Craniocervical Imaging: Traumatic and Nontraumatic

Daniel Ortiz, MD

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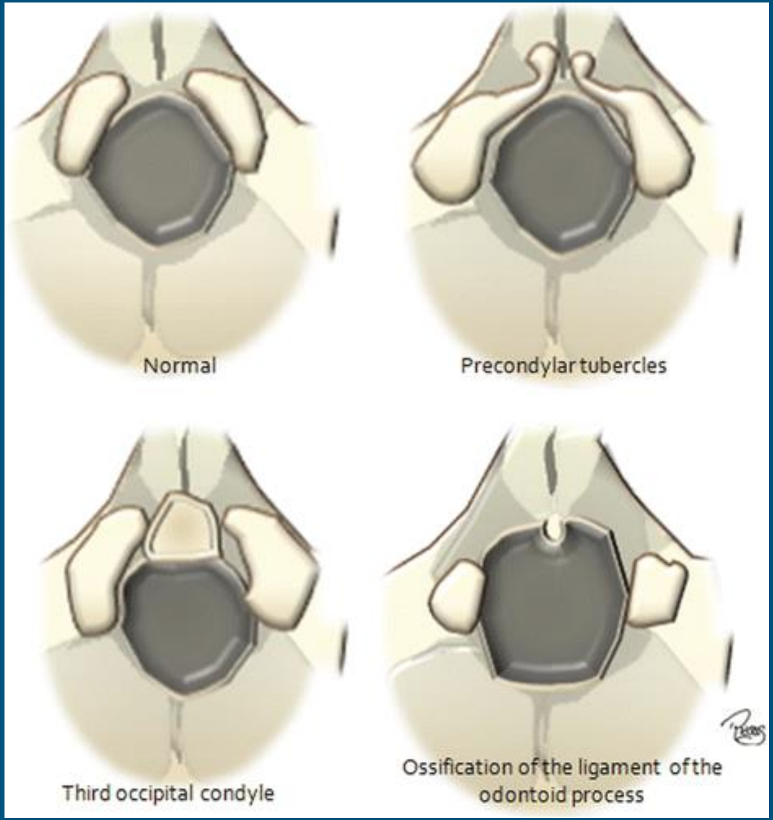
Learning Objectives

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

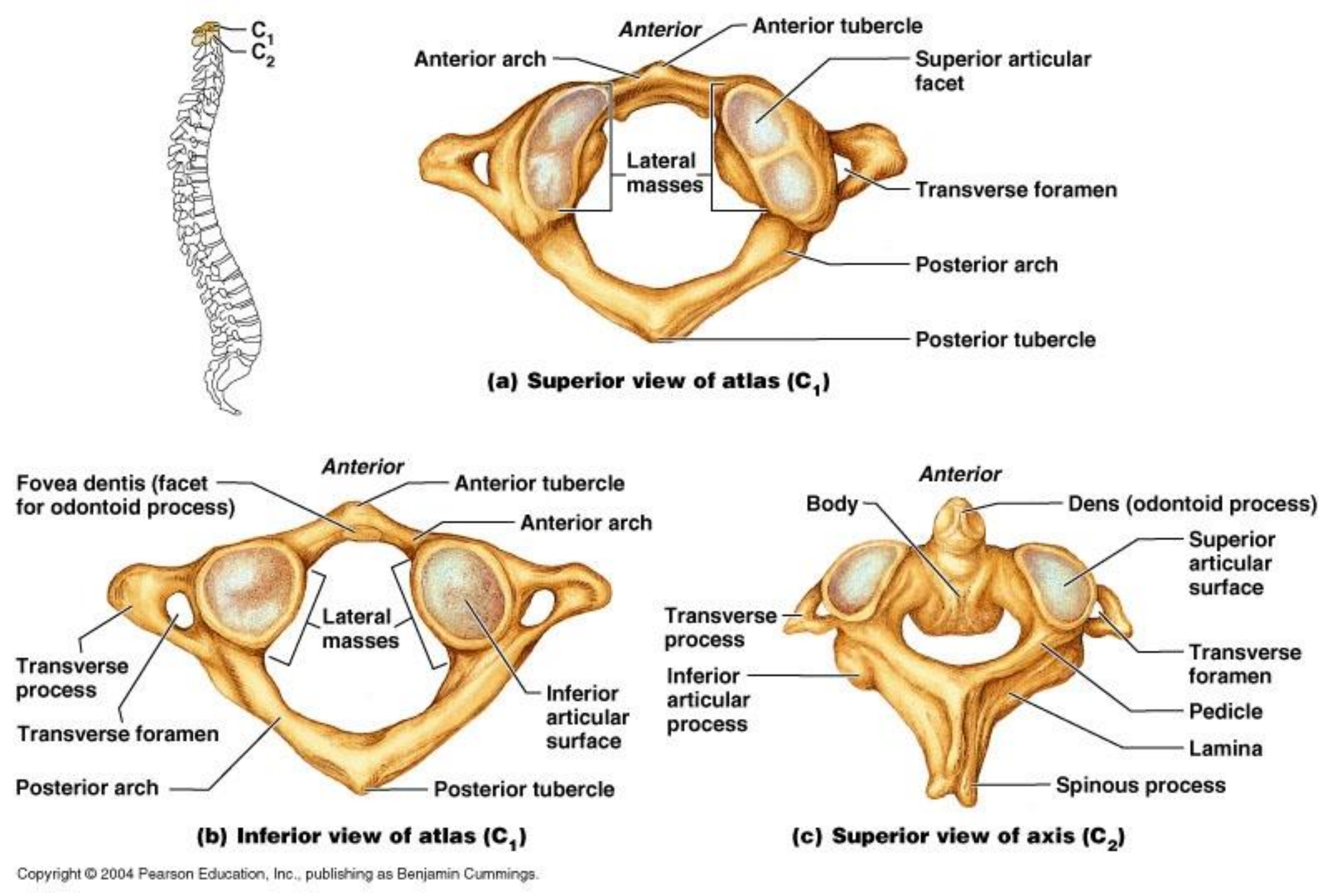
What comprises the CCJ?

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

Occiput anatomy



R Riascos, et al. Imaging of the Atlanto-Occipital and Atlantoaxial Traumatic Injuries: What the Radiologist Needs to Know. Radiographics 2015, 35, 2121-2134



http://brachialartery.com/wp-content/uploads/2016/08/axis-vertebra-atlas-and-axis-vertebrae-humananatomy-co.jpg

Ligaments of the CCJ

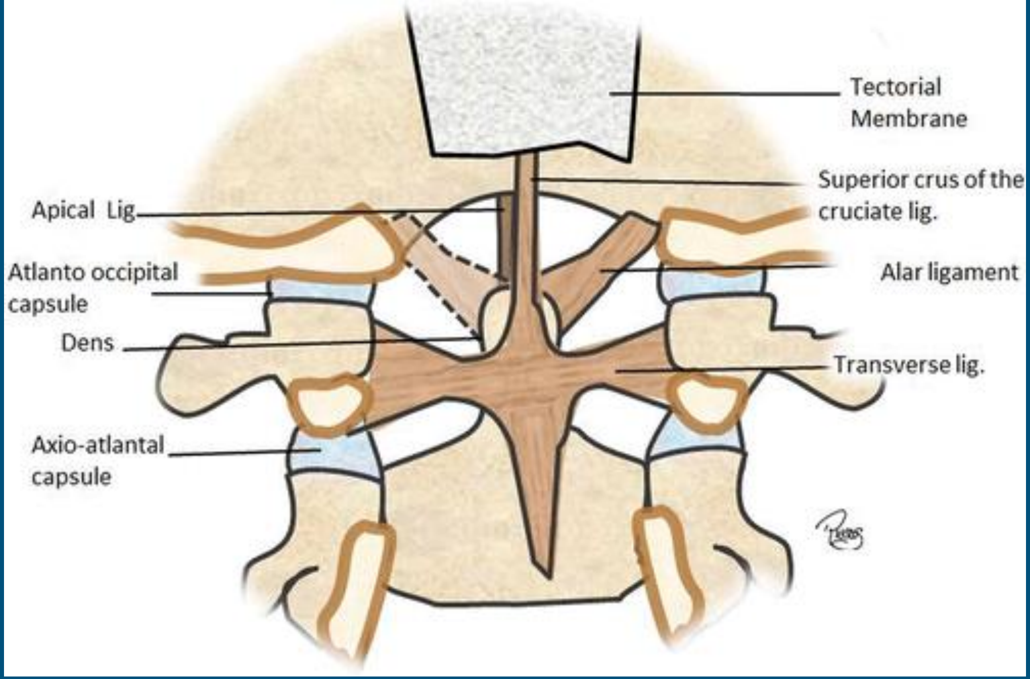
Intrinsic ligaments (3 layers anterior to the dura)

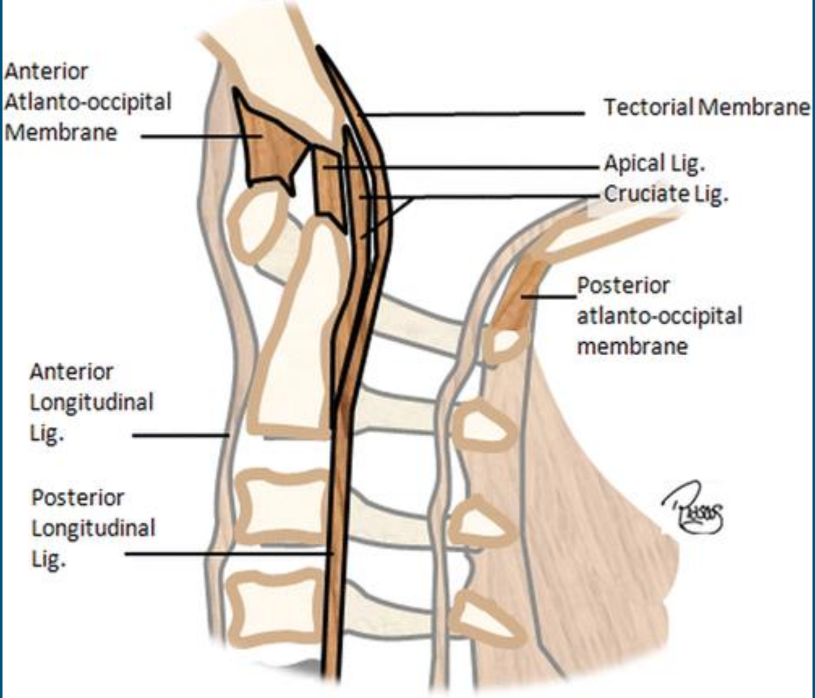
- Odontoid ligament
- Cruciate ligament
- Tectorial membrane

Extrinsic ligaments

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

CCJ Ligaments





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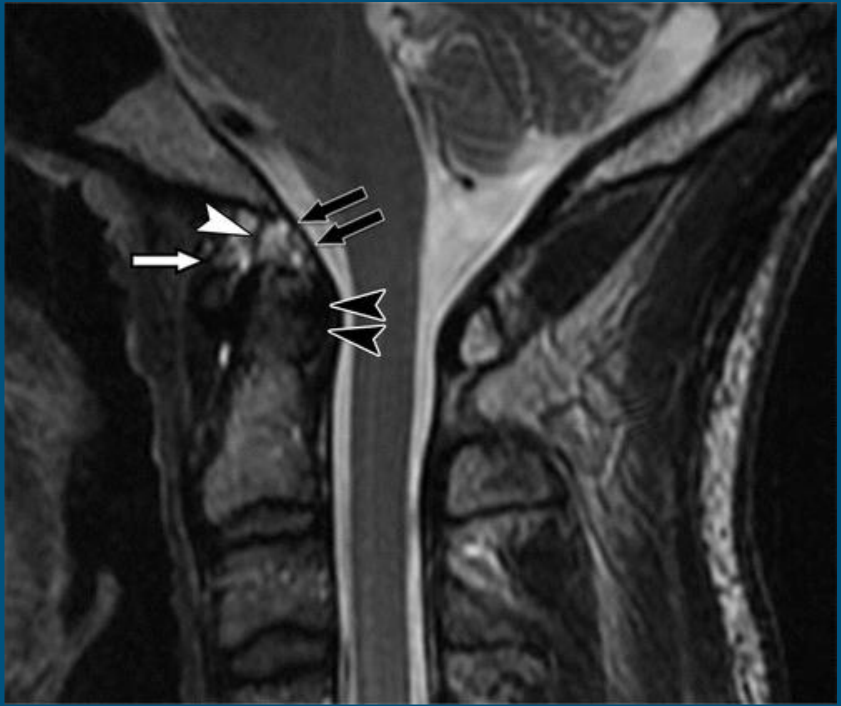
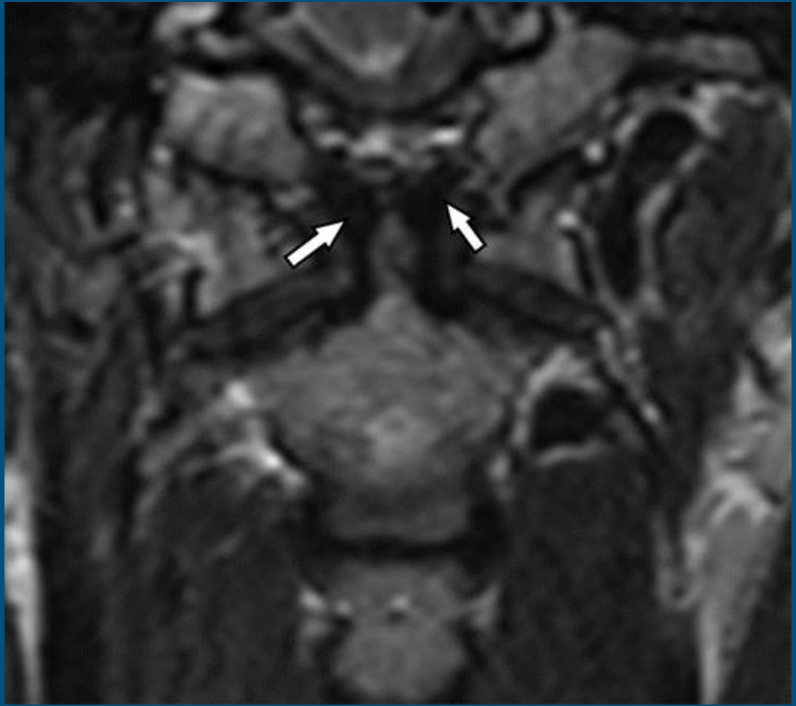
CCJ Ligaments





