Imaging in Spine Surgery

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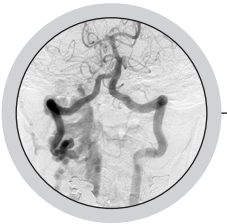

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Dedications

Wise words bring many benefits,
And hard work brings rewards.
~ Proverbs 12:14

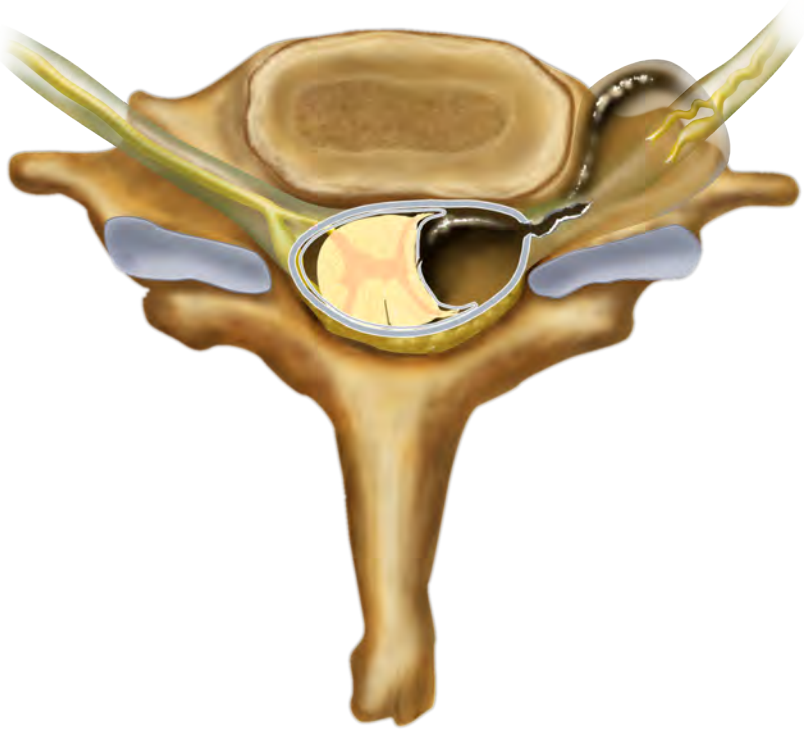
JR

To my parents, wife, and children.

BB

To my family.

JM



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Preface

The spine is complicated, the variety of pathologies legion, and you are busy. Where can you go for up-to-date, easily accessible information regarding spine imaging? Look no further!

This book's purpose is to provide key imaging findings for the most common and important spine surgical disorders in an easy-to-understand format, using typical imaging examples, pathologic examples when appropriate, and spectacular illustrations that demonstrate key findings.

This book covers a wide variety of pathologic conditions with sections on congenital and genetic disorders, disorders of alignment, trauma, degenerative arthritides, infection and inflammation, neoplasms, vascular disorders, and peripheral nerve and plexus diseases. There are overview chapters to problematic subjects like scoliosis, fracture classifications, degenerative disc disease nomenclature, surgical complications, and instrumentation. There are anatomic overviews of the cervical, thoracic, lumbar, and sacral spine as well as craniovertebral junction, vascular anatomy, and brachial and lumbar plexus. The wide variety of common image-guided procedures are also covered, including epidural, nerve root, and facet injections, as well as more complicated procedures such as kyphoplasty/vertebroplasty and percutaneous discectomy.

Each chapter is written to point out the main imaging findings for each disorder or anatomic area. Then, the key clinical features are addressed. The organization of each chapter makes it easy for a surgeon to quickly know the key terminology, imaging findings, pathologic underpinnings, and important clinical details. The images were specifically chosen to be classic examples with the liberal use of arrows describing the key findings.

We see this book being of value to every practicing surgeon or physician who sees patients with spine pathology. Additionally, we see residents using this book to study for board and in-service examinations.

We hope you find this resource of value in providing ongoing care to your patients.

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Sections

Imaging Anatomy

There are **33** spinal vertebrae, which are composed of 2 components: A cylindrical ventral bone mass, which is the vertebral **body**, and the dorsal **arch**.

7 cervical, 12 thoracic, 5 lumbar bodies

- 5 fused elements form sacrum
- 4-5 irregular ossicles form coccyx

Arch

- 2 pedicles, 2 laminae, 7 processes (1 spinous, 4 articular, 2 transverse)
- Pedicles attach to dorsolateral aspect of body
- Pedicles unite with pair of arched flat laminae
- Lamina capped by dorsal projection called spinous process
- Transverse processes arise from sides of arches
- 2 articular processes (zygapophyses) are diarthrodial joints: Superior process bearing facet with surface directed dorsally and inferior process bearing facet with surface directed ventrally

Pars interarticulars is the part of the arch that lies between the superior and inferior articular facets of all subatlantal movable elements. The pars are positioned to receive biomechanical stresses of translational forces displacing superior facets ventrally, while inferior facets remain attached to dorsal arch (spondylolysis). C2 exhibits a unique anterior relation between the superior facet and the posteriorly placed inferior facet. This relationship leads to an elongated C2 pars interarticularis, which is the site of the hangman fracture.

