocervical ligaments, prevertebral soft tissues, and spinal cord. Axial gradient-echo MR images may be particularly useful in assessing the integrity of the transverse atlantal ligament. All imaging studies should be conducted with special attention to bone integrity and the possibility of soft-tissue injury. Atlanto-occipital injuries are now recognized as potentially survivable, although commonly with substantial morbidity. Swift diagnosis by the trauma radiologist is crucial for ensuring prompt, effective treatment and preventing delayed neurologic deficits in patients who survive such injuries.

**Abbreviation:** STIR = short-inversion-time inversion recovery

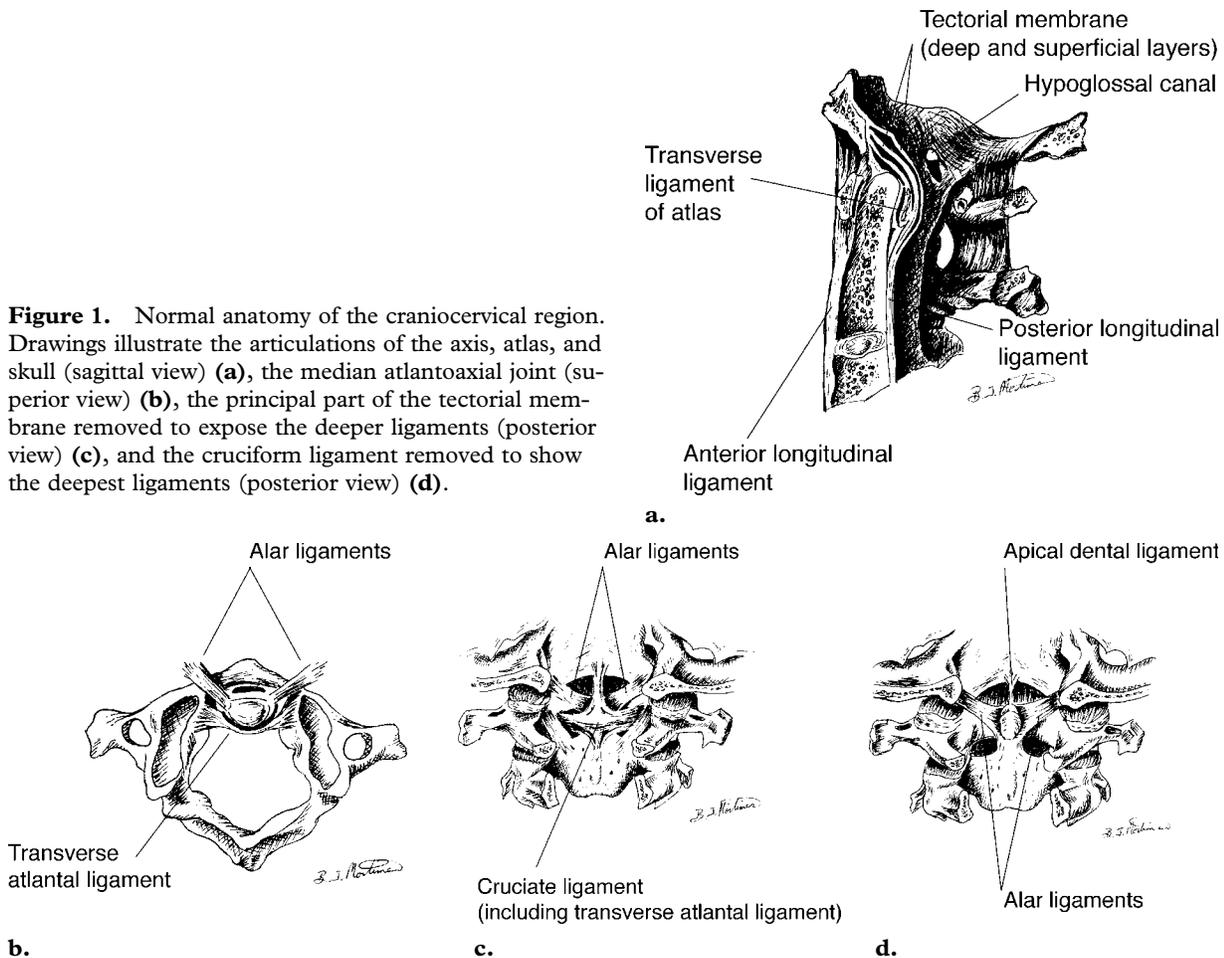
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**Figure 1.** Normal anatomy of the craniocervical region. Drawings illustrate the articulations of the axis, atlas, and skull (sagittal view) (a), the median atlantoaxial joint (superior view) (b), the principal part of the tectorial membrane removed to expose the deeper ligaments (posterior view) (c), and the cruciform ligament removed to show the deepest ligaments (posterior view) (d).



**Introduction**

Osteoligamentous injuries at the craniocervical junction are uncommon but are of critical clinical importance. Injury to the upper cervical spine occurs frequently in fatal motor vehicle accidents, particularly among pedestrians and motorcyclists (1). Likely mechanisms include violent distractive hyperflexion or hyperextension with or without associated rotation. In one series of over 100 consecutive victims of fatal motor vehicle accidents, cervical spine injuries were present in 23% of cases, with nearly half of these injuries localized to the occiput-C1 region (2). Other series estimate that up to 20% of all traffic fatalities involve upper cervical spine injuries (3,4). Cervical spine injuries (including up to 50% of craniocervical injuries) are frequently missed at initial im-

aging in survivors of high-speed accidents. This can be an important factor in subsequent morbidity, with up to one-third of affected patients experiencing later neurologic deterioration (5). In this article, we review the normal anatomy of the craniocervical region and the use of radiography, computed tomography (CT), and magnetic resonance (MR) imaging in the evaluation of this area. We also discuss and illustrate various patterns of craniocervical injury, including atlanto-occipital and atlantoaxial distraction, neurovascular injury, and pediatric atlanto-occipital dislocation.