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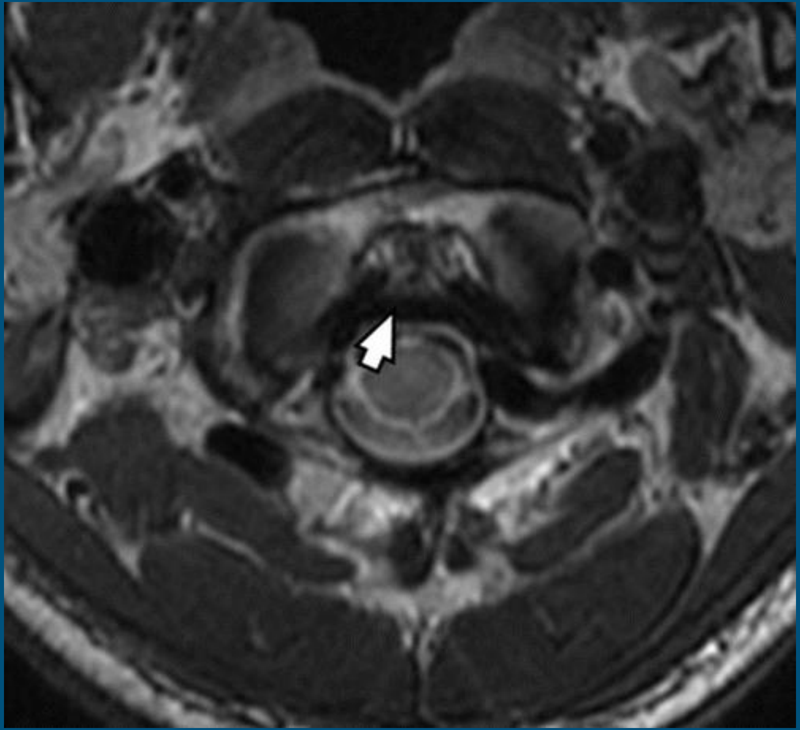
CCJ Ligaments



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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

NEXUS criteria
No posterior midline cervical tenderness
No intoxication
No focal neurologic deficit
No painful distracting injuries
Canadian C-spine rule criteria
Age < 65 years
No dangerous mechanism, such as:
Fall from height of >91 cm (>3 ft)
Axial loading injury (eg, diving accident)
High-speed motor vehicle collision (MVC) (>100 km/h), rollover, or ejection
Recreational motor vehicle, motorcycle, or bicycle injury
No paresthesias
Sitting position in emergency department
Ambulatory at any time
Neck rotation of 45° left and right

Dreizin, et al. Multidetector CT of Blunt Cervical Spine Trauma in Adults. Radiographics 2014, 34: 1842-1865.

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

Le Fort II or III facial fractures
Skull base fracture extending to petrous internal carotid artery canal
Fractures of C1–C3
Fracture line reaching a transverse foramen
Facet subluxation or dislocation
Scalp degloving injury
Severe mandibular fractures
Closed head injury
Major chest trauma

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Traumatic Pathology

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

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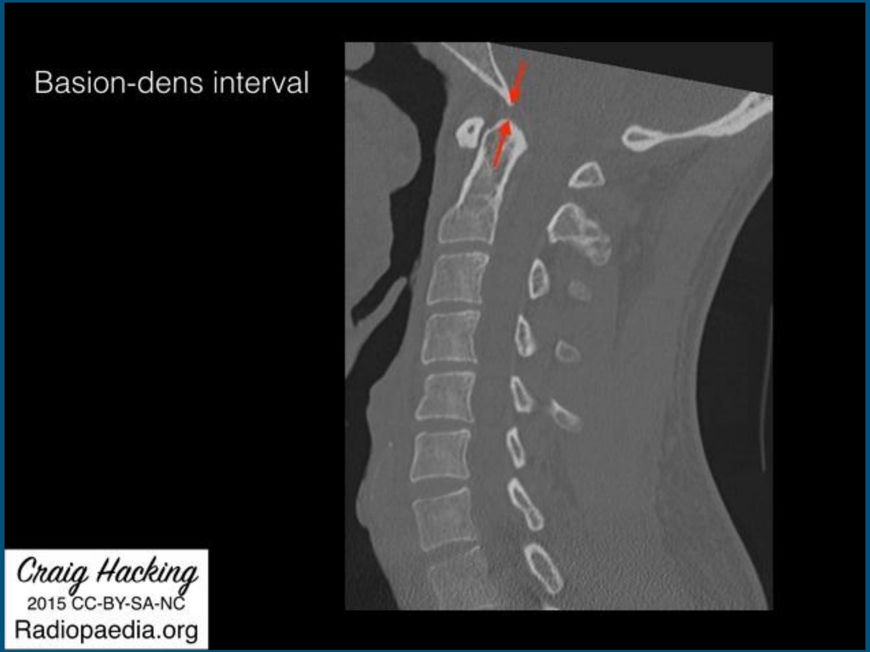
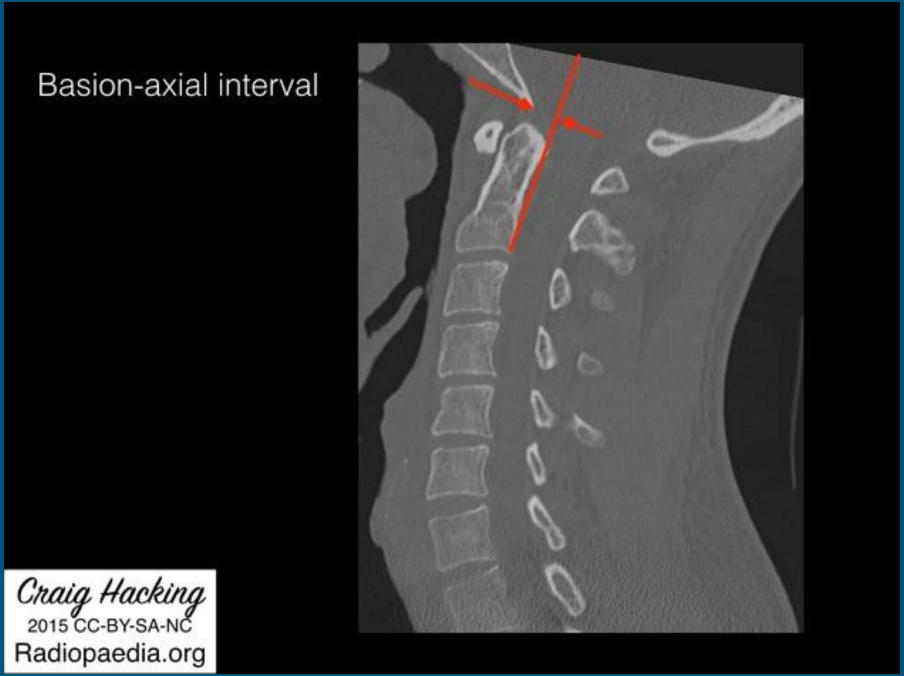
Important Measurements - Basion-dens int.

Normal is less than 8.5-9.5 mm on CT, 12 mm on XR



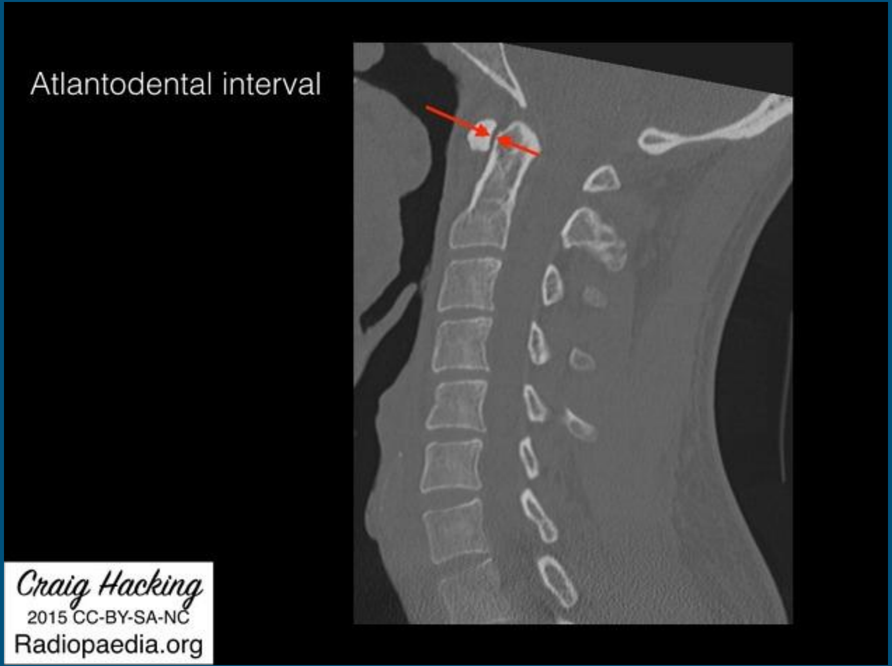
Important Measurements - Basion-axial int.

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

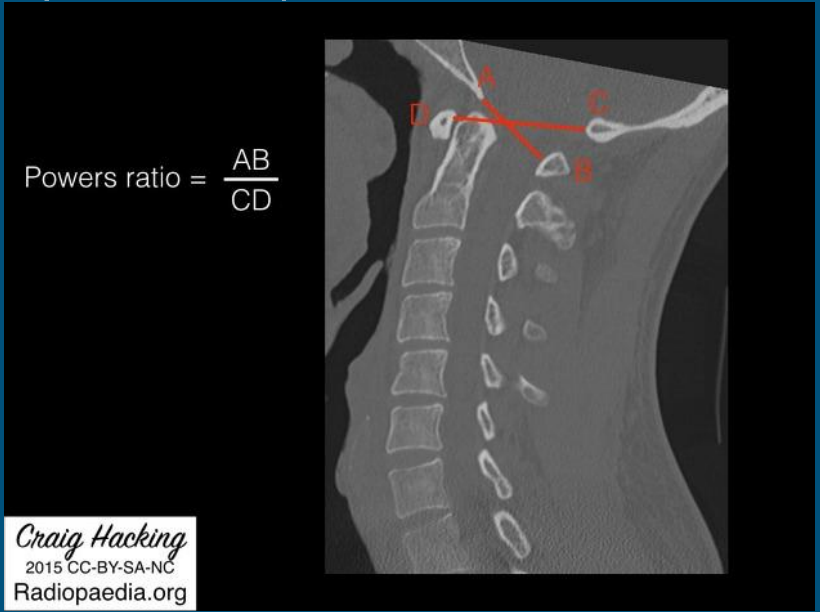


Important Measurements - Powers Ratio

Powers Ratio = __Distance from basion to anterior C1__

Distance from opisthion to posterior C1

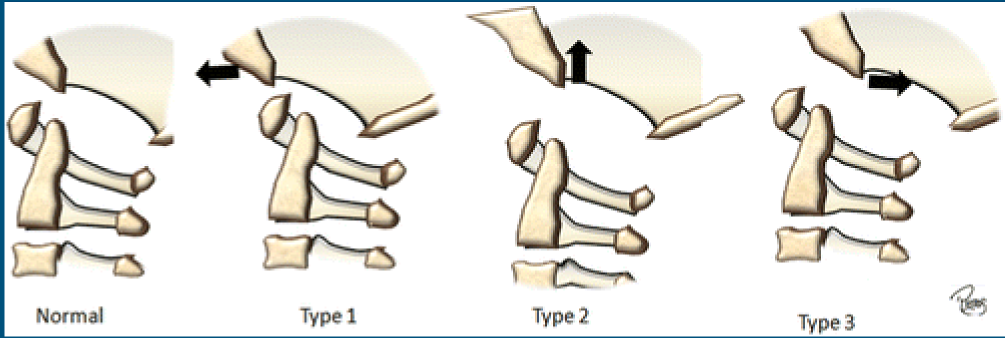
Less than 1.0 on CT



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)



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Atlanto-occipital dissociation