Cervical

- Cervical bodies are small and thin relative to size of arch and foramen with transverse > AP diameter; lateral edges of superior surface of body are turned upward into uncinate processes; transverse foramen perforates transverse processes
- C1 has no body and forms circular bony mass; superior facets of C1 are large ovals that face upward, and inferior facets are circular in shape; large transverse processes are present on C1 with fused anterior and posterior tubercles
- C2 complex consists of axis body with dens/odontoid process; odontoid embryologically arises from centrum of 1st cervical vertebrae
- C7 shows transitional morphology with prominent spinous process

Thoracic

- Bodies are heart-shaped and increase in size from superior to inferior
- Facets are present for rib articulation, and laminae are broad and thick; spinous processes are long, directed obliquely caudally; superior facets are thin and directed posteriorly
- T1 shows complete facet for capitulum of 1st rib and inferior demifacet for capitulum of 2nd rib
- T12 resembles upper lumbar bodies with inferior facet directed more laterally

Lumbar

- Lumbar vertebral bodies are large, wide, and thick and lack transverse foramen or costal articular facets; pedicles are strong and directed posteriorly; superior articular processes are directed dorsomedially and almost face each other; inferior articular processes are directed anteriorly and laterally

Joints

- **Synarthrosis** is immovable joint of cartilage and occurs during development and in 1st decade of life; neurocentral joint occurs at union point of 2 centers of ossification for 2 halves of vertebral arch and centrum
- **Diarthrosis** is true synovial joint that occurs in articular processes, costovertebral joints, and atlantoaxial and sacroiliac articulations; pivot type joint occurs at median atlantoaxial articulation; all others are gliding joints
- **Amphiarthroses** are nonsynovial, movable connective tissue joints; **symphysis** is fibrocartilage fusion between 2 bones, as in intervertebral disc; **syndesmosis** is ligamentous connection common in spine, such as paired ligamenta flava, intertransverse ligaments, and interspinous ligaments; unpaired syndesmosis is present in supraspinous ligament
- Atlantooccipital articulation is composed of diarthrosis between lateral mass of atlas and occipital condyles and syndesmoses of atlantooccipital membranes; anterior atlantooccipital membrane is extension of anterior longitudinal ligament (ALL); posterior atlantooccipital membrane is homologous to ligamenta flava
- Atlantoaxial articulation is pivot joint; transverse ligament maintains relationship of odontoid to anterior arch of atlas; synovial cavities are present between transverse ligament/odontoid and atlas/odontoid junctions

Disc

- Intervertebral disc is composed of 3 parts: Cartilaginous endplate, annulus fibrosis, and nucleus pulposus
- Height of lumbar disc space generally increases as one progresses caudally; annulus consists of concentrically oriented collagenous fibers, which serve to contain the central nucleus pulposus (these fibers insert into vertebral cortex via Sharpey fibers and also attach to anterior and posterior longitudinal ligaments)
- Type I collagen predominates at periphery of annulus, while type II predominates in inner annulus; normal contour of posterior aspect of annulus is dependent upon contour of its adjacent endplate (typically this is slightly concave in axial plane, although commonly at L4-5 and L5-S1 these posterior margins will be flat or even convex; convex shape on axial images alone should not be interpreted as degenerative bulging)
- Nucleus pulposus is remnant of embryonal notochord and consists of well-hydrated noncompressible proteoglycan matrix with scattered chondrocytes; proteoglycans form major macromolecular component, including chondroitin 6-sulfate, keratan sulfate, and hyaluronic acid
- Proteoglycans consist of protein core with multiple attached glycosaminoglycan chains; nucleus occupies eccentric position within confines of annulus and is more dorsal with respect to center of vertebral body
- At birth, ~ 85-90% of nucleus is water; this water content gradually decreases with advancing age; within nucleus pulposus on T2-weighted sagittal images, there is often linear hypointensity coursing in anteroposterior direction, intranuclear cleft (this region of more prominent fibrous tissue should not be interpreted as intradiscal air or calcification)

Anterior Longitudinal Ligament

- Runs along ventral surface of spine from skull to sacrum; ALL is narrowest in cervical spine and is firmly attached at ends of each vertebral body; it is loosely attached at midsection of disc

Posterior Longitudinal Ligament (PLL)

- Runs on dorsal surface of bodies from skull to sacrum; PLL has segmental denticulate configuration and is wider at disc space but narrows and becomes thicker at vertebral body level

Craniocervical Ligaments

- Located anteriorly to spinal cord and occur in 3 layers: Anterior, middle, and posterior
- Anterior ligaments consist of odontoid ligaments (apical and alar); apical ligament is small fibrous band extending from dens tip to basion; alar ligaments are thick, horizontally directed ligaments extending from lateral surface of dens tip to anteromedial occipital condyles; middle layer consists of cruciate ligament
- Transverse ligament is strong horizontal component of cruciate ligament extending from behind dens to medial aspect of C1 lateral masses; craniocaudal component consists of fibrous band running from transverse ligament superiorly to foramen magnum and inferiorly to C2; posteriorly, tectorial membrane is continuation of PLL and attaches to anterior rim of foramen magnum

Vertebral Artery

- Vertebral artery arises as 1st branch of subclavian artery on both sides; vertebral artery travels cephalad within foramen transversarium within transverse processes
- 1st segment of vertebral artery extends from its origin to entrance into foramen of transverse process of cervical vertebrae, usually 6th; most common variation is origin of left vertebral from arch, between left common carotid and left subclavian arteries (2-6%) (vertebral artery in these cases almost always enters foramen of the transverse process of C5)
- 2nd segment runs within transverse foramen to C2 level; nerve roots pass posterior to vertebral artery
- 3rd segment starts at C2 level where artery loops and turns lateral to ascend in C1 transverse foramen; it then turns medial crossing on top of C1 in groove 4
- 4th segment starts where artery perforates dura and arachnoid at lateral edge of posterior occipitoatlantal membrane, coursing ventrally on medulla to join with other vertebral artery to make basilar artery