**Normal Anatomy and Imaging Approaches**

The articulations of the craniocervical junction are defined by the middle atlantoaxial joint, which consists of two synovial compartments that sur-

**Table 1**  
**Protocols for Imaging Evaluation of Suspected Upper Cervical Spine Injury**

Modality	Protocol
Lateral radiography	Cassette positioned against the shoulder with cranial extent no lower than the top of the ear, 1.5-m tube-object distance
Screening cervical CT	Helical scanning, 3-mm collimation, 1.5/1 pitch, foramen magnum–T4 scan length, sagittal or coronal reformatted images
Cranio-cervical CT	Helical scanning, 1-mm collimation, 1.0/1 pitch, foramen magnum–C3 scan length, sagittal or coronal reformatted images
Trauma cervical MR imaging	Sagittal T1-weighted, short-inversion-time inversion recovery (STIR), gradient-echo, fat-saturated fast spin-echo T2-weighted images; coronal T1-weighted or STIR images; axial fast spin-echo or gradient-echo T2-weighted images

**Table 2**  
**Guidelines for the Imaging Assessment of the Craniocervical Junction**

Modality	Items Assessed
Lateral radiography	Basion-dens interval, posterior axial line; prevertebral soft tissues, osseous integrity, spinolaminar line, anterior atlanto-dens interval, clivus, C1, C2
Anteroposterior radiography	Lateral atlanto-dens interval, atlanto-occipital articulation, atlantoaxial articulation, C1-C2 overhang, occipital condyles, C1, C2 and dens
CT	Foramen magnum, occipital condyles, C1, C2, atlanto-occipital congruity, atlantoaxial congruity, prevertebral soft tissues, presence of subarachnoid hemorrhage or epidural hematoma
MR imaging	Bone marrow signal intensity, atlanto-occipital joints, atlantoaxial joints, prevertebral soft tissues, presence of epidural hematoma, nuchal ligament signal intensity, interspinous ligament, tectorial membrane, spinal cord

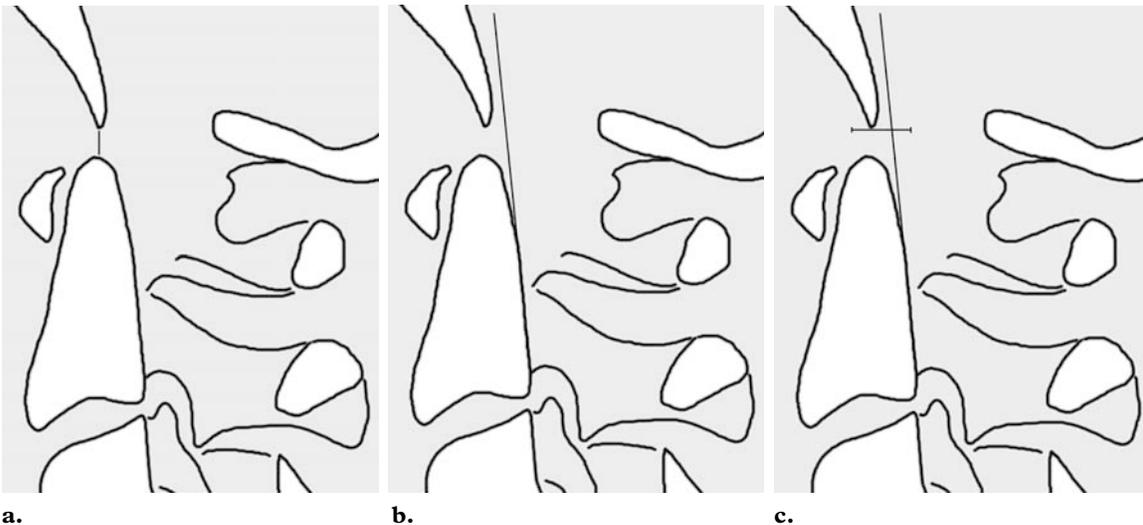
round the dens and allow rotation of C1 and C2 with respect to each other, and the paired lateral atlantoaxial and atlanto-occipital articulations. These joints are bound and supported by several ligaments, including the anterior longitudinal ligament, the anterior atlantoaxial and atlanto-occipital ligaments, the cruciform ligaments, the alar ligaments, and the tectorial membrane, which extends cranially as the cephalic extension of the posterior longitudinal ligament (Fig 1) (6). Structures that are critical for maintaining craniocervical continuity include the tectorial membrane, the alar ligaments, and the transverse fibers of the cruciate ligament (eg, the transverse atlantal ligament). Any of these ligaments may fail from avul-

sion, fracture of the bone attachment, or intra-substance tear.

Craniocervical biomechanical continuity depends on the integrity of the skull base, atlas, and axis and their attaching ligaments. Most trauma patients initially undergo cross-table lateral radiography. Further imaging options include conventional tomography, CT with coronal and sagittal reformatted images, MR imaging, and dynamic imaging (Table 1). Each of these studies should be conducted with special attention to bone integrity and the possibility of soft-tissue injury (Table 2). Normal measurements have been determined for

**Table 3**  
**Normal Dimensions of the Craniocervical Junction at Lateral Radiography**

Anatomic Location	Dimensions
Basion-dens interval	<12 mm
Basion-posterior axial line interval	<12 mm posterior to basion, <4 mm anterior to basion
Prevertebral soft tissues	<6 mm at C2, flat or concave
Anterior atlanto-dens interval	<2 mm
Lateral atlanto-dens interval	<2-3-mm side-to-side difference
Atlanto-occipital articulation	1-2 mm
Atlantoaxial articulation	2-3 mm