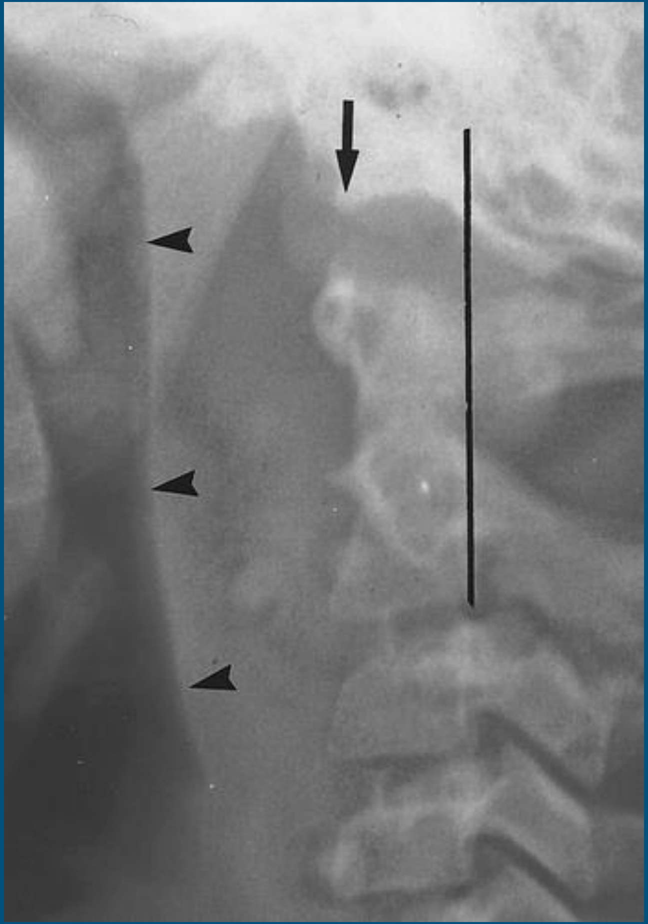
Associated with high impact trauma

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%)

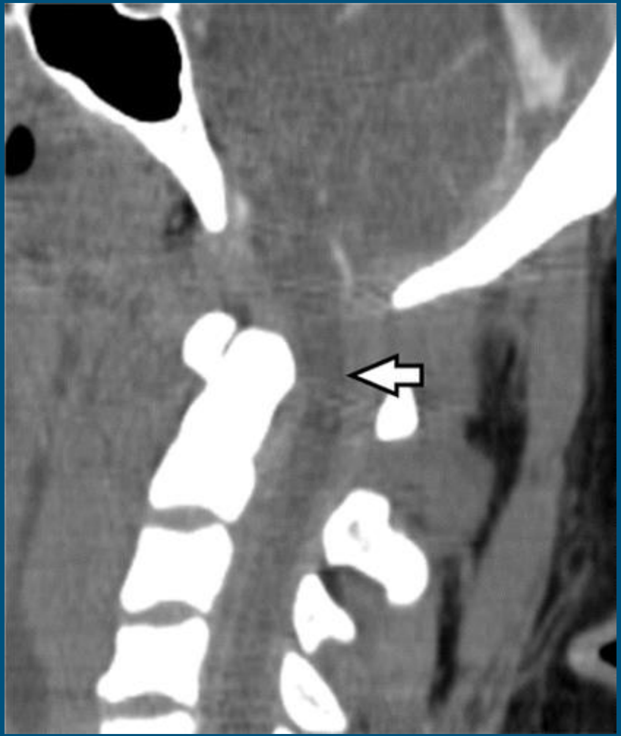
Early diagnosis is important to try and minimize residual neuro defects

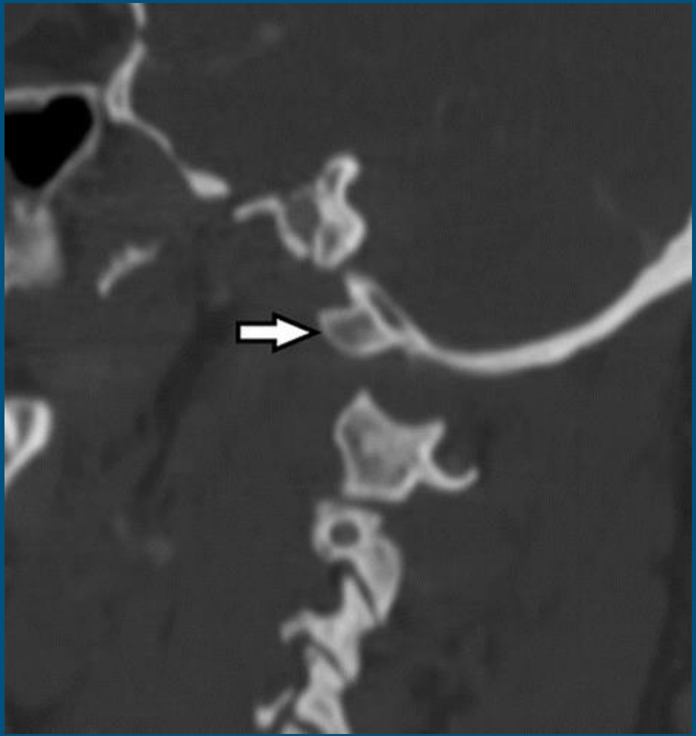
AOD Type 1



JH Harris. The Cervicocranium: Its Radiographic Assessment. Radiology 2001; 218: 337-351.

AOD Type 1





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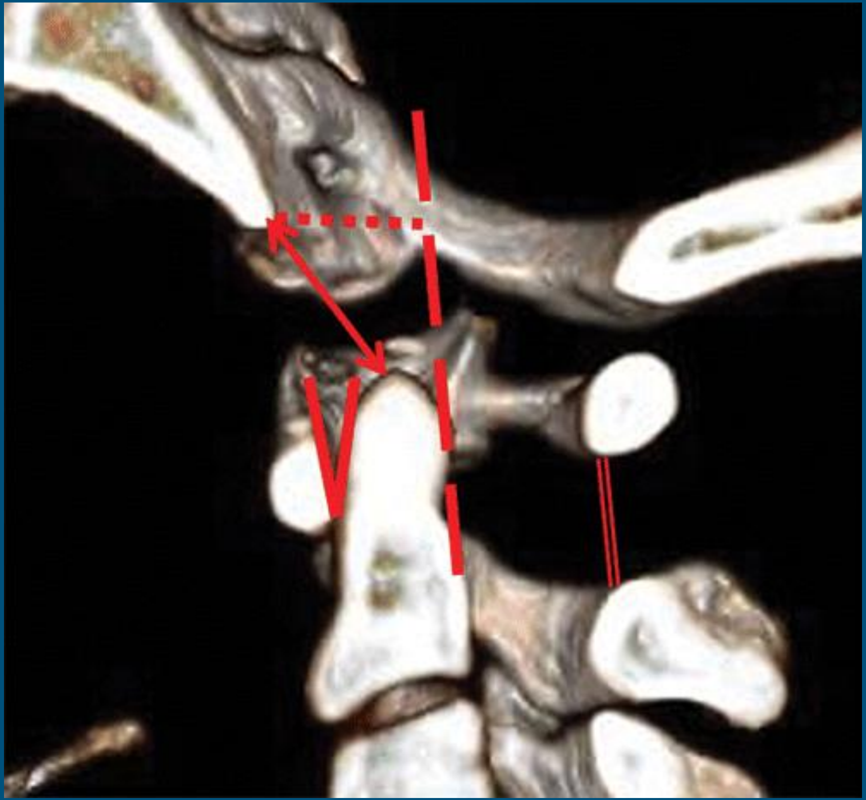
AOD Type 1

- V sign: suggests transverse ligament Injury
- V is associated with AOD and isolated C1-C2 distraction is rare



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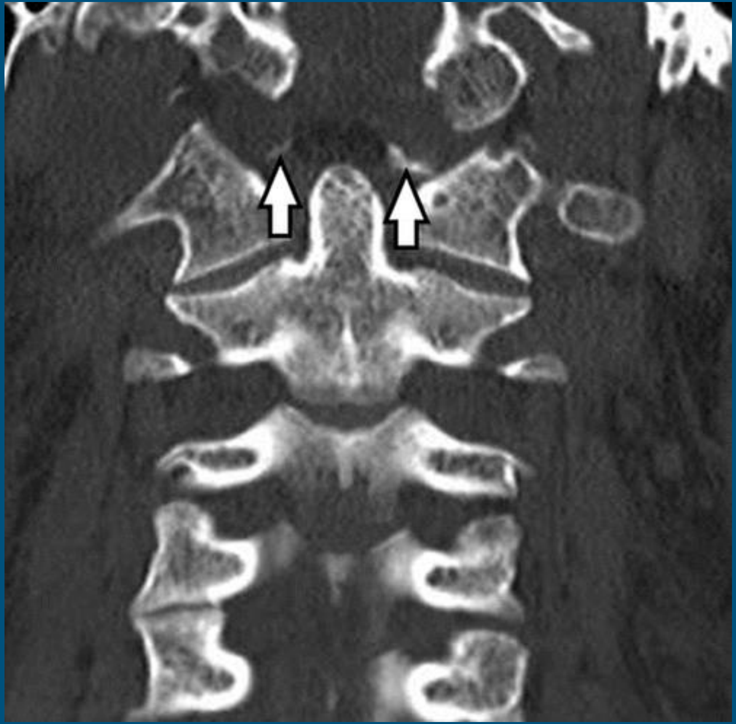
AOD Type 2



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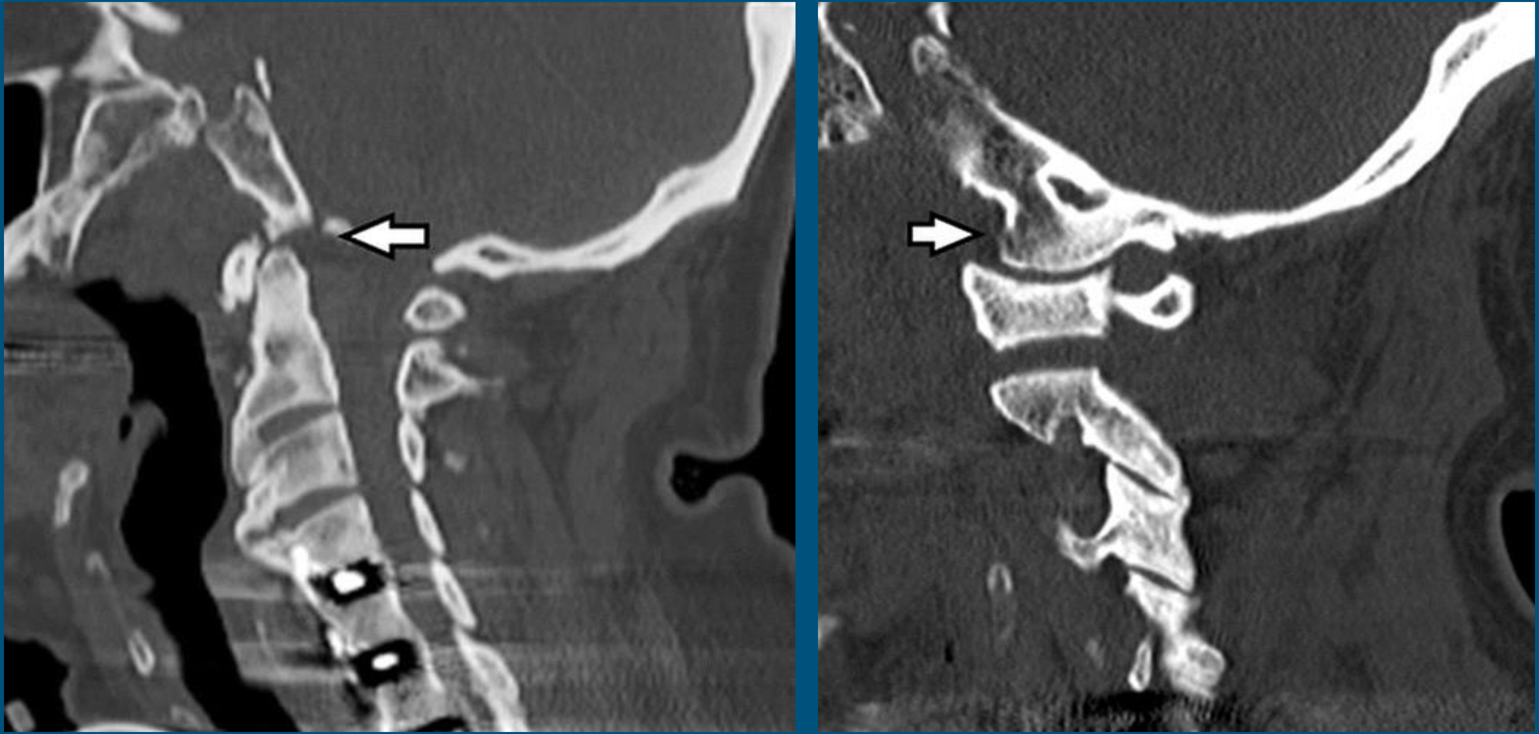
AOD Type 3



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

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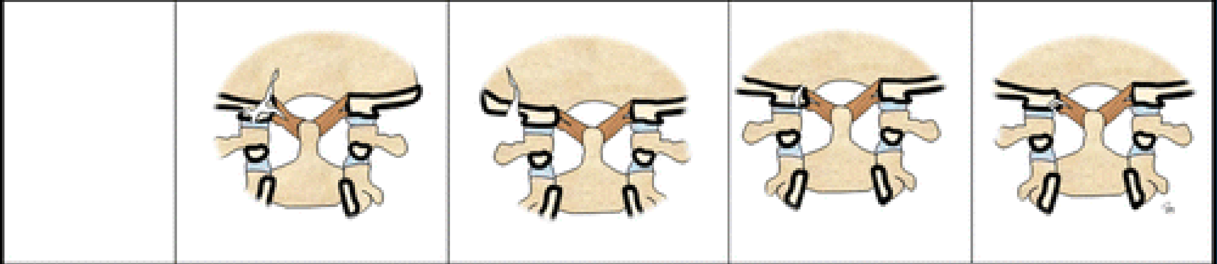
Occipital Condylar Fractures