Vertebral Column Blood Supply

- Paired segmental arteries (intercostals, lumbar arteries) arise from aorta and extend dorsolaterally around middle of vertebral body; near transverse process, segmental artery divides into lateral and dorsal branches
- Lateral branch supplies dorsal musculature, and dorsal branch passes lateral to foramen giving off branch(es) providing major vascular supply to bone and vertebral canal contents; posterior central branch supplies disc and vertebral body, while prelaminal branch supplies inner surface of arch and ligamenta flava, regional epidural tissue
- Neural branch entering neural foramen supplies pia, arachnoid, and cord; postlaminar branch supplies musculature overlying lamina and branches to bone

Nerves

- Spinal nerves are arranged in 31 pairs and grouped regionally: 8 cervical, 12 thoracic, 5 lumbar, 5 sacral, 1 coccygeal
- Ascensus spinalis is apparent developmental rising of cord related to differential spinal growth
- Course of nerve roots becomes longer and more oblique at lower segments
- C1 nerve from C1 segment and exits above C1
- C8 nerve from C7 segment and exits at C7-T1
- T6 nerve from T5 segment and exits at T6-T7
- T12 nerve from T8 segment and exits at T12-L1
- L2 nerve from T10 segment and exits at L2-3
- S3 nerve from T12 segment and exits at the S3 foramen

Meninges are divided into dura, arachnoid, and pia.

- **Dura** is dense, tough covering corresponding to meningeal layer of cranial dura; epidural space is filled with fat, loose connective tissue, and veins; dura continues with spinal nerves through foramen to fuse with epineurium; cephalic attachment of dura is at foramen magnum and caudal attachment at back of coccyx
- **Arachnoid** is middle covering, which is thin, delicate, and continuous with cranial arachnoid; arachnoid is separated from dura by potential subdural space
- **Pia** is inner covering of delicate connective tissue closely applied to cord; longitudinal fibers are laterally concentrated as denticulate ligaments lying between posterior and anterior roots and attach at 21 points to dura; longitudinal fibers are concentrated dorsally as septum posticum attaching dorsal cord to dorsal midline dura