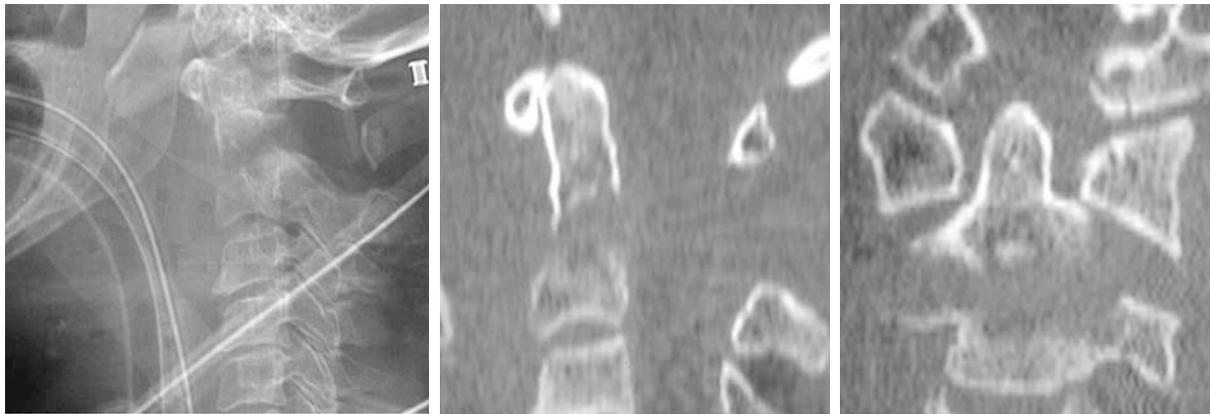
**Figure 2.** Normal relationships within the craniocervical junction. Drawings illustrate the basion-dens interval (a), the posterior axial line, which is drawn along the posterior cortex of the axis (b), and the basion-posterior axial line interval (c). Horizontal line in c represents the range of acceptable basion positions.

many of the bone relationships and soft-tissue contours at the craniocervical junction and are valuable for excluding upper cervical spine injury (Table 3).

Harris et al (7,8) have identified a practical method for evaluating the normal osseous relationships at the craniocervical junction using lateral conventional radiographs obtained at a 1-m target-film distance with the cassette positioned against the skull (7,8). They determined the upper limits of normal for adults and children by measuring the basion-dens interval (tip of dens to basion) and the basion-posterior axial line interval (basion to posterior axial line, a vertical line drawn along the posterior aspect of the subdental body

of C2). In 95% of adults, the basion-dens interval was less than 12 mm, and in 98%, the basion was situated no more than 12 mm anterior or 4 mm posterior to the posterior axial line (Fig 2).

An abnormal distance between the dens or posterior axial line and the basion suggests failure or insufficiency of the alar ligaments, tectorial membrane, or both. Enlargement of the predental space, which should be less than 5 mm in children under 9 years of age and less than 3 mm in adults, points to injury of the transverse atlantal ligament. On the anteroposterior ("open-mouth" or odontoid) view of the craniocervical junction, the lateral masses of C1 should align exactly with the lateral margins of C2 when degenerative spurring is ignored. Stress views obtained with fluoroscopic guidance and performed in conjunction with the referring clinical service may reveal otherwise unidentified atlanto-occipital junction instability.



**Figure 3.** Type 3 dens fracture with associated left occipital condyle fracture. **(a)** Cross-table lateral radiograph demonstrates a widely diastatic fracture through the body of C2. **(b)** Sagittal reformatted CT scan shows a dens fracture. **(c)** Coronal reformatted CT scan demonstrates a left occipital condyle fracture.

CT with sagittal and coronal reformatted images permits optimal detection and evaluation of fracture and luxation. The atlanto-occipital and atlantoaxial articulations should be congruent on both coronal and sagittal reformatted images. Fractures of the tip of the dens or of the occipital condyles may be associated with alar ligament insufficiency. Subarachnoid hemorrhage and epidural hematoma may accompany injuries to the craniocervical junction and should be sought on CT scans of both the cervical spine and cranium.

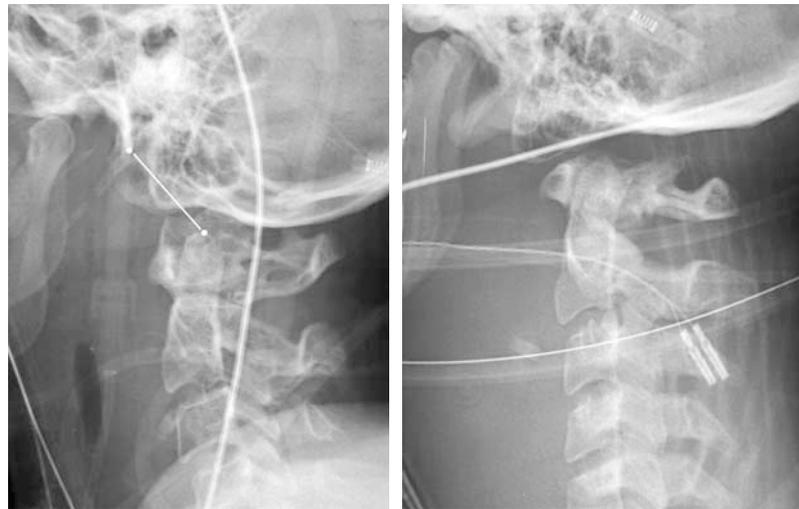
Following mandatory lateral cervical spine radiography, screening CT of the cervical spine is the dominant imaging strategy in “adults” (ie, patients over 12 years old) if the patient’s pretest probability of injury is 5% or greater. Injury mechanisms or clinical findings that, when present, place the patient in a high-risk category (>5% risk of cervical spine fracture) include a high-speed (>35-mph) motor vehicle accident, a crash resulting in death at the scene of the accident, a fall from a height greater than 10 feet, significant closed head injury (or intracranial hemorrhage seen at CT), neurologic signs or symptoms referred to the cervical spine, and pelvic or multiple extremity fractures (9). Otherwise, conventional radiographic screening is the most appropriate strategy. Data to help formulate screening criteria in children are lacking. We believe that routine screening CT of the cervical spine in children aged 9 years or younger is not indicated except in cases of known cervical spine fracture seen at other modalities. Three-dimensional CT does not appear to have a routine role in the

work-up of cervical spine trauma. However, in complex fracture dislocations, particularly those with rotary components (eg, C1-C2 fracture rotary dislocations, atypical C1-C2 rotary fixations), three-dimensional imaging may be very useful in communicating findings to other clinicians and to the patient’s family.