Two classification schemes: Anderson/Montesano and Tuli



Anderson and Montesano	Type I	Type II	Type III	
Tuli	Type 1		Type 2A	Type 2B

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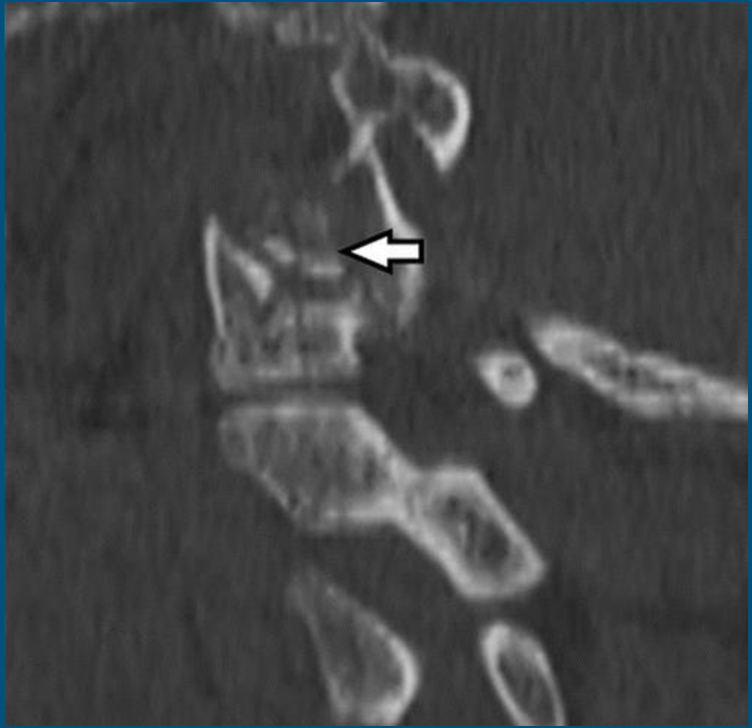
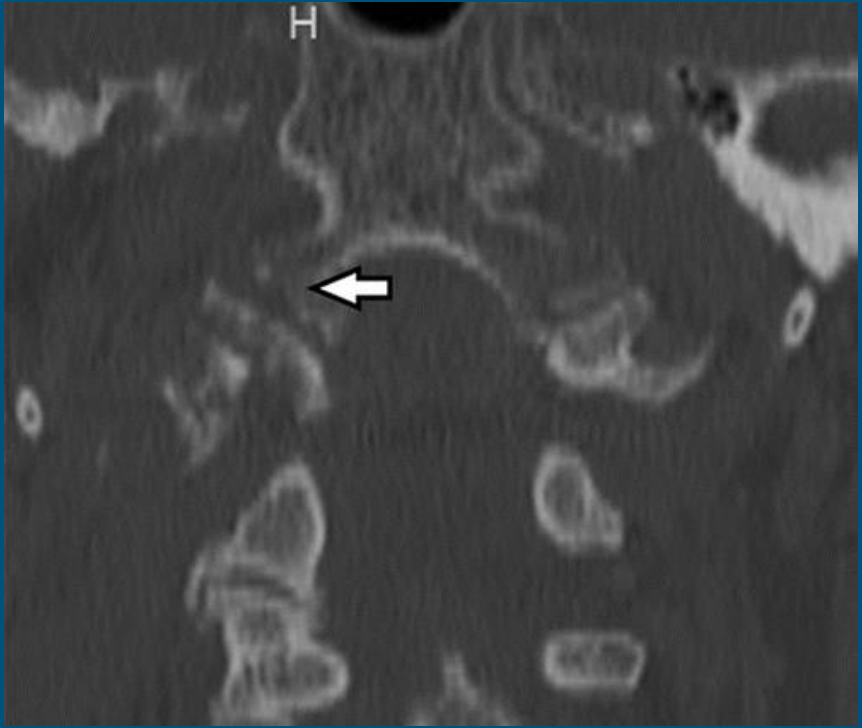
Anderson/Montesano Type I





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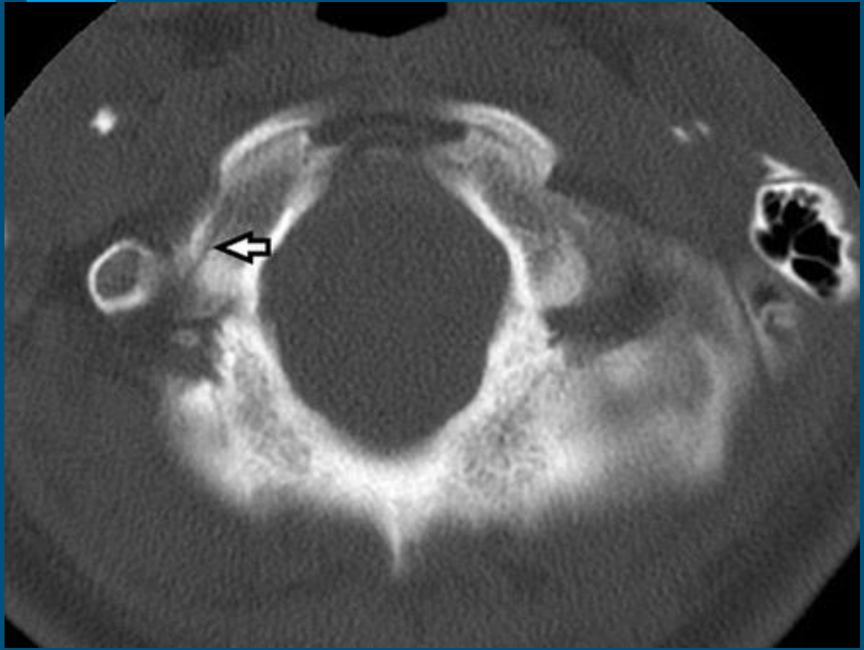
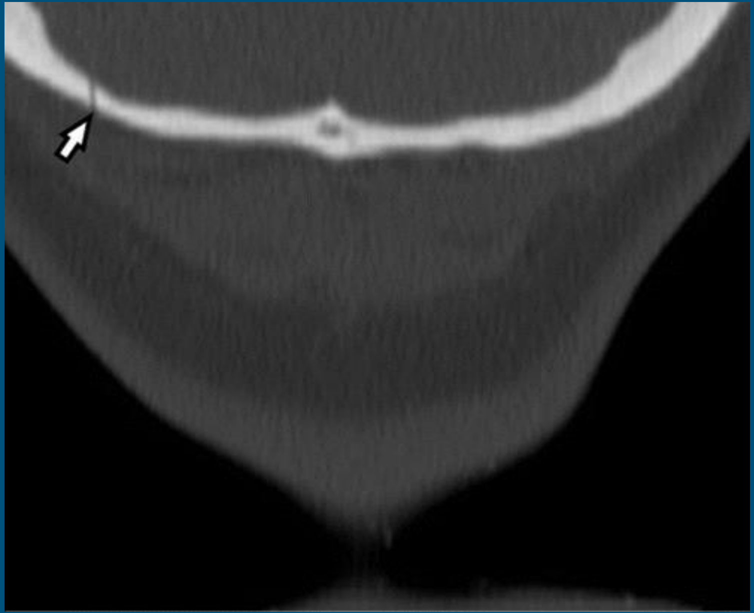
Anderson/Montesano Type II





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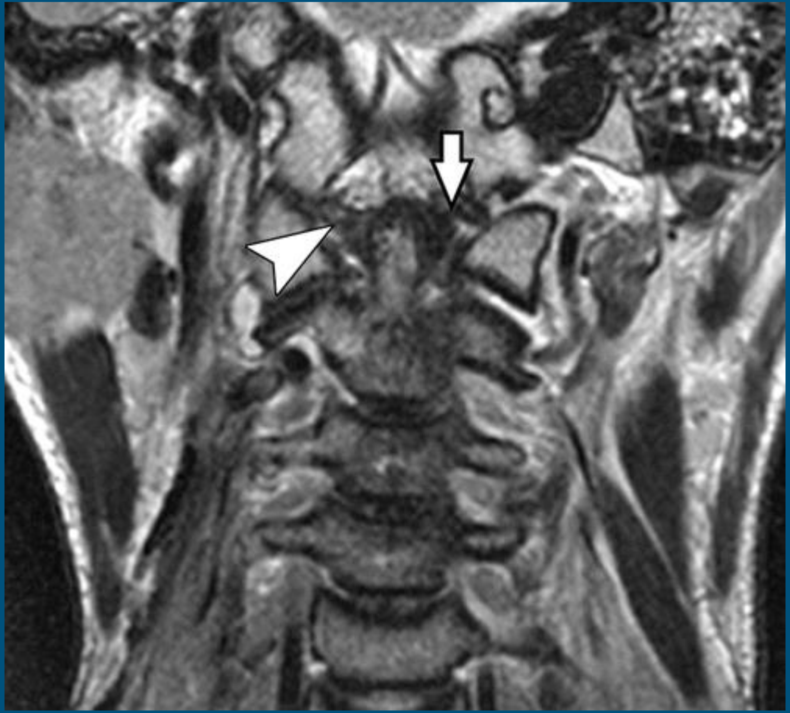
Anderson/Montesano Type III



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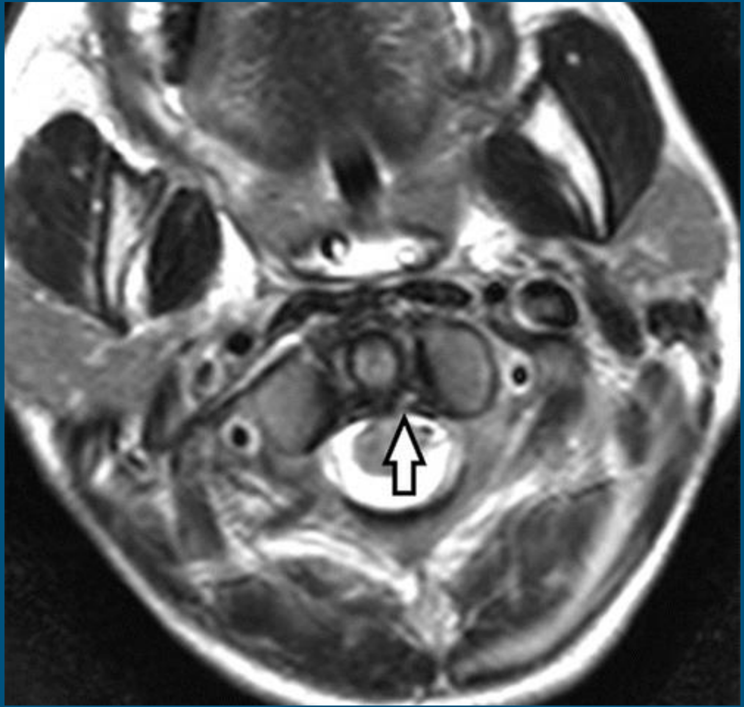
Anderson/Montesano Type III



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Fractures of the Atlas (C1)

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

44% of C1 fractures have associated C2 fractures

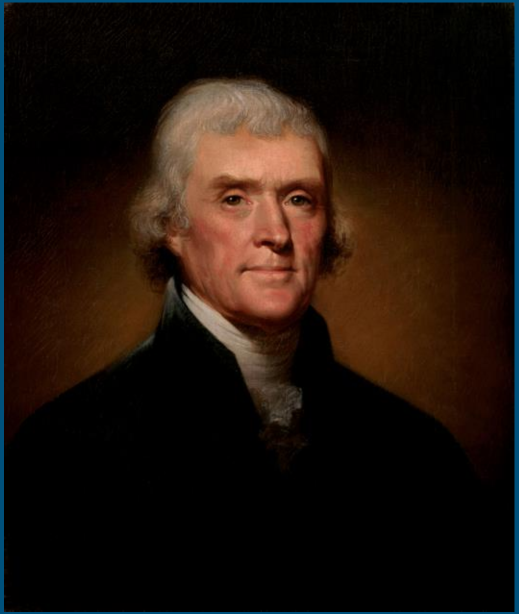
Anterior and posterior arches are the weakest points