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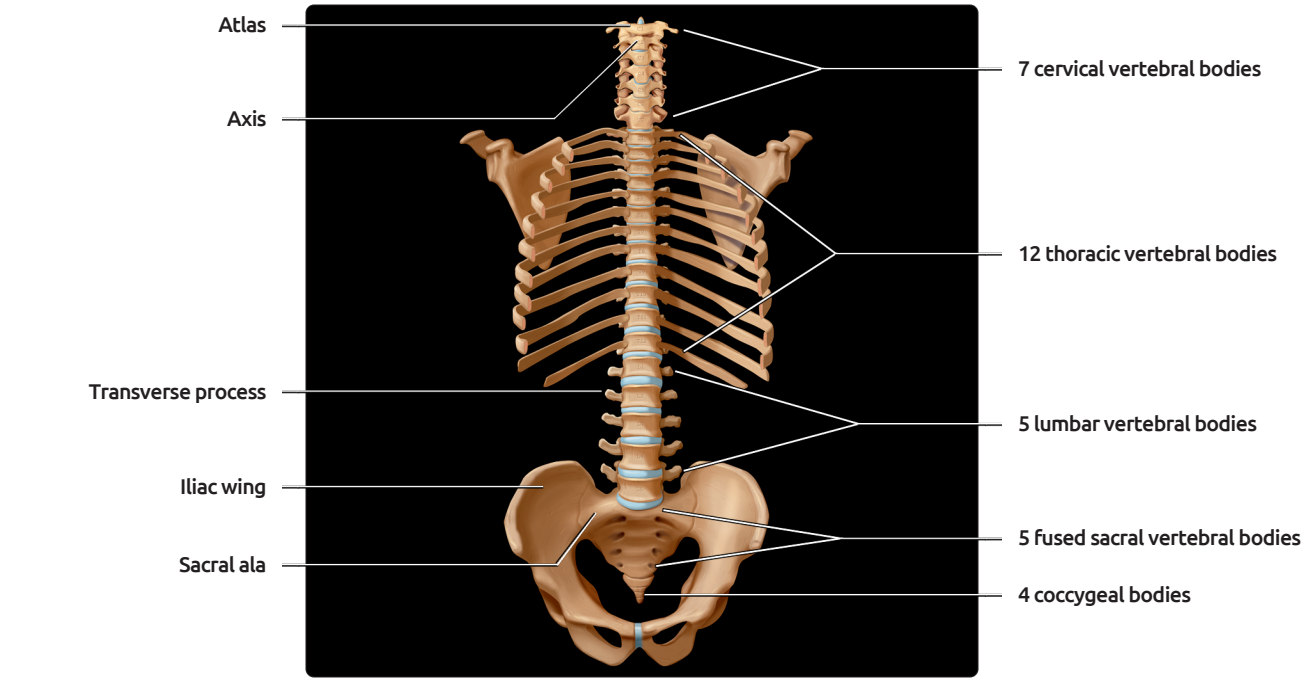
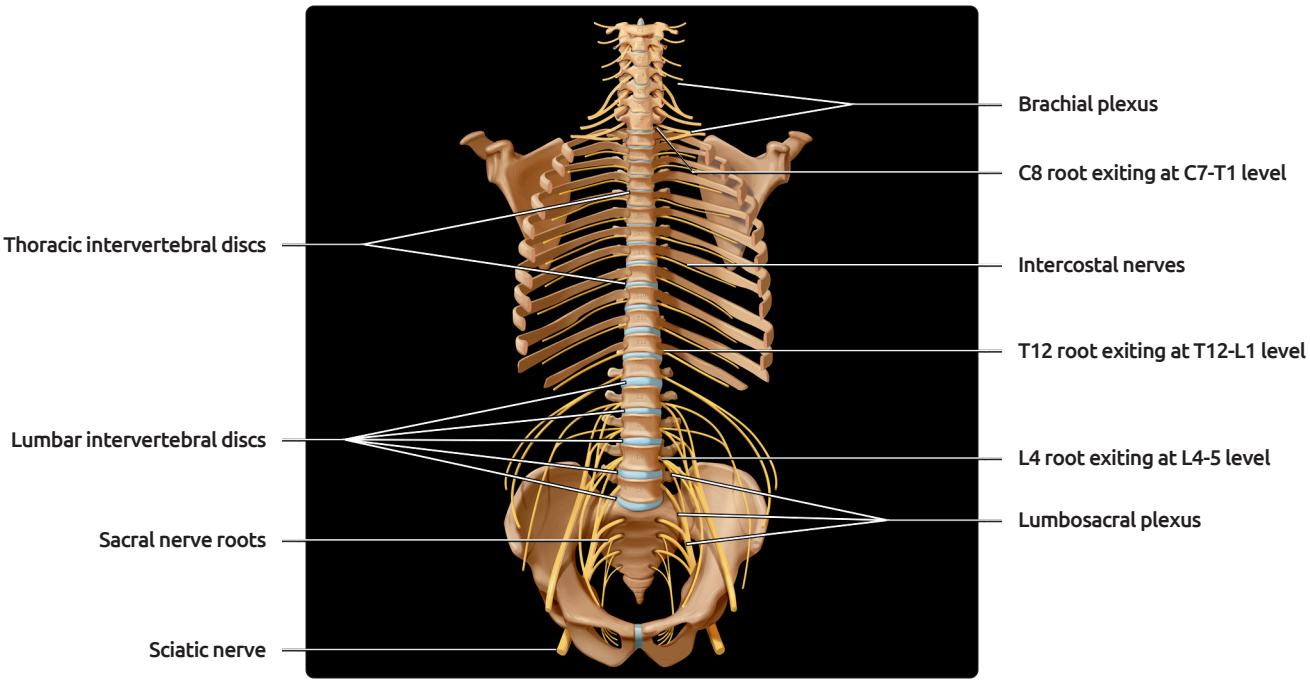
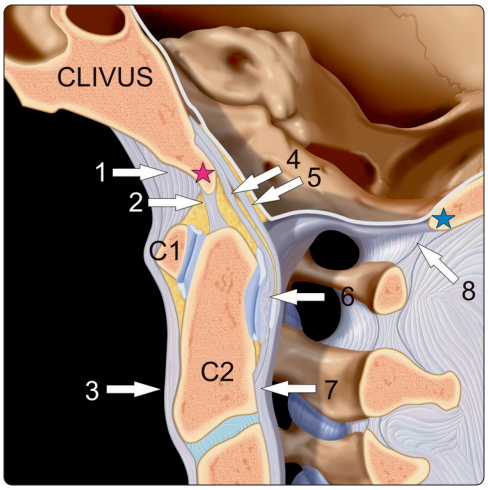
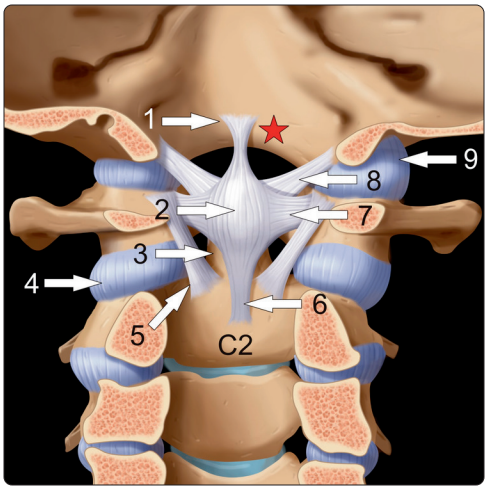
SPINE ANATOMY GENERAL OVERVIEW