MR imaging of the cervical spine with fat-suppressed gradient-echo T2-weighted or STIR sequences can demonstrate increased signal intensity in the atlantoaxial and atlanto-occipital joints, craniocervical ligaments, prevertebral soft tissues, and spinal cord (10). Axial gradient-echo MR images may be particularly useful in assessing the integrity of the transverse atlantal ligament (11).

### Patterns of Injury

Dislocations at the craniocervical junction are grossly unstable injuries, often with significant neurologic or vascular compromise, and are frequently caused by high-speed motor vehicle collisions. Rotational and shearing forces at the craniocervical junction that result in clinical instability do so by injuring the alar ligaments, transverse ligament, or tectorial membrane. Ligamentous continuity can be disrupted by fractures near the attachments, avulsion, or tear within the substance of the ligament. Distraction injuries that result in craniocervical separation may be unilateral or bilateral and usually occur between the occiput and C1, between C1 and C2, or both (Fig 3).



4.

5a.



5b.



5c.



6.

**Figure 4.** Atlanto-occipital dislocation. Cross-table lateral radiograph shows atlanto-occipital dislocation with a basion-dens interval of 25 mm. The patient died shortly after presentation.

**Figure 5.** Cross-table lateral radiographs obtained in three different patients show varying amounts of pathologic widening (>12 mm) between the basion and dens with space clearly seen between the cranium and the C1 vertebral body. All three patients died shortly after presentation.

**Figure 6.** Cross-table lateral radiograph demonstrates significant widening between the cranium and upper cervical spine as well as of the basion-dens interval. The patient died 2 days later.

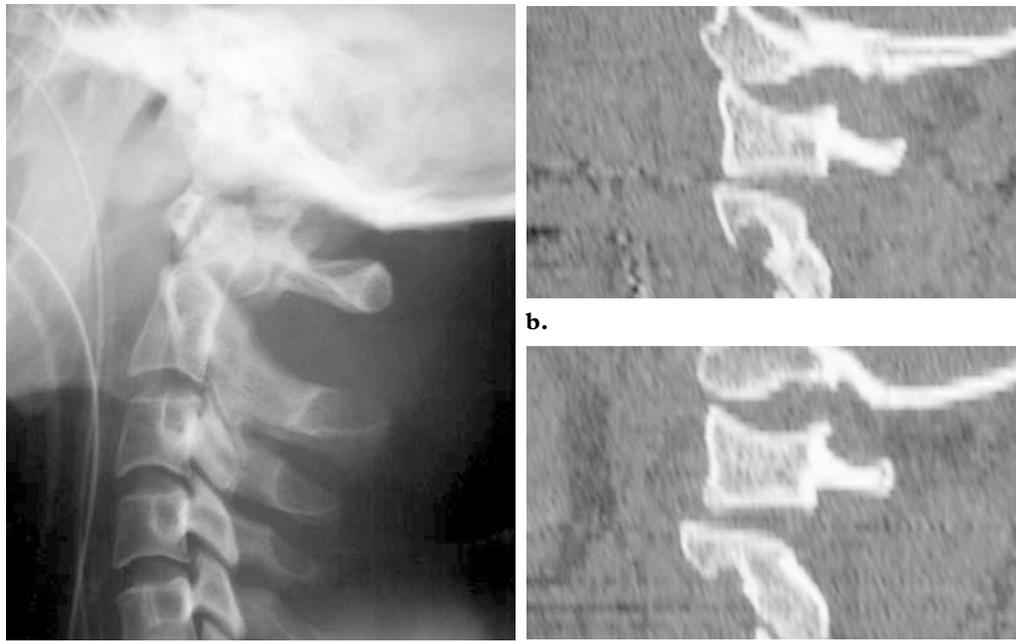
Dislocations are characterized by complete loss of articular continuity with varying degrees of distraction. Subluxations are generally less severe injuries in which some articular continuity is retained.

### Atlanto-occipital Distraction

Ligamentous atlanto-occipital dislocation, displaced occipital condyle fractures with alar ligament avulsion, and tectorial membrane disruption account for most distraction injuries be-

tween the occiput and C1. Werne (12) demonstrated that disruption of both the tectorial membrane and the alar ligaments is required to produce isolated atlanto-occipital dislocation (Figs 4–7). Variants include unilateral injury, which may be subtle, and subluxations with minimal craniocervical separation (Fig 8).