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

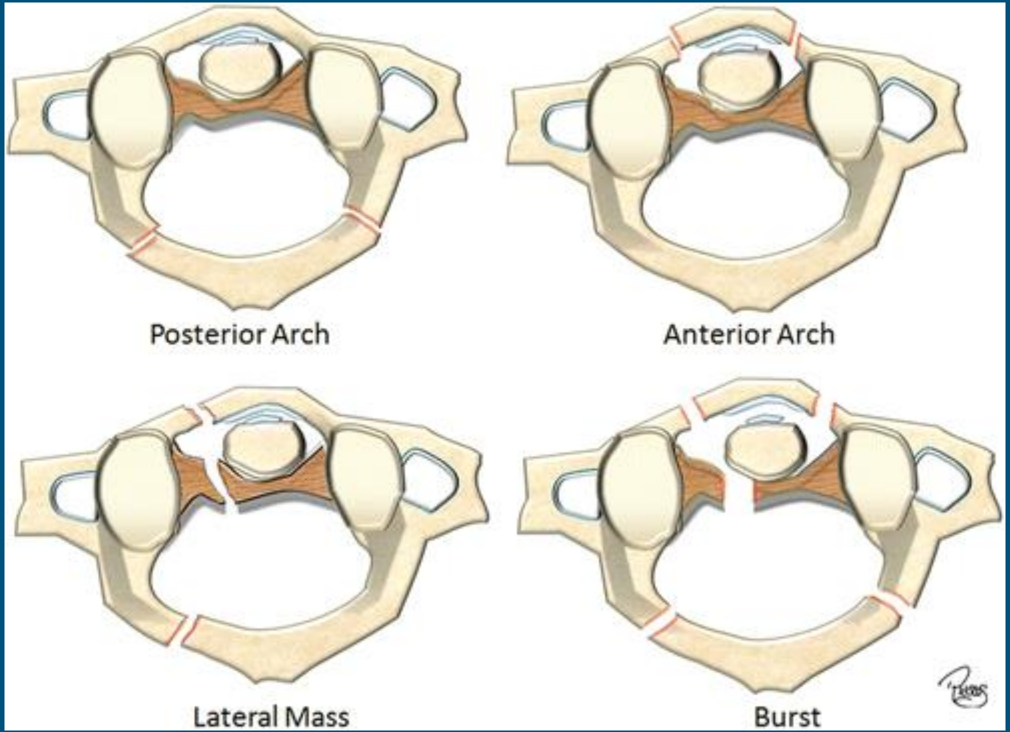
Type II and III most common

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

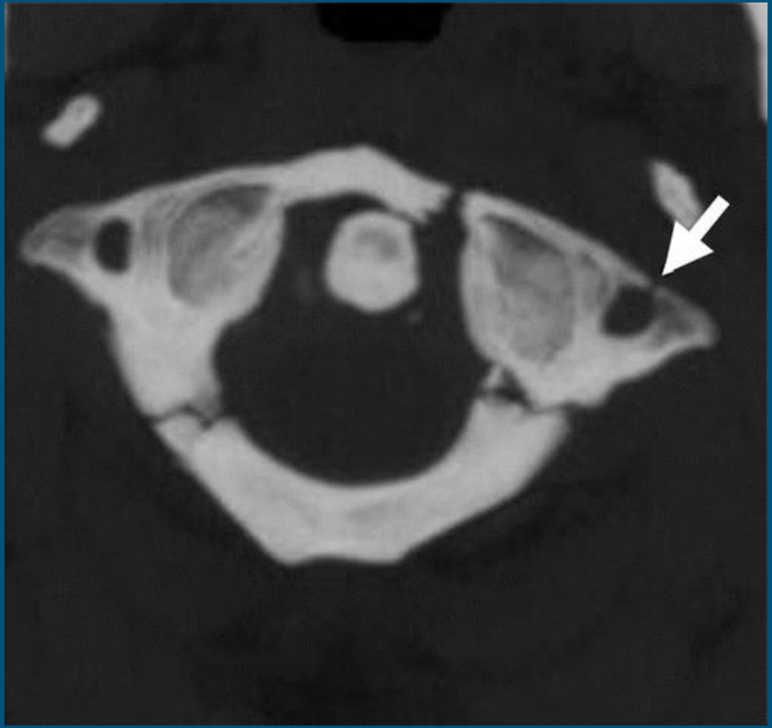
Dickman further classified transverse ligament injuries

- 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



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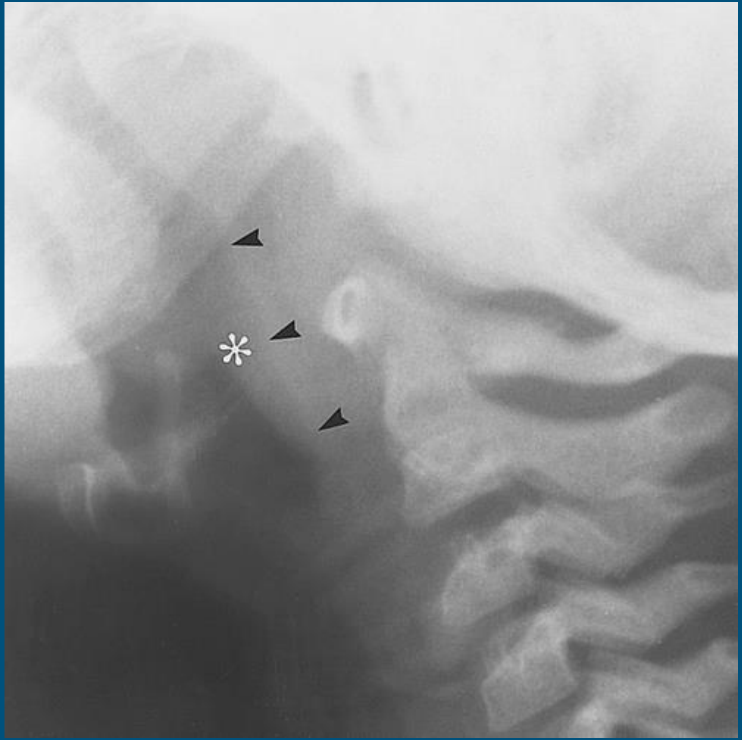
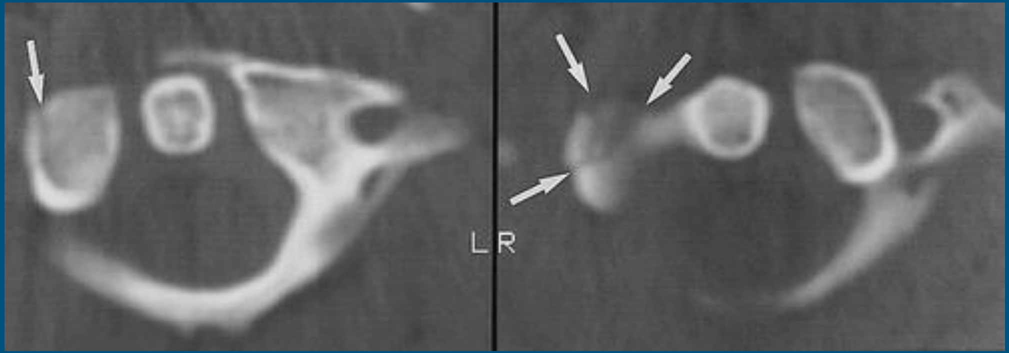
Atlas (C1) Fractures - Type IV





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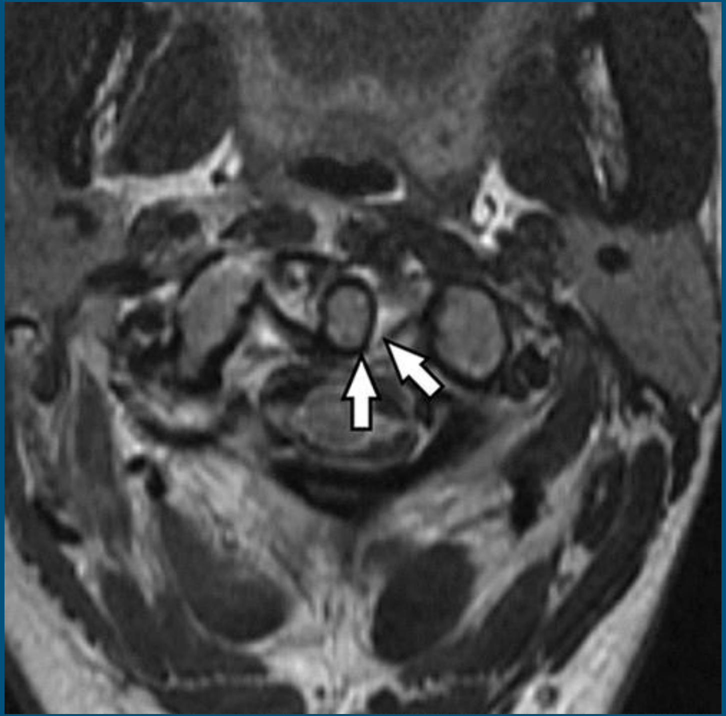
Atlas (C1) Fractures - Type III



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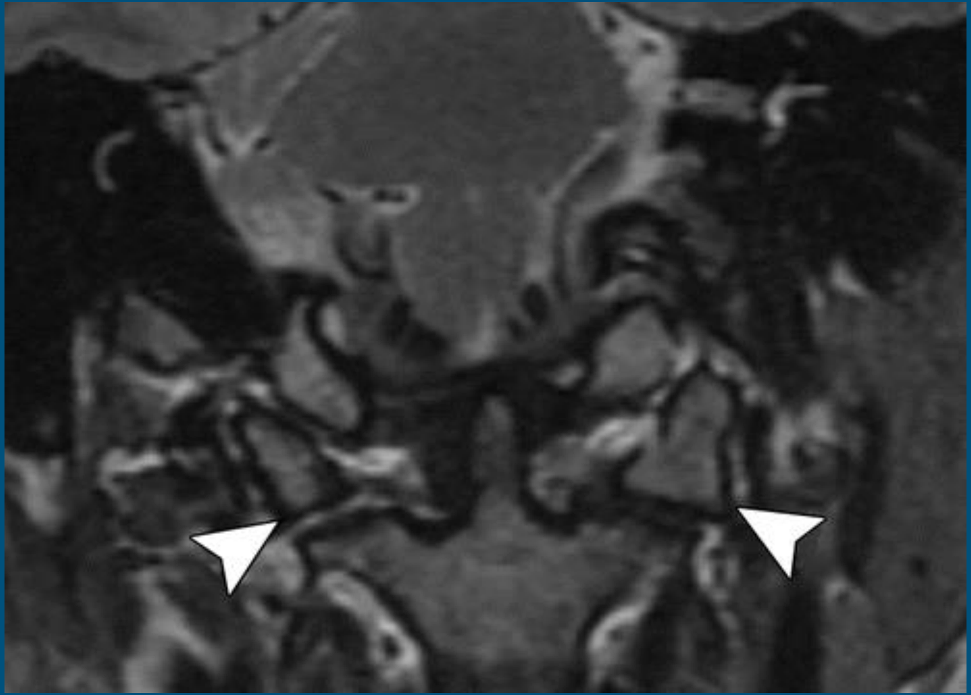
Atlas (C1) Fractures - Type III (same patient)



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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 cancelous part of C2 body (39-42% of dens fractures)

Dens Fracture - Type I

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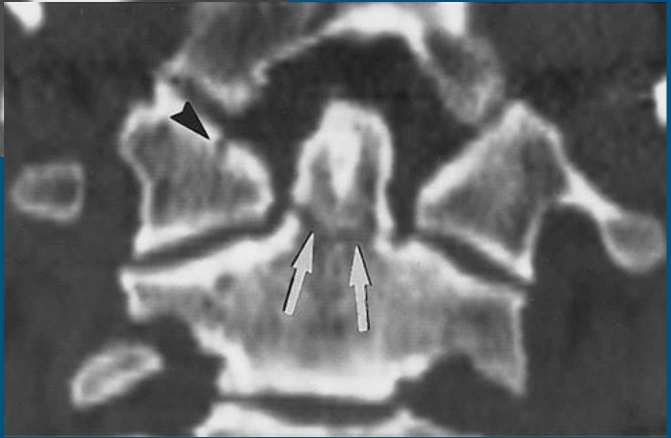
Dens Fracture - Type II



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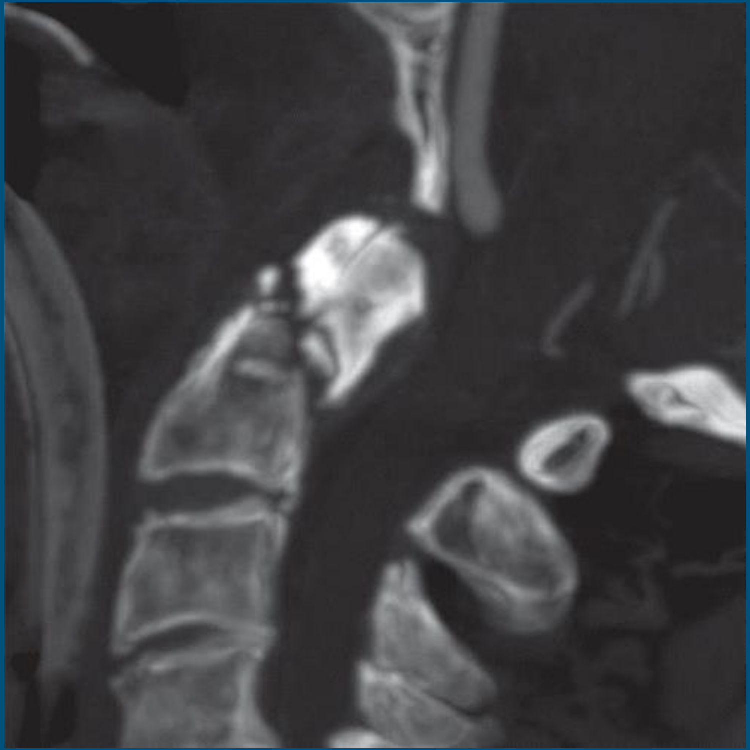
Dens Fracture - Type IIa