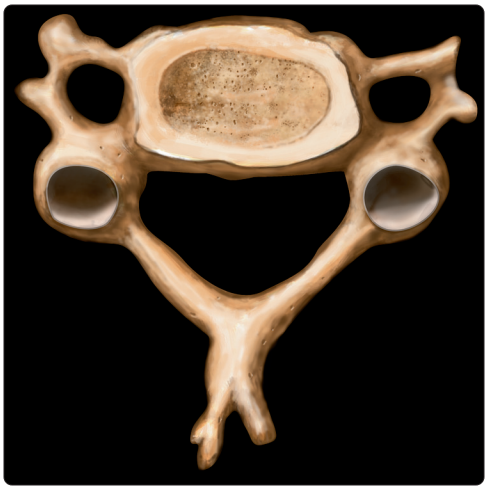


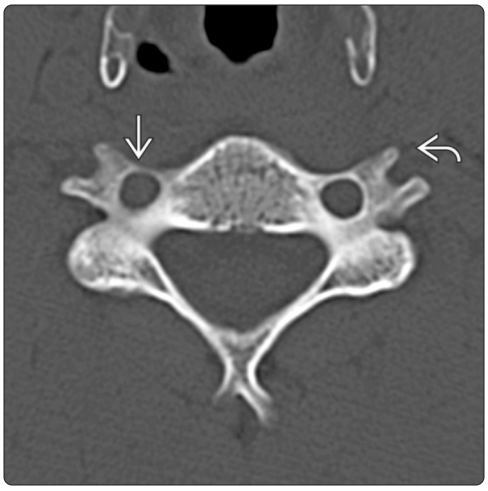
(Top) *Coronal graphic of the spinal column shows the relationship of 7 cervical, 12 thoracic, 5 lumbar, 5 fused sacral, and 4 coccygeal bodies. Note the cervical bodies are smaller with the neural foramina oriented at 45° and capped by the unique C1 and C2 morphology. Thoracic bodies are heart-shaped, have thinner intervertebral discs, and are stabilized by the rib cage. Lumbar bodies are more massive with prominent transverse processes and thick intervertebral discs.* **(Bottom)** *Coronal graphic demonstrates exiting spinal nerve roots. C1 exits between the occiput and C1, while the C8 root exits at the C7-T1 level. Thoracic and lumbar roots exit below their respective pedicles.*



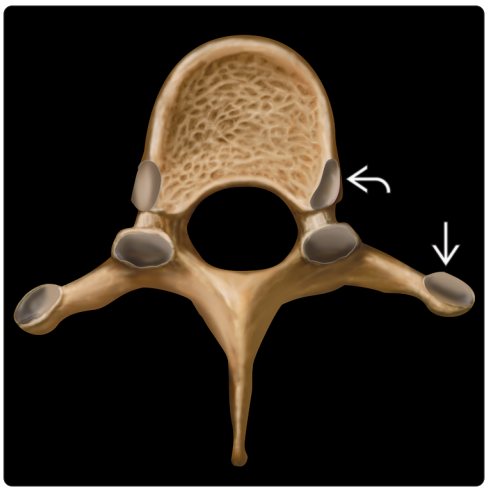


(Left) *Sagittal CVJ graphic shows 1) ant. atlantooccipital membrane, 2) apical ligament, 3) ALL, 4) cruciate ligament, 5) tectorial membrane, 6) transverse ligament, 7) post. longitudinal ligament, 8) post. atlantooccipital membrane: Red star = basion, blue star = opisthion.* **(Right)** *Posterior CVJ graphic shows 1) sup. cruciate ligament, 2) cruciate lig., 3) odontoid ant. to cruciate lig., 4) atlantoaxial jt., 5) accessory atlantoaxial lig., 6) inf. cruciate lig., 7) transverse lig., 8) alar lig., and 9) atlantooccipital jt. (Red star = basion).*



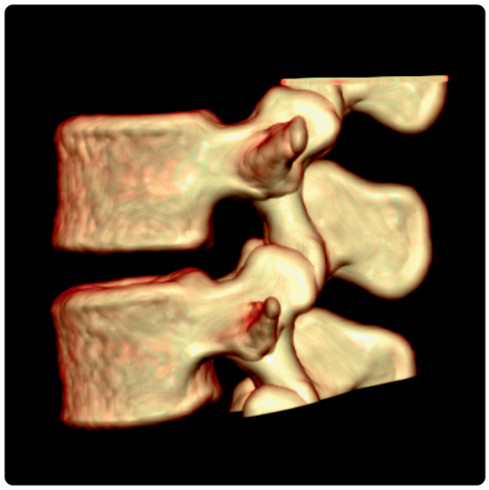


(Left) *Graphic shows the cervical vertebra from above. The vertebral body is broad transversely; the central canal is large & triangular in shape; the pedicles are directed posterolaterally; the laminae are delicate. Lateral masses contain the vertebral foramen for passage of vertebral artery & veins.* **(Right)** *Mid C5 body at the pedicle level shows transverse foramina are prominent, encompassing the vertical course of the vertebral artery. The anterior and posterior tubercles give rise to muscle attachments in the neck.*

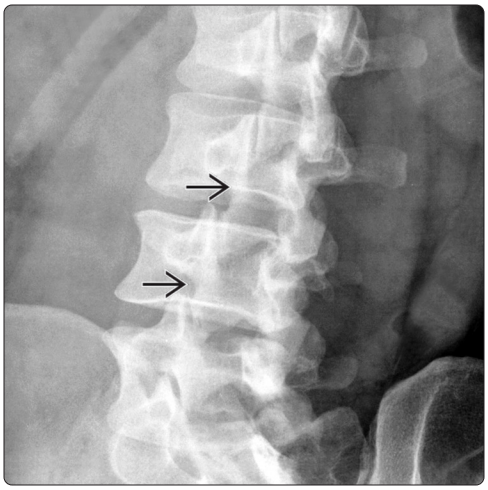


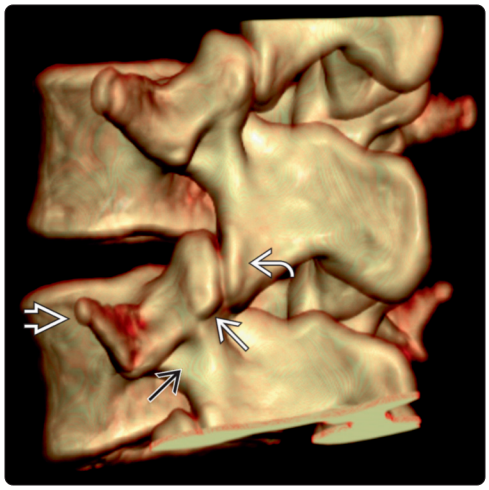
(Left) *Graphic shows thoracic vertebral body from above. Thoracic bodies are characterized by long spinous processes and transverse processes. Complex rib articulation includes both costotransverse joints & costovertebral joints. Facet joints are oriented in the coronal plane.* **(Right)** *Image through the pedicle level of the thoracic spine shows the coronal orientation of the facet joints is well identified in this section. The pedicles are thin & gracile with adjacent rib articulations.*