Occipital condyle fractures may be classified as impaction fractures, extensions of occipital skull fractures, or avulsion fractures at the insertions of the alar ligaments (13). The latter are potentially unstable fractures, particularly if displaced (14), and when associated with tectorial

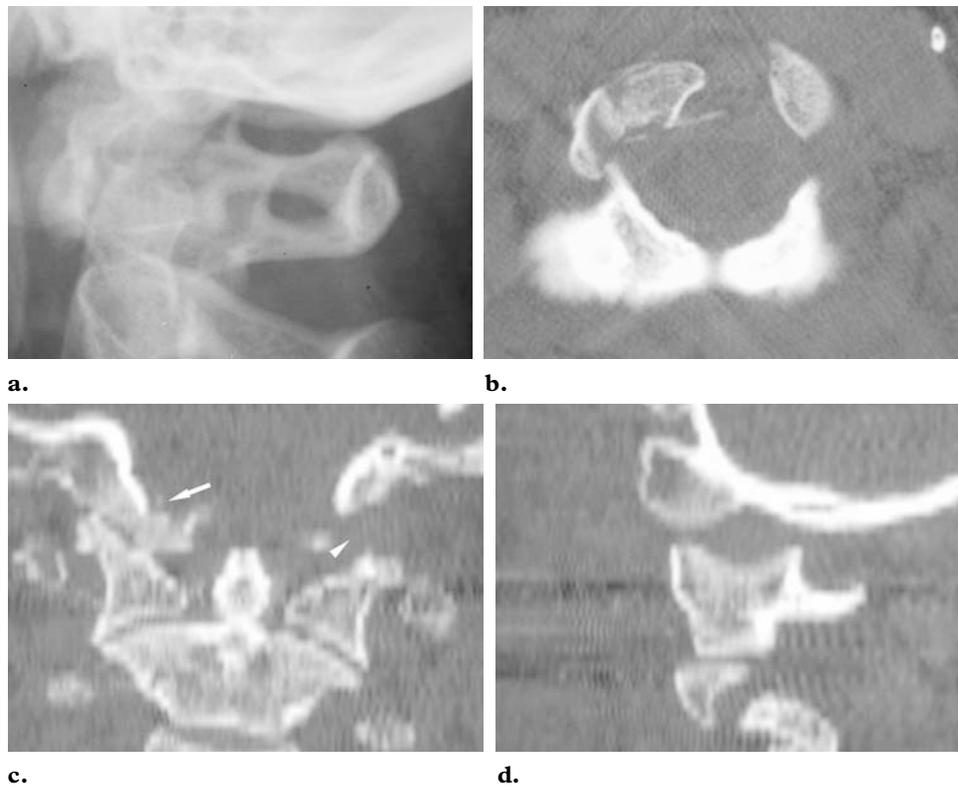


**Figure 7.** Atlanto-occipital dislocation. **(a)** Cross-table lateral radiograph shows a widened basion-dens interval of 18 mm. **(b, c)** Left **(b)** and right **(c)** sagittal reformatted CT scans show bilateral widening of the atlanto-occipital joints with anterior displacement of the occipital condyles relative to the opposing atlantal articular masses. The patient survived but had substantial neurologic deficit.



**Figure 8.** Atlanto-occipital subluxation. **(a)** Cross-table lateral radiograph shows a mildly widened (13-mm) basion-dens interval. **(b)** Coronal reformatted CT scan shows unilateral widening of the right atlanto-occipital (top arrowhead) and atlantoaxial (bottom arrowhead) joints. **(c)** Sagittal reformatted CT scan demonstrates unilateral widening of the right atlanto-occipital joint. **(d)** Parasagittal STIR MR image of the right side shows abnormal fluid in the atlanto-occipital and atlantoaxial joints (\*).

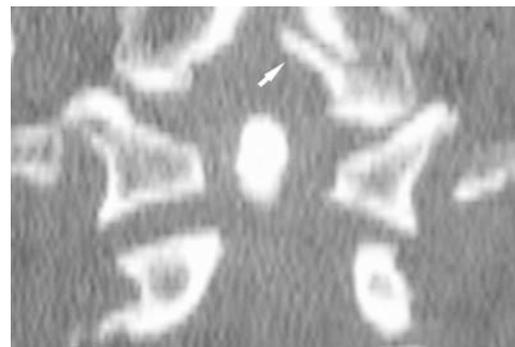
**a.** **b.** **c.** **d.**



**Figure 9.** Occipital condyle fracture with atlanto-occipital dislocation. **(a)** Cross-table lateral radiograph shows a widened basion-dens interval of 18 mm. **(b)** Axial CT scan shows a right-sided occipital condyle fracture. **(c)** Coronal reformatted CT scan shows dislocation of the left atlanto-occipital joint (arrowhead) and a right-sided occipital condyle fracture (arrow). **(d)** Sagittal reformatted CT scan shows anterior dislocation of the left atlanto-occipital joint.

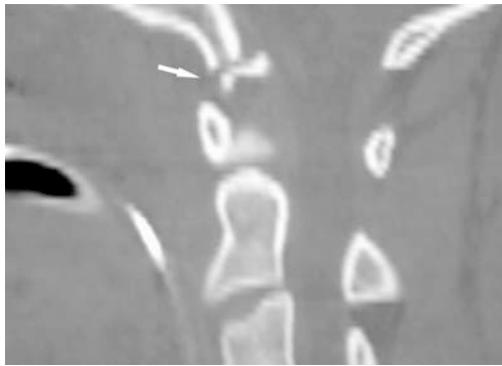
membrane injury can result in gross atlanto-occipital discontinuity (Figs 9, 10). Occipital condyle fractures may be unilateral or bilateral, may extend in a ringlike pattern around the foramen magnum, and are extremely difficult to identify on conventional radiographs (Fig 11) (15,16). Palsies of lower cranial nerves may also be seen in association with occipital condyle fractures (17). The 12th cranial nerve is most commonly involved, most often due to fracture extension through the hypoglossal canal (Fig 12).