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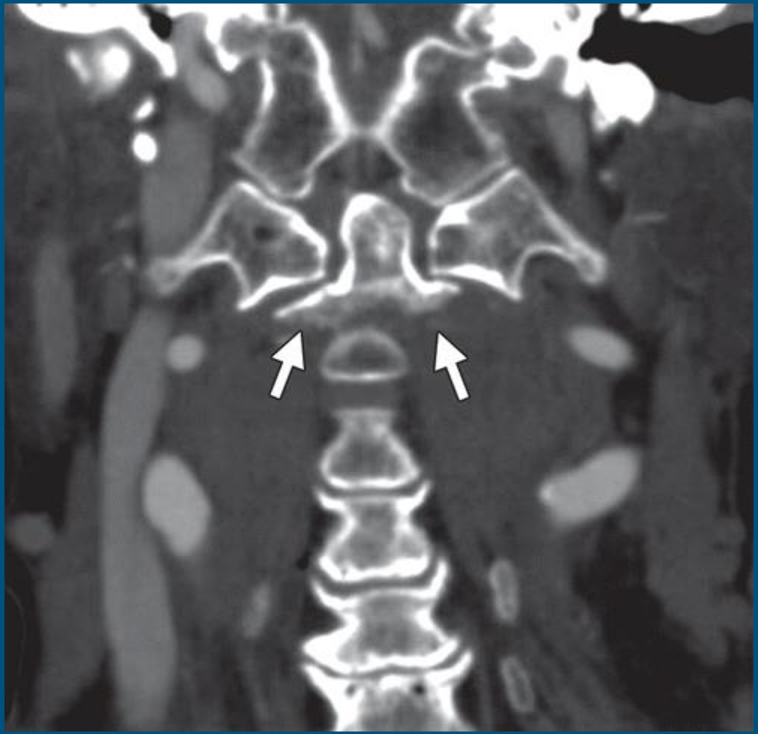
Dens Fracture - Type III



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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

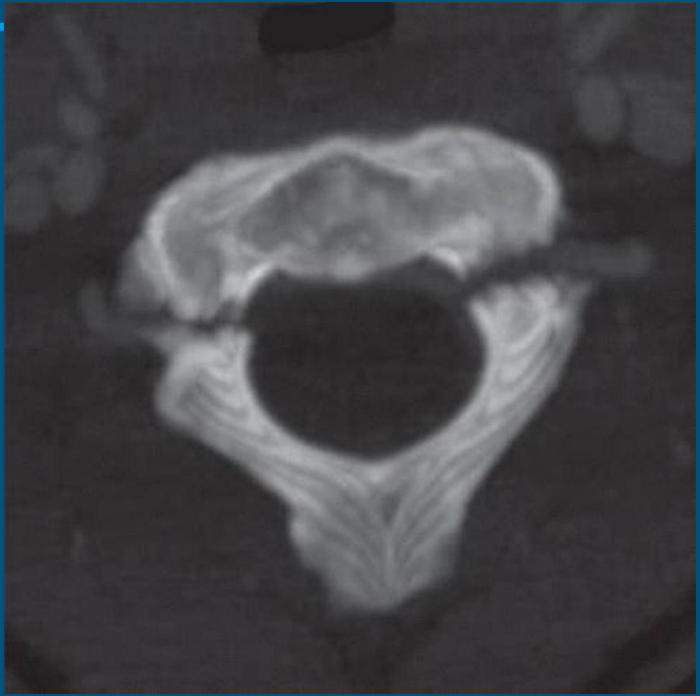
Type I: Minimally displaced, <2 mm

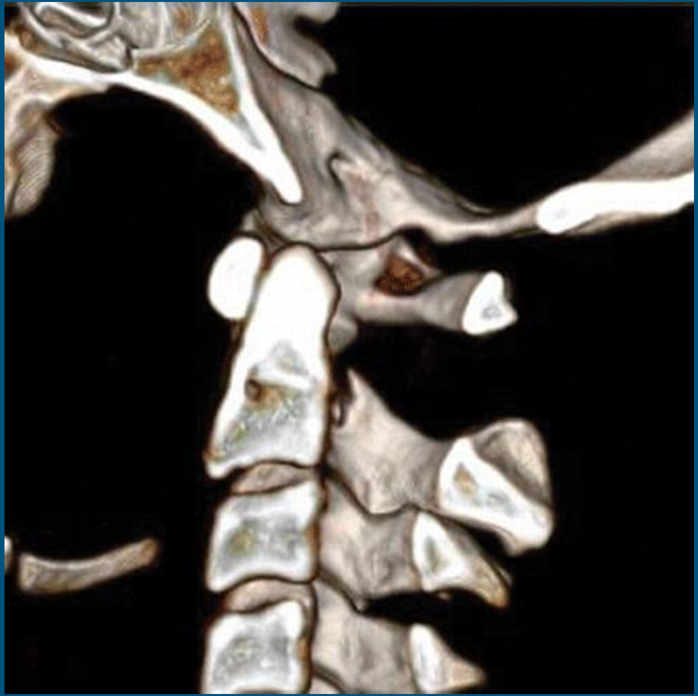
Type II: Anterior angulation >11°, >2 mm anterior translation

Type IIa: Severe angulation without translation

Type III: Bilateral facet fracture-dislocation

Hangman Fracture - Type I



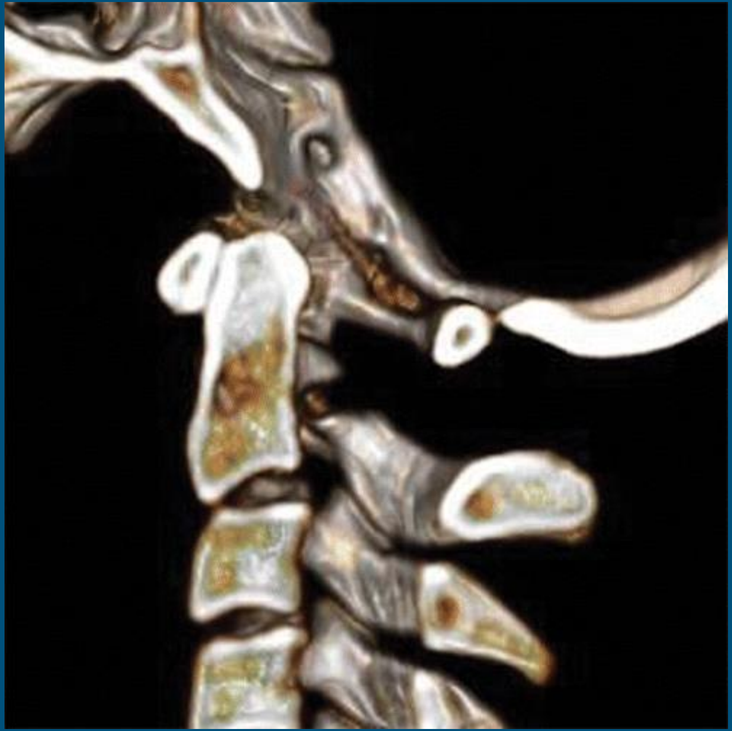


Dreizin, et al. Multidetector CT of Blunt Cervical Spine Trauma in Adults. Radiographics 2014, 34: 1842-1865.

Hangman Fracture - Type II

Dreizin, et al. Multidetector CT of Blunt Cervical Spine Trauma in Adults. Radiographics 2014, 34: 1842-1865.

Hangman Fracture - Type IIa



Dreizin, et al. Multidetector CT of Blunt Cervical Spine Trauma in Adults. Radiographics 2014, 34: 1842-1865.

Hangman Fracture - Type III

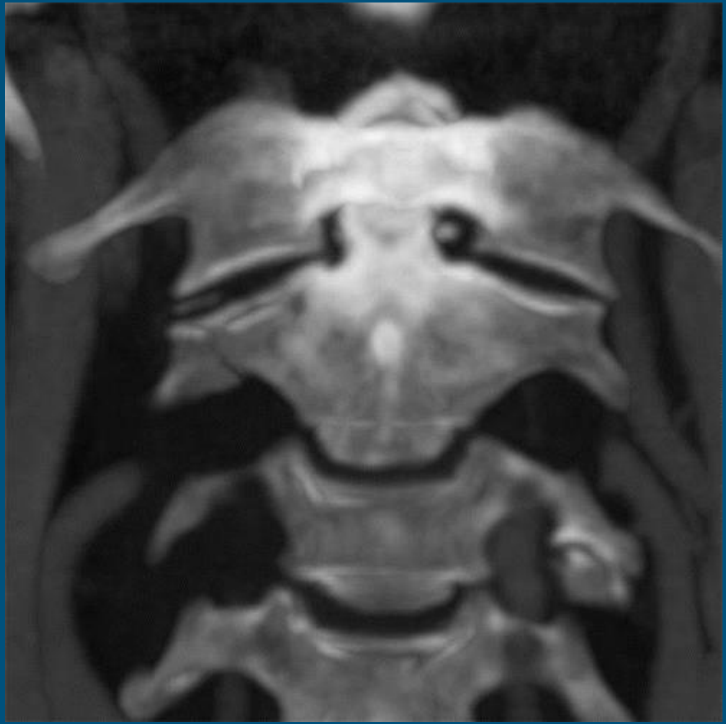
Dreizin, et al. Multidetector CT of Blunt Cervical Spine Trauma in Adults. Radiographics 2014, 34: 1842-1865.

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



Dreizin, et al. Multidetector CT of Blunt Cervical Spine Trauma in Adults. Radiographics 2014, 34: 1842-1865.

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 w/ 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.

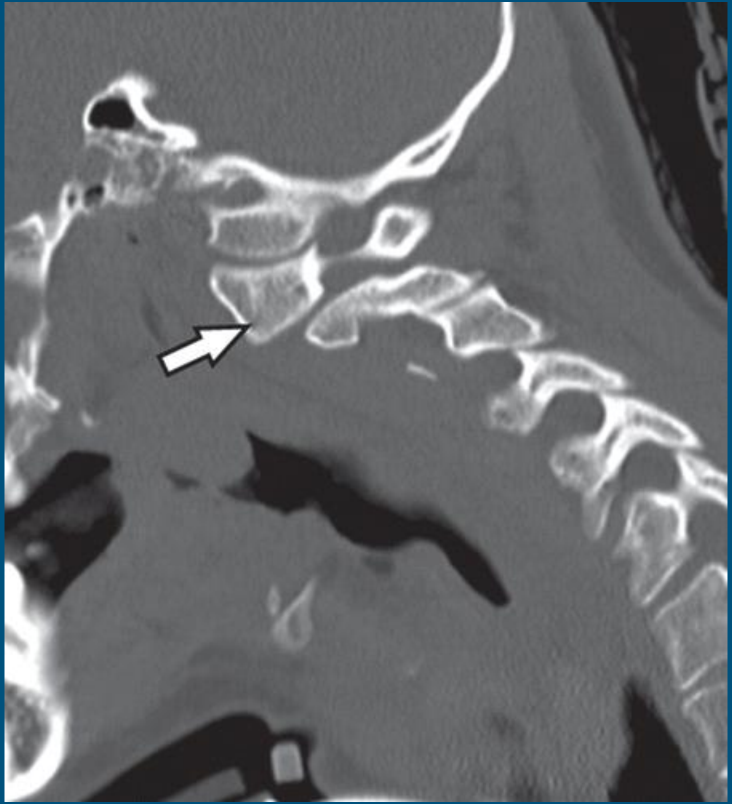
III: Anterior displacement of C1 > 5 mm

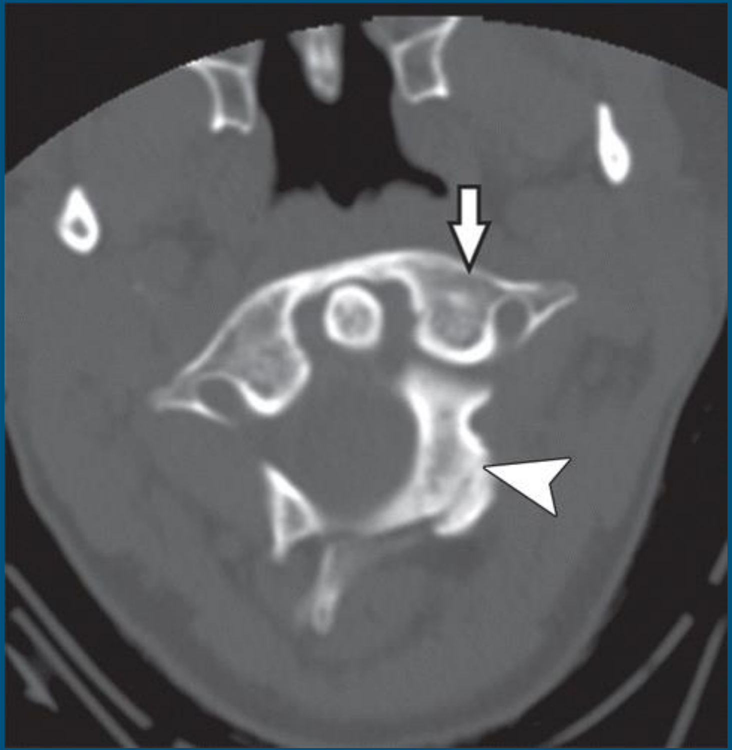
Transverse and alar ligaments injured

IV: Posterior displacement of C1

Deficient odontoid

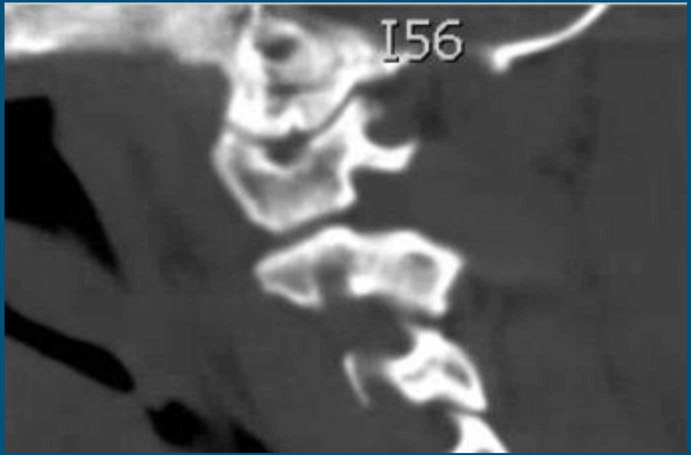
AARF





R Riascos, et al. Imaging of the Atlanto-Occipital and Atlantoaxial Traumatic Injuries: What the Radiologist Needs to Know. Radiographics 2015, 35, 2121-2134