(Left) *Graphic shows the lumbar body from above. Large, sturdy lumbar bodies connect to thick pedicles and transversely directed transverse processes. Facets maintain oblique orientation favoring flexion/extension.* **(Right)** *Lateral 3D scan of the lumbar spine shows large bodies joined by thick posterior elements with superior and inferior articular processes angled in the lateral plane. Transverse processes jut out laterally for muscle attachments. Pars interarticularis form junction between articular processes.*

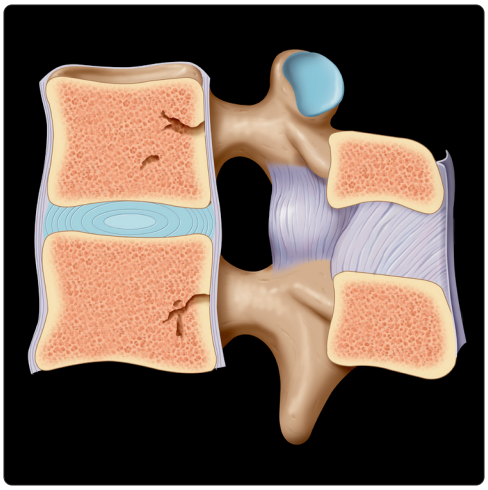


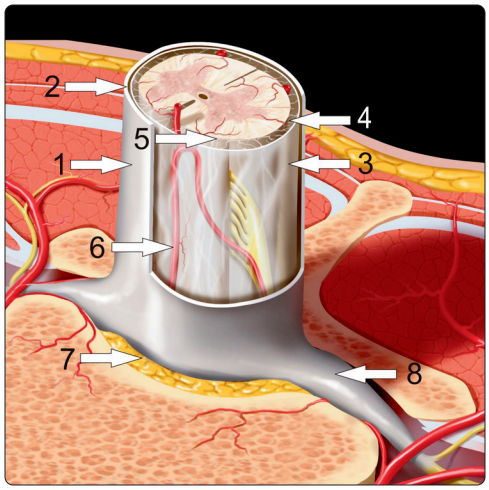
(Left) *Oblique view of the lumbar spine shows the typical Scotty dog appearance of the posterior elements. The neck of the dog is the pars interarticularis.* **(Right)** *Oblique 3D exam of the lumbar spine shows the surface anatomy of the "Scotty dog": Transverse process (nose), superior articular process (ear), inferior articular process (front leg), and intervening pars interarticularis (neck). The pedicle that forms the "eye" on CT reconstructions is obscured.*



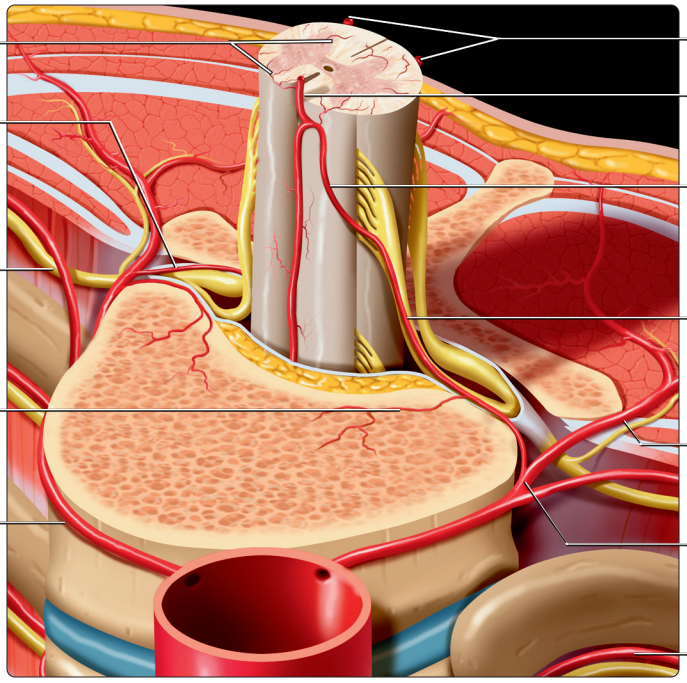


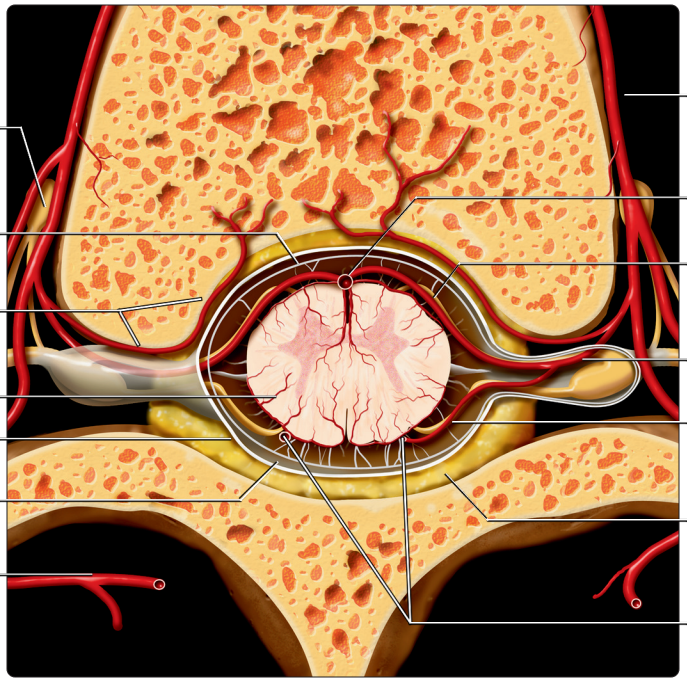
(Left) *Graphic shows lumbar vertebral bodies joined by disc & ant. & post. longitudinal ligaments. Posteriorly are paired pedicles, transverse processes, articular facets, lamina, & spinous process. Paired ligamentum flavum & interspinous ligaments join posterior elements with midline supraspinous ligaments.* **(Right)** *Graphic shows spinal cord & coverings: 1) dura mater, 2) subdural space, 3) arachnoid mater, 4) subarachnoid space, 5) pia mater, 6) ant. spinal artery, 7) epidural space, & 8) root sleeve.*