Lateral radiographic findings in atlanto-occipital distraction injuries include soft-tissue swelling and pathologic convexity of the soft tissues anterior to C2 (generally greater than 10 mm in thickness), a basion-dens interval greater than 12 mm, or a basion-posterior axial line interval more than 12 mm anterior or 4 mm posterior to the posterior axial line. Axial CT can help detect condylar fractures, which are often occult on conventional radiographs. Coronal and parasagittal reformatted images can show widening or incongruity of the articulation between the occipital condyles and the lateral masses of C1 as well as fractures of

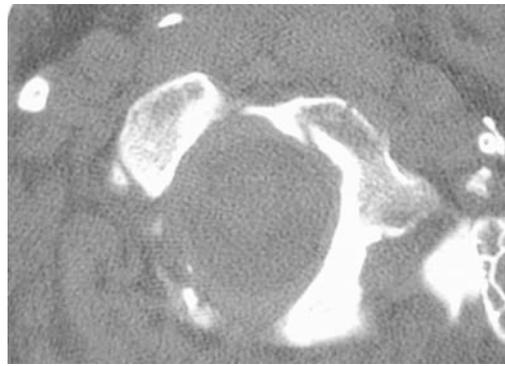


**Figure 10.** Occipital condyle fracture with atlanto-occipital and atlantoaxial subluxation. Coronal reformatted CT scan demonstrates an occipital condyle fracture (arrow) with contralateral subluxation of the atlanto-occipital and atlantoaxial joints.

the basion (Fig 13). Sagittal or coronal MR imaging with T2-weighted or STIR sequences can easily demonstrate prevertebral soft-tissue swelling as well as fluid within the articular capsules, nuchal ligament, and interspinous ligaments. Complications including epidural hematoma,



a.

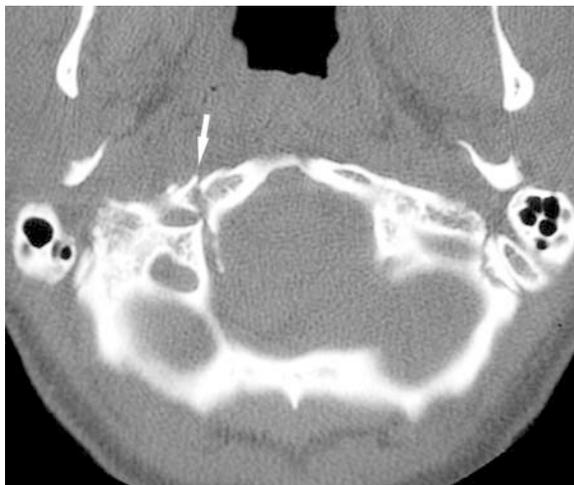


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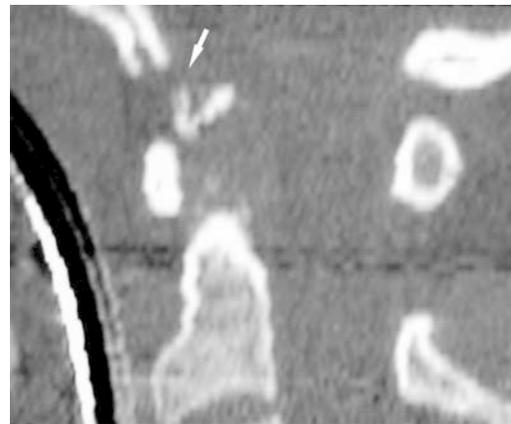


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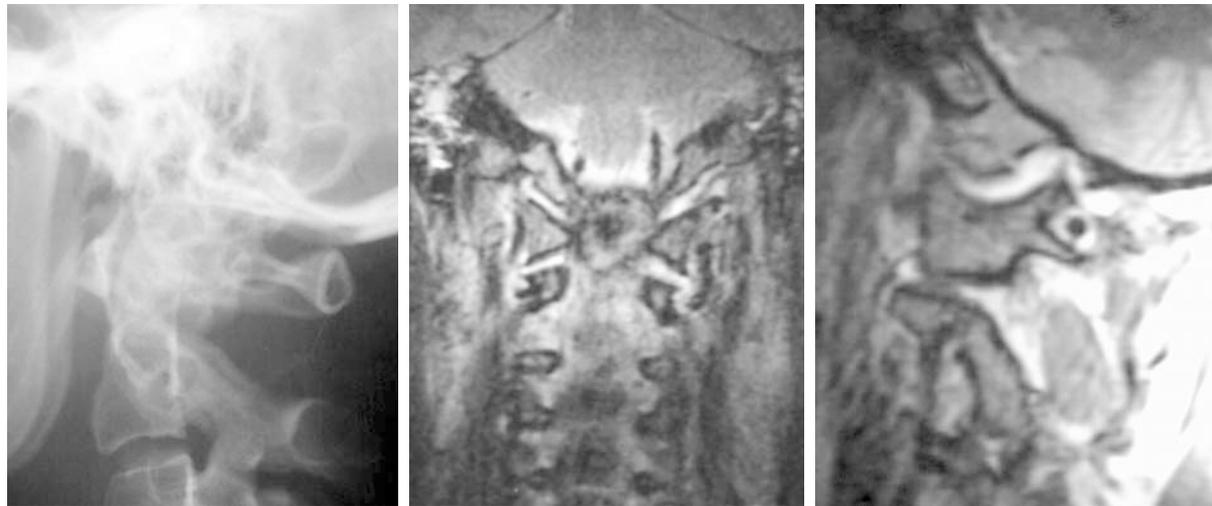
**Figure 11.** Occipital condyle fracture. (a) Sagittal reformatted CT scan shows an avulsion-type fracture of the basion (arrow). (b) CT scan shows a fracture line extending through the left occipital condyle. (c) Sagittal fat-saturated MR image (repetition time msec/echo time msec = 3,272/68) shows abnormal high signal intensity in the precervical space (\*), a finding that is consistent with edema or hemorrhage, as well as a spinal cord contusion (arrow).



**Figure 12.** Occipital condyle fracture in a patient with a 12th cranial nerve palsy. Axial CT scan demonstrates a displaced fracture through the region of the hypoglossal canal (arrow).