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

BI Causes - PF ROACH

Table 1

Most common causes of primary and secondary basilar invagination

Basilar invagination	Basilar impression
Chiari malformation	Paget disease
Basioccipital hypoplasia	Osteomalacia
Atlas hypoplasia	Severe osteoporosis
Occipital condyle hypoplasia	Osteogenesis imperfecta
Achondroplasia	Rickets
Incomplete ring of C1	Hyperparathyroidism
Atlanto-occipital assimilation	Renal osteodystrophy
Fused upper vertebrae	Skull base infection
	Hurler syndrome

Lines in evaluating (BI)

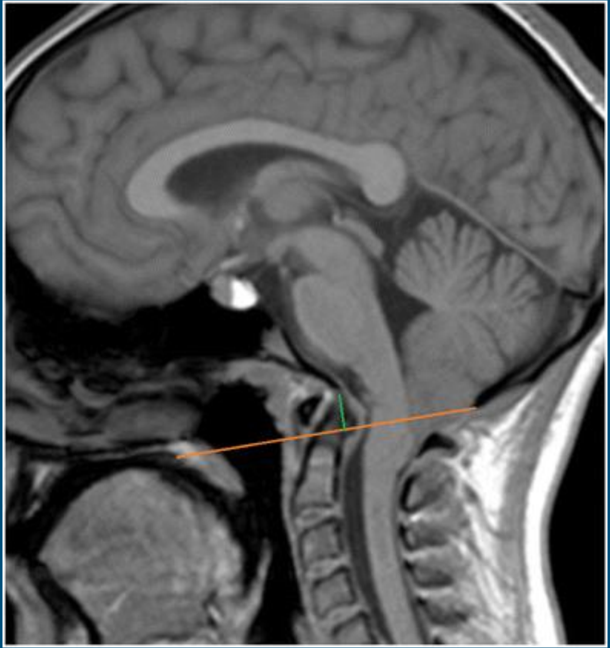
Chamberlain (orange)

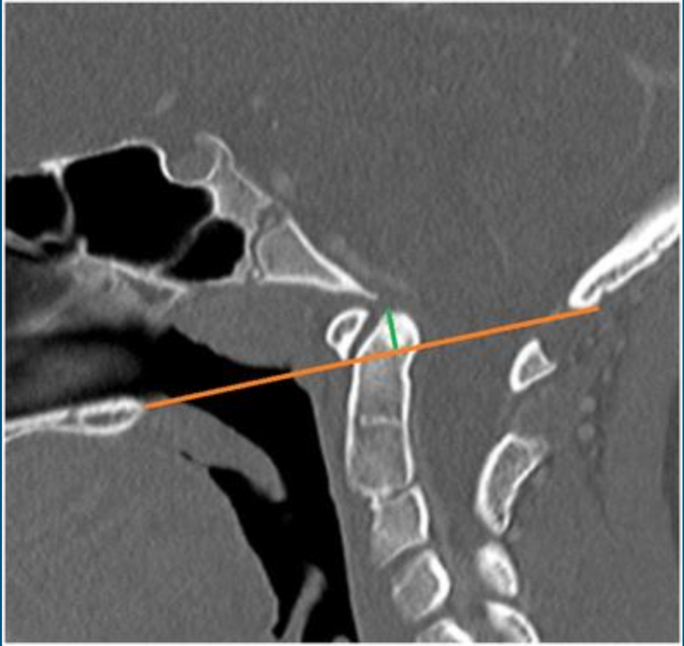
McGregor (green)

Welcher basal angle (yellow)

Pinter, N.K., McVige, J. & Mechtler, L. Basilar Invagination, Basilar Impression, and Platybasia: Clinical and Imaging Aspects. Curr Pain Headache Rep (2016) 20: 49.

BI





Pinter, N.K., McVige, J. & Mechtler, L. Basilar Invagination, Basilar Impression, and Platybasia: Clinical and Imaging Aspects. Curr Pain Headache Rep (2016) 20: 49.

BI

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

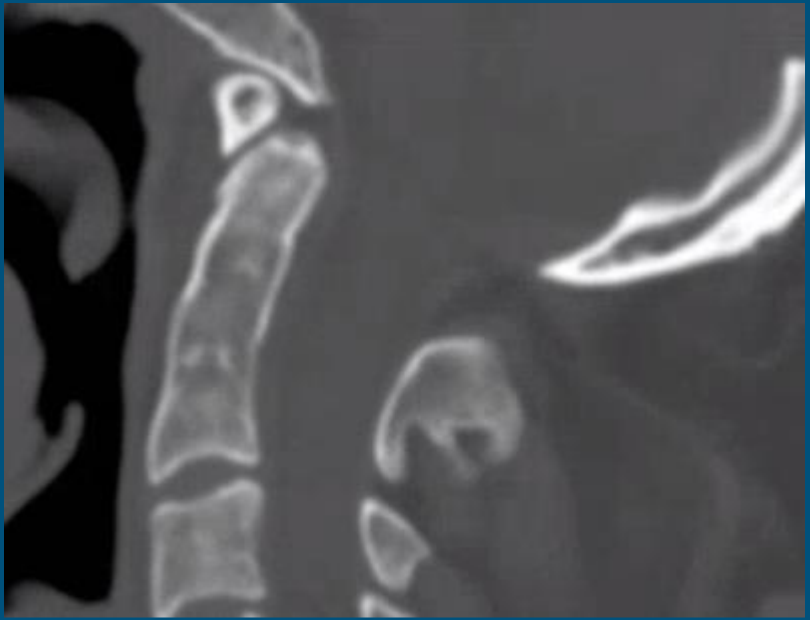
Cervical fusion reserved for:

- Cervical myelopathy
- Instability in flexion and extension
- Intractable pain

KA Robson. Os Odontoideum: Rare Cervical Lesion. West J Emer Med 2011. 2011 Nov; 12(4): 520–522.

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%)

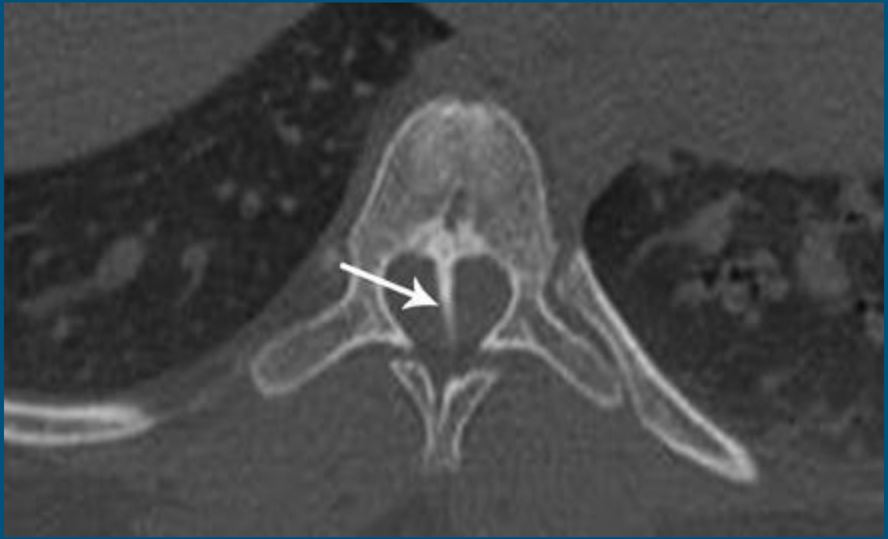
Associated with tethered cord/myelomeningocele in infants

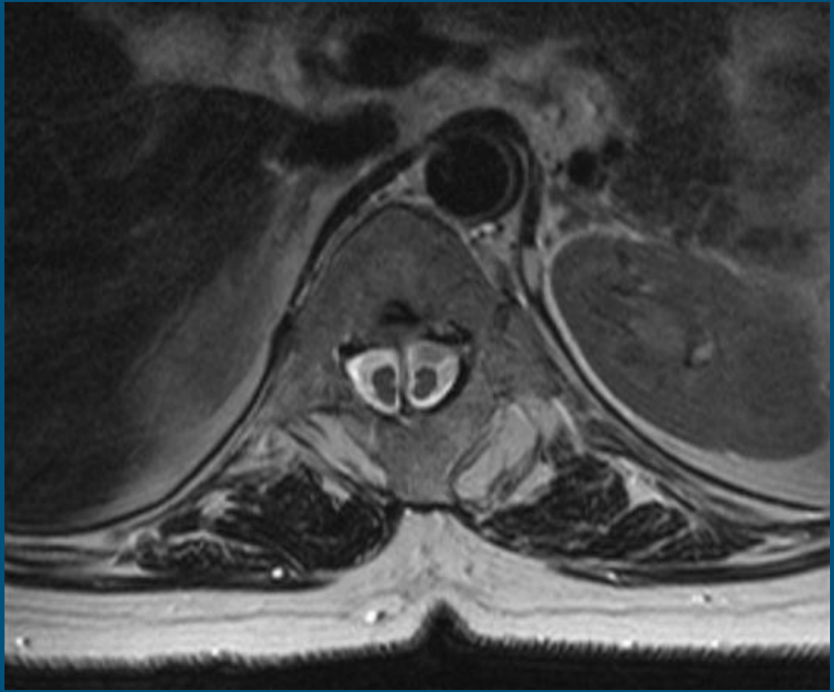
Older children present with scoliosis or leg weakness

Adults usually present with gradual onset of myelopathy

Treatment is surgical resection of spur

Diastematomyelia





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

Achondroplasia

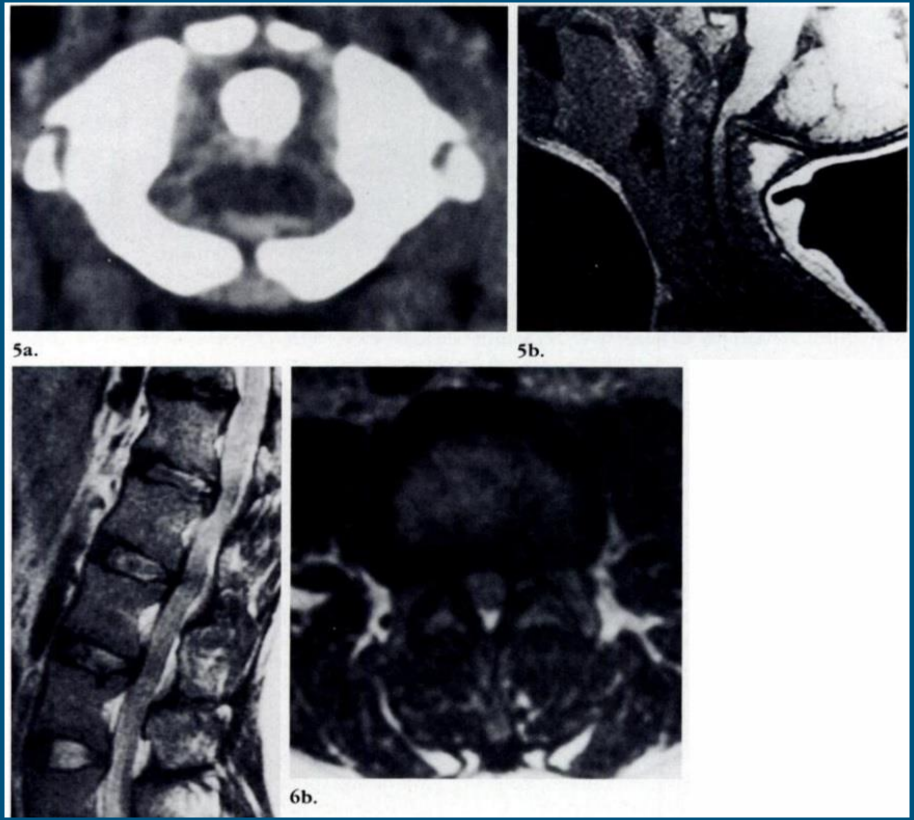
Autosomal dominant form of dwarfism

Short limbs, thoracolumbar kyphosis in infancy, and lordosis in older patients

Foreshortening of the skull base

Shortened pedicles

Posterior body concavity



TL Munday, et al. Musculoskeletal Causes of Spinal Axis Compromise: Beyond the Usual Suspects. Radiographics 1994; 14: 1225-1245.