VASCULAR ANATOMY





(Top) *Axial oblique graphic of the thoracic spinal cord and arterial supply at T10 shows segmental intercostal arteries arising from the lower thoracic aorta. The artery of Adamkiewicz is the dominant segmental feeding vessel to the thoracic cord, supplying the anterior aspect of the cord via the anterior spinal artery. Adamkiewicz has a characteristic hairpin turn on the cord surface as it first courses superiorly, then turns inferiorly.* **(Bottom)** *Axial graphic shows the anterior and posterior radiculomedullary arteries anastomosing with the anterior and posterior spinal arteries. Penetrating medullary arteries in the cord are largely end-arteries with few collaterals. The cord "watershed" zone is at the central gray matter.*

TERMINOLOGY

Definitions

- Craniocervical junction (CCJ) = C1, C2, and articulation with skull base

GROSS ANATOMY

Overview

- Craniocervical junction comprises occiput, atlas, axis, their articulations, ligaments

Components of Craniocervical Junction

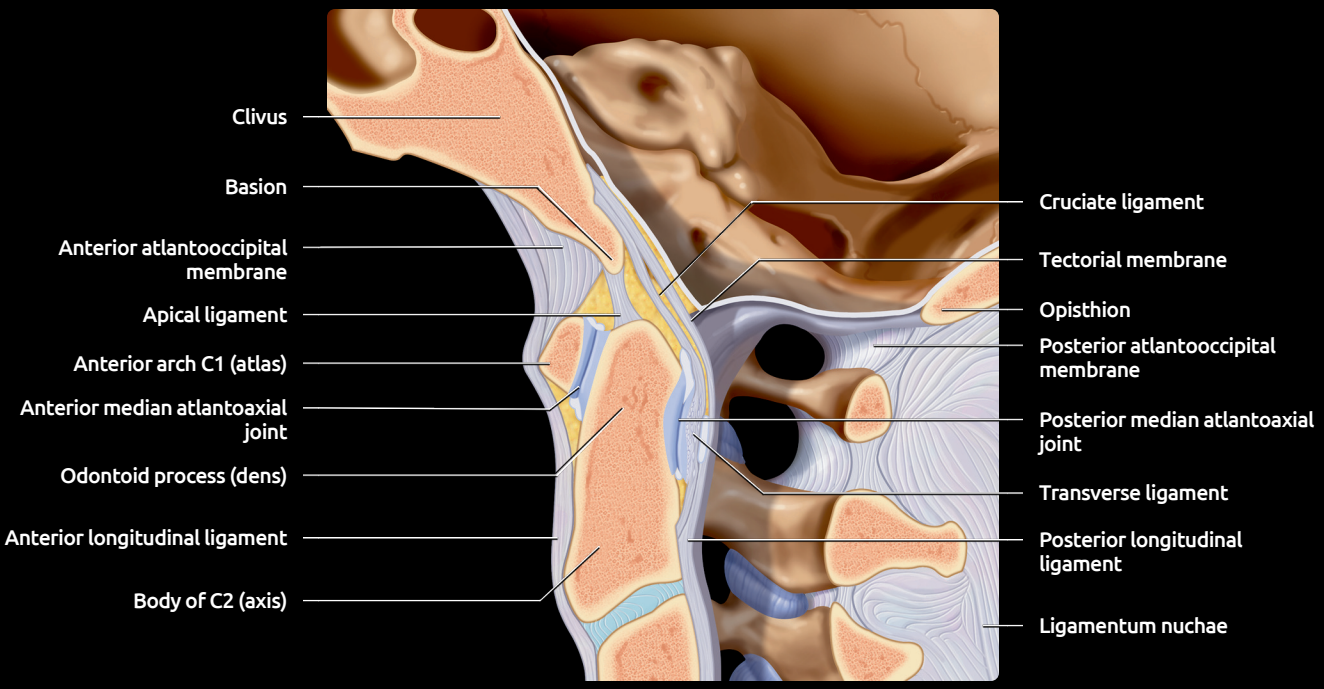
- **Bones**
  - **Occipital bone**
    - Occipital condyles are paired, oval-shaped, inferior prominences of lateral exoccipital portion of occipital bone
    - Articular facet projects laterally
  - **C1 (atlas)**
    - Composed of anterior and posterior arches, no body
    - Paired lateral masses with their superior and inferior articular facets
    - Large transverse processes with transverse foramen
  - **C2 (axis)**
    - Large body and superiorly projecting odontoid process
    - Superior articulating facet surface is convex & directed laterally
    - Inferior articular process + facet surface is typical of lower cervical vertebrae
    - Superior facet is positioned relatively anteriorly; inferior facet is posterior with elongated pars interarticularis
- **Joints**
  - **Atlantooccipital joints**
    - Inferior articular facet of occipital condyle: Oval, convex surface, projects laterally
    - Superior articular facet of C1: Oval, concave anteroposteriorly, projects medially
  - **Median atlantoaxial joints**
    - Pivot-type joint between dens + ring formed by anterior arch + transverse ligament of C1
    - Synovial cavities between transverse ligament/odontoid & atlas/odontoid articulations
  - **Lateral atlantoaxial joints**
    - Inferior articular facet of C1: Concave mediolaterally, projects medially in coronal plane
    - Superior articular facet of C2: Convex surface, projects laterally
- **Ligaments** (from anterior to posterior)
  - **Anterior atlantooccipital membrane**: Connects anterior arch C1 with anterior margin foramen magnum
  - **Odontoid ligaments**
    - Apical ligament: Small fibrous band extending from dens tip to basion
    - Alar ligaments: Thick, horizontally directed ligaments extending from lateral surface of dens tip to anteromedial occipital condyles
  - **Cruciate ligament**
    - Transverse ligament: Strong horizontal component between lateral masses of C1, passes behind dens
    - Craniocaudal component: Fibrous band running from transverse ligament superiorly to foramen magnum and inferiorly to C2
  - **Tectorial membrane**: Continuation of posterior longitudinal ligament; attaches to anterior rim foramen magnum (posterior clivus)
  - **Posterior atlantooccipital membrane**
    - Posterior arch C1 to margin of foramen magnum
    - Deficit laterally where vertebral artery enters on superior surface of C1
- **Biomechanics**
  - Atlantooccipital joint: 50% cervical flexion/extension and limited lateral motion
  - Atlantoaxial joint: 50% cervical rotation