**Figure 13.** Basion fracture. CT scan shows a displaced fracture of the tip of the basion (arrow). This type of fracture may lead to a false low measurement of the basion-dens interval.



**Figure 14.** Subtle atlanto-occipital injury. **(a)** On a cross-table lateral radiograph, the basion-dens interval (10 mm) and basion-posterior axial line interval are both normal. **(b, c)** Coronal **(b)** and parasagittal **(c)** fat-saturated MR images (5,000/36) show excessive joint fluid at the atlanto-occipital and atlantoaxial joints. **(d)** Sagittal fat-saturated MR image (5,000/36) shows precervical swelling (white \*) and an expanding hematoma impinging on the spinal cord (black \*).

spinal cord injury, and brainstem compression can also be detected (Fig 14).

### Atlantoaxial Distraction

Atlantoaxial distraction can result from the same severe extension and distraction forces as atlanto-occipital dislocation. Disruption of the articular capsules, alar ligaments, transverse ligament, and tectorial membrane between C1 and C2 (Fig 15) as well as occasional type 1 dens fractures characterize these injuries (18). Type 1 dens fractures that occur at the insertion of the alar ligaments may not directly affect the atlanto-occipital articulations but will result in instability from disruption of the C1-C2 joint capsules and supporting longitudinal ligaments (Fig 16). In such cases, the transverse atlantal ligament generally remains intact.

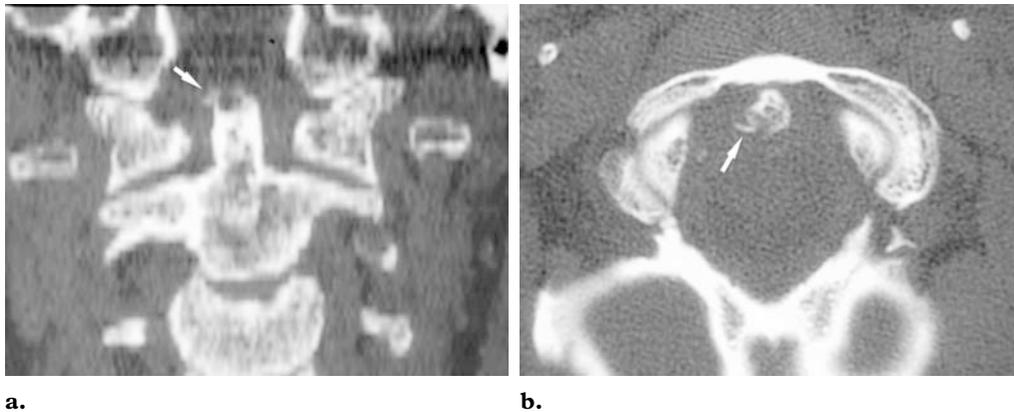
Conventional radiographic and CT findings in atlantoaxial distraction include prevertebral soft-tissue swelling, C1-C2 dislocation or subluxation, and widening of the C1-C2 facets. MR imaging findings consist of prevertebral, interspinous, or nuchal ligament edema as well as facet widening or fluid, possible epidural hematoma, and increased signal intensity of the spinal cord on T2-weighted or STIR images.

### Neurovascular Injury

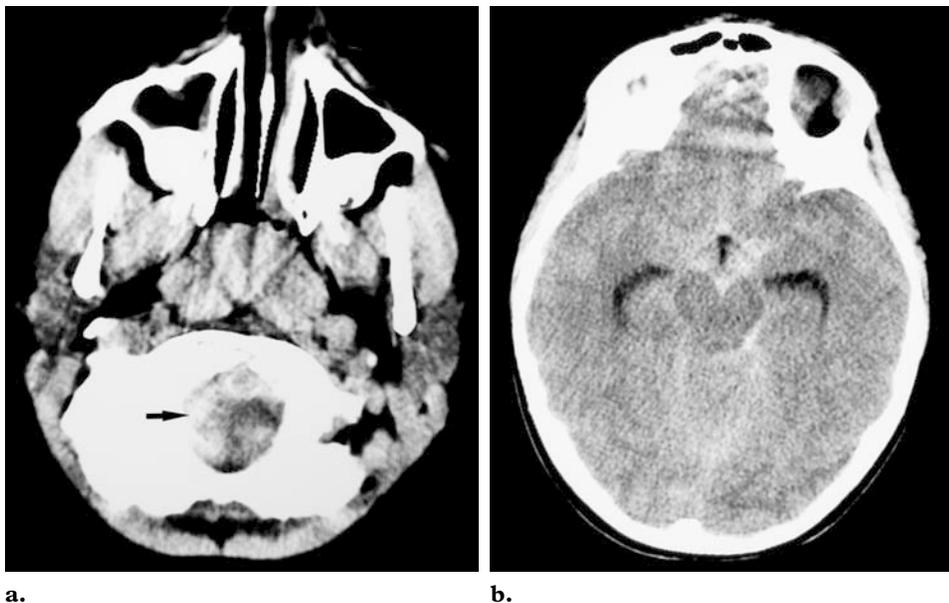
In fatal cases of atlanto-occipital dislocation, the most common spinocerebral injuries include lacerations of the pontomedullary junction (75%),



**Figure 15.** Atlantoaxial distraction. Cross-table lateral radiograph shows wide distraction between C1 and C2. The relationship between the C1 vertebral body and the cranium is normal, but distraction is seen at the atlantoaxial joints. The patient died in the emergency department.