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 ⅔ 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

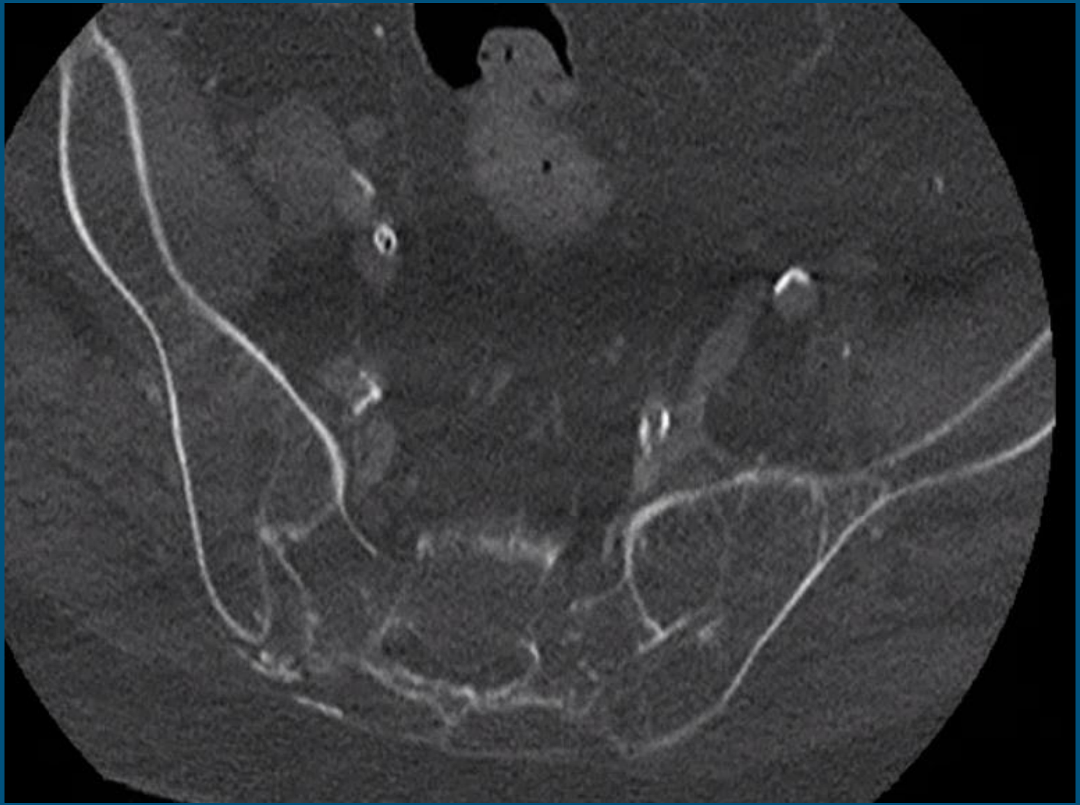
Ankylosing spondylitis

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

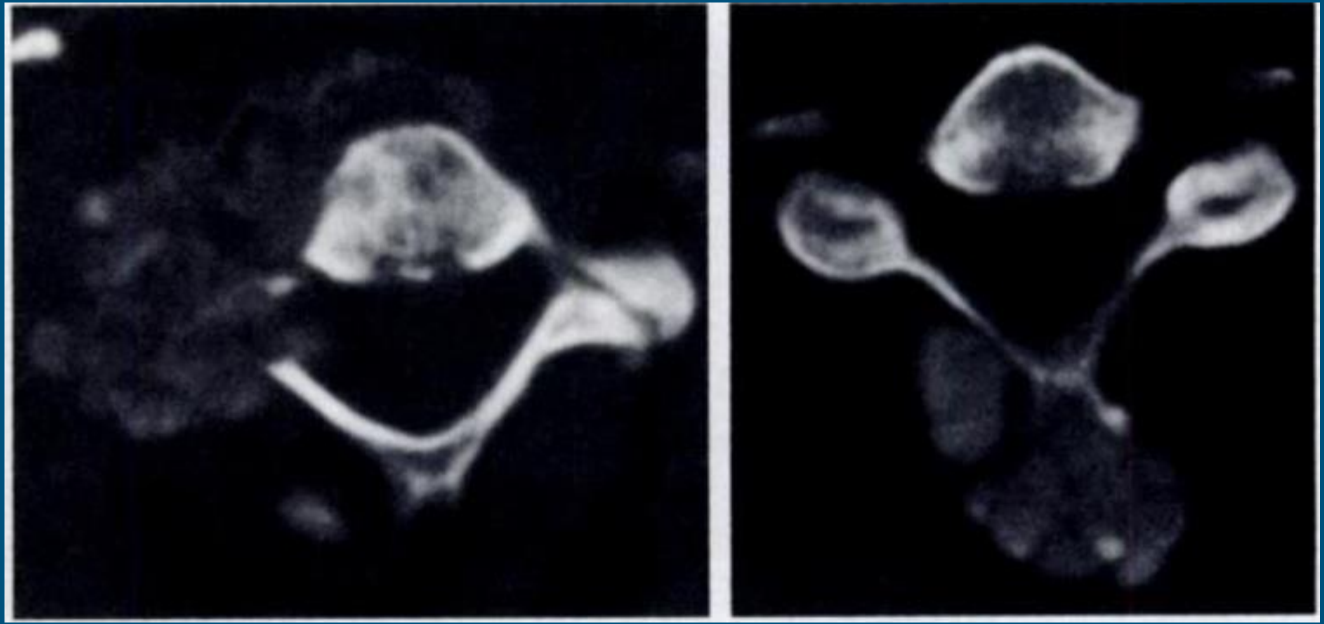
Deposits are made on PLL, ISL, and ligamentum flavum

Deposits can also be in disc space, which accelerate DDD

Deposition Diseases - CPPD

EY Chang, et al. Frequency of Atlantoaxial Calcium Pyrophosphate Dihydrate Deposition at CT. Radiology 2013; 269: 519-524.

HADD



TL Munday, et al. Musculoskeletal Causes of Spinal Axis Compromise: Beyond the Usual Suspects. Radiographics 1994; 14: 1225-1245.

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

1. R Riascos, et al. Imaging of the Atlanto-Occipital and Atlantoaxial Traumatic Injuries: What the Radiologist Needs to Know. Radiographics 2015; 35, 2121-2134

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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

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    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

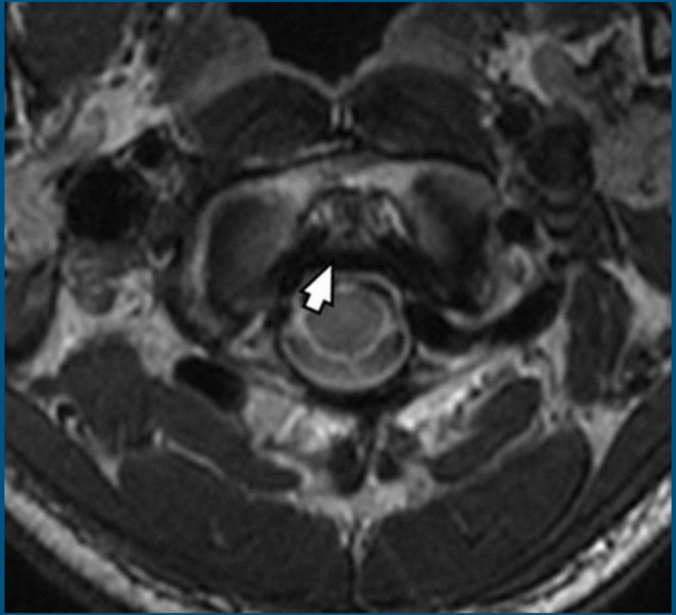
1) Which ligament is labeled?

    a) Alar

    b) Apical

    c) Transverse

    d) Nuchal



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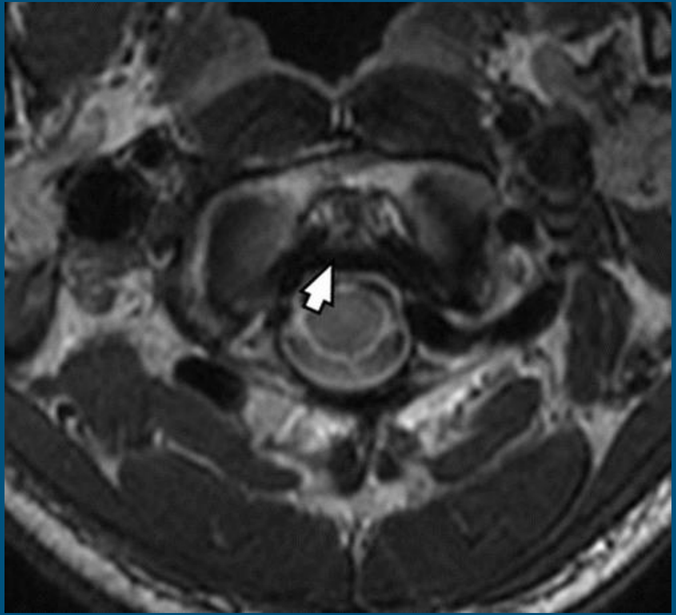
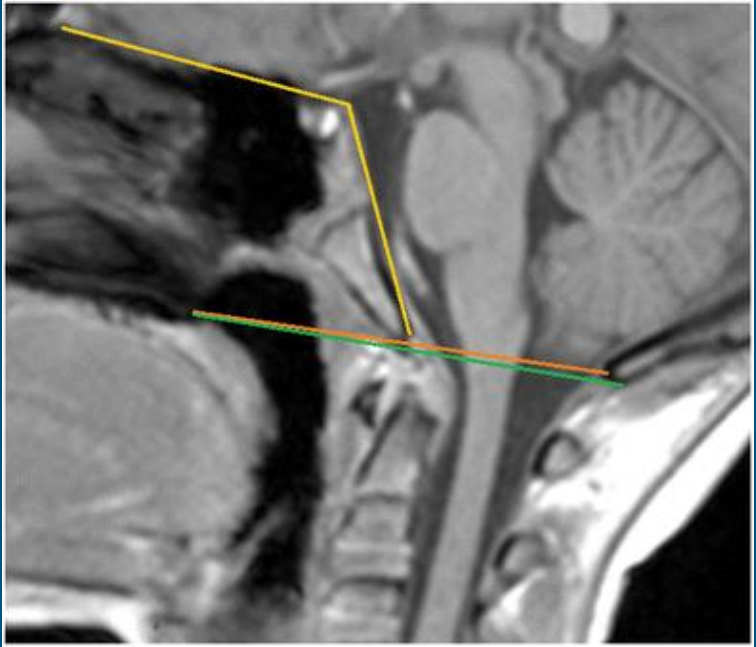


Question 3

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

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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 4

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

    a) Hyperflexion

    b) <u>Hyperextension</u>

    c) Axial loading (Burst)

    d) Forced atlantoaxial rotation

Question 5

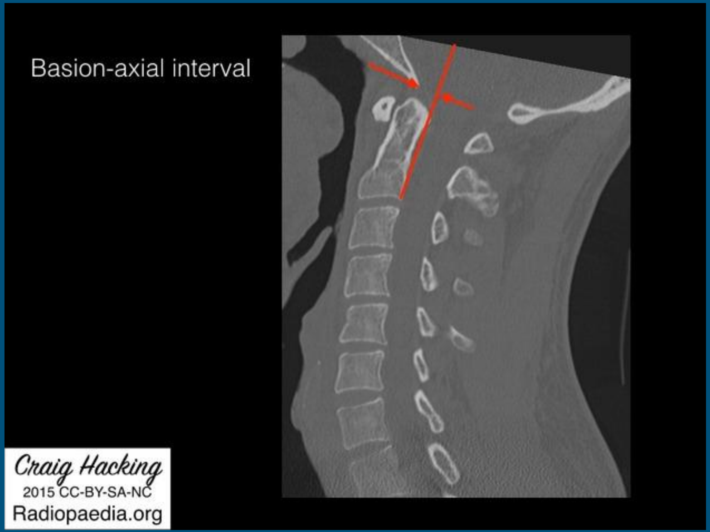
1. What is the upper limit of normal for the Basion-axial interval (on CT)?

    a. 4 mm

    b. 6 mm

    c. 8 mm

    d. 10 mm



Question 5

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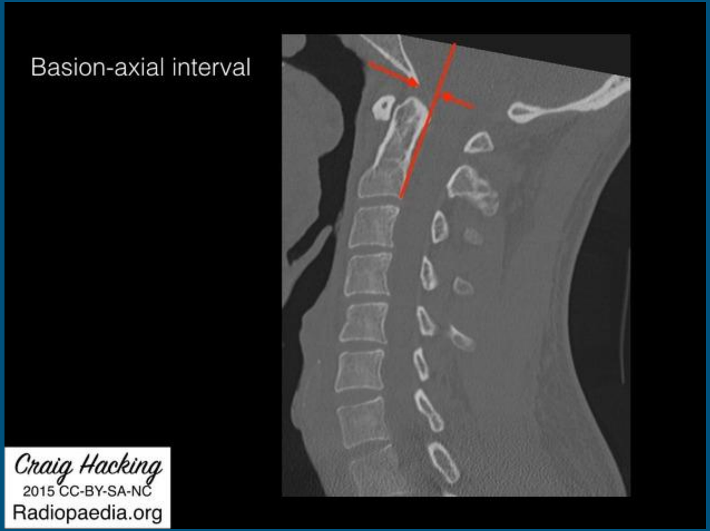
    d. <u>10 mm</u>



Fin.