**Figure 16.** Type 1 dens fracture. Coronal (a) and axial (b) CT scans demonstrate a type 1 dens fracture (arrow).



**Figure 17.** Hemorrhage associated with atlanto-occipital injuries. (a) Unenhanced head CT scan shows areas of hyperattenuation surrounding the spinal cord and layering dependently (arrow), findings that are consistent with subarachnoid hemorrhage. (b) Unenhanced head CT scan demonstrates areas of hyperattenuation in the perimesencephalic and supra-sellar cisterns, findings that are also consistent with subarachnoid hemorrhage.

contusion or laceration of the caudal medulla and rostral spinal cord (42%), and stretching or laceration of the midbrain (33%). Subarachnoid hemorrhage is common but may be minimal (Fig 17). Subdural hemorrhage is seen in 16% of cases (18). Vasospasm and dissection of the internal carotid and vertebral arteries have been documented at angiography in several survivors of atlanto-occipital dislocation who did not have significant injuries to the spinal cord or brainstem (19). MR or CT angiography can noninvasively demonstrate vascular patency, although these modalities are presumably less sensitive for the diagnosis of small subintimal flaps (20).

### **Pediatric Atlanto-occipital Dislocation**

Traumatic atlanto-occipital dislocation in children presents a diagnostic challenge owing in part to the variability of bone ossification in the craniocervical junction. Because of this variability in ossification and fusion, particularly of the dens, Harris et al (7) found the basion-dens interval diagnostically unreliable in children under the age of 13 years. However, the basion-posterior axial line interval was found to be reproducible and normally did not exceed 12 mm. Children may be

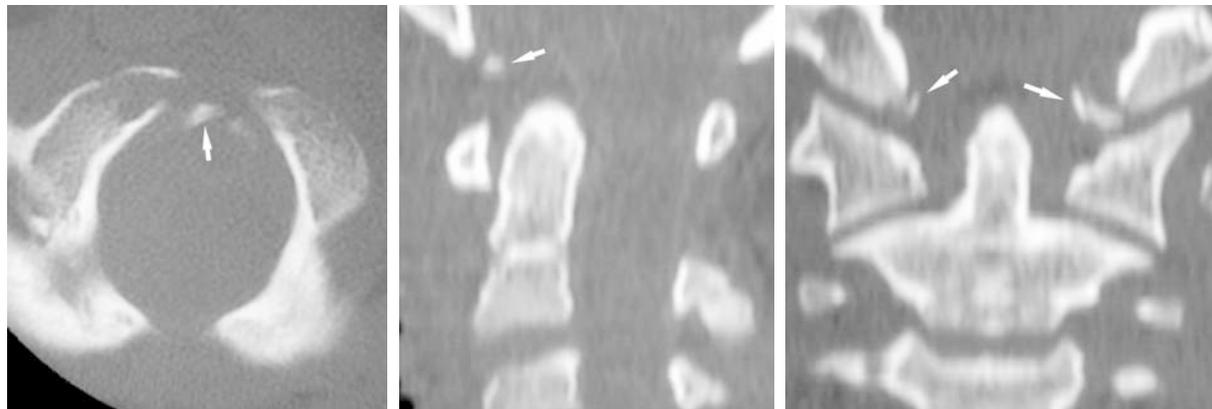


**Figure 18.** Atlanto-occipital dislocation in a 6-year-old boy. Cross-table lateral radiograph demonstrates marked widening of the basion-dens and basion-posterior axial line intervals. The patient died in the emergency department.



a.

e.



b.

c.

d.

**Figure 19.** Atlanto-occipital dislocation in a 10-year-old girl. **(a)** Cross-table lateral radiograph shows widening of the basion-dens and basion-posterior axial line intervals. **(b)** Axial CT scan shows displaced fractures of the basion (arrow) and occipital condyles. **(c)** Sagittal reformatted CT scan shows displaced fractures of the basion (arrow). **(d)** Coronal reformatted CT scan shows displaced fractures of the occipital condyles (arrows). **(e)** Parasagittal MR image (3,816/30; inversion time msec = 180) shows abnormal high signal intensity in the precervical space (\*), a finding that is consistent with fluid, as well as hemorrhage or edema below the posterior longitudinal ligament (arrowhead). The patient survived but had substantial neurologic deficit.



**Figure 20.** Normal occipital condyle synchondrosis in a 7-year-old boy. Axial CT scan obtained at the level of the occipital condyles shows linear areas of low attenuation through the left occipital condyle representing normal synchondrosis (arrowhead). This finding should not be confused with fracture in pediatric patients.

at particular risk for atlanto-occipital injury due to increased ligamentous laxity, large size of the head relative to the body, and hypoplastic occipital condyles (Figs 18–20) (21,22).

### Conclusions

Injuries to the atlanto-occipital region may be radiographically dramatic or, occasionally, subtle; in either case, however, they are usually of critical clinical importance. Several areas merit intense scrutiny by the trauma radiologist, particularly when an atlanto-occipital injury is suspected. On cross-table lateral radiographs, the basion-dens and basion-posterior axial line intervals should be measured. Fractures, when present, raise the possibility of associated ligamentous injury and instability. At CT, joint congruity must be assessed. Even small, flakelike fractures may portend significant ligamentous avulsions and potential instability.

Other CT findings that may suggest atlanto-occipital injury include focal hematomas, vertebral artery injury, capsular swelling, and, rarely, fractures through cranial nerve canals (usually suspected clinically due to a cranial nerve palsy).

At MR imaging, precervical fluid and widened, often fluid-filled joint spaces are important clues to injury, as is direct visualization of ligamentous or spinal cord injuries. Atlanto-occipital injuries, including atlanto-occipital dislocations, were long believed to be almost uniformly fatal; now, however, they are recognized as potentially survivable, although commonly with substantial morbidity (23–25). Increasing survival is probably attributable to prompt in-field spine immobilization and intubation and rapid transfer to a trauma center (26). Swift diagnosis of these injuries by the trauma radiologist is crucial for ensuring prompt, effective treatment for affected patients.

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