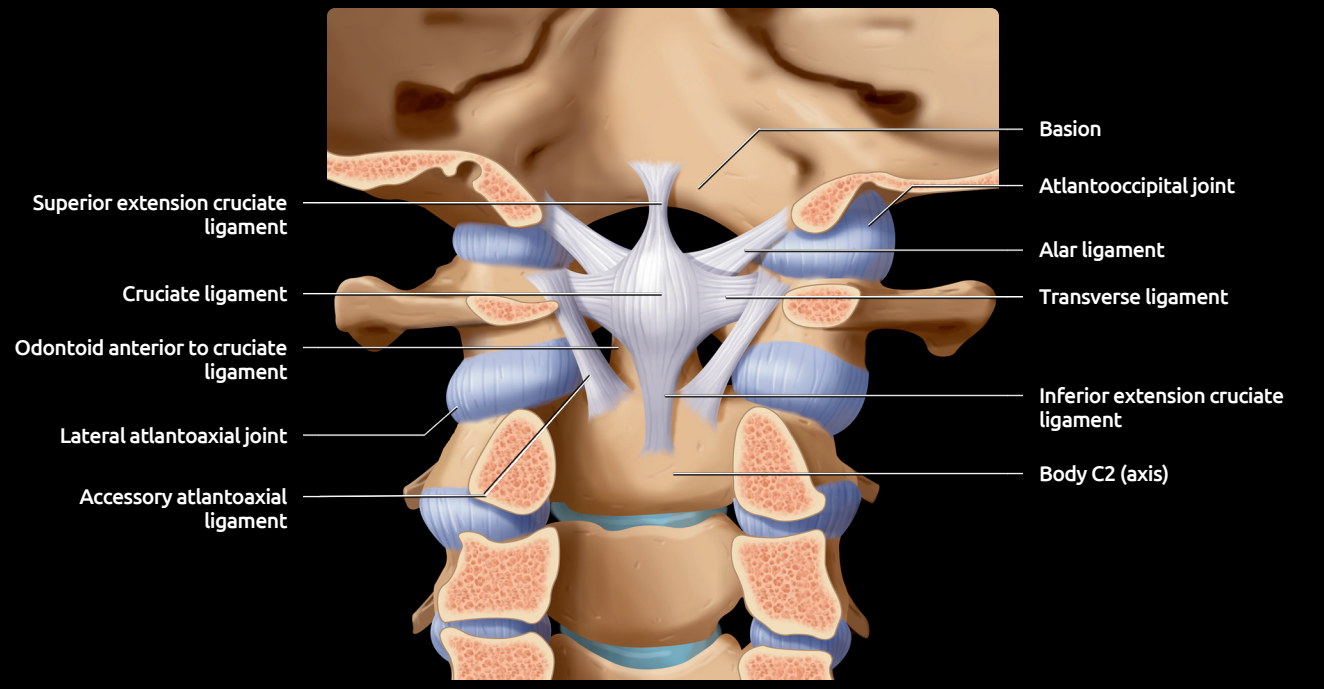
IMAGING ANATOMY

Overview

- **Lateral assessment of CCJ**
  - **C1-C2 interspinous space**: ≤ 10 mm
  - **Atlantodental interval (ADI)**
    - Adults < 3 mm, children < 5 mm in flexion
  - **Pseudosubluxation**
    - Physiologic anterior displacement seen in 40% at C2-C3 level and 14% at C3-C4 level to age 8
    - Anterior displacement of C2 on C3 up to 4 mm
  - **Posterior cervical line**: Line is drawn from anterior aspect of C1-C3 spinous processes → anterior C2 spinous process should be within 2 mm of this line
  - **Wackenheim line**
    - Posterior surface of clivus → posterior odontoid tip should lie immediately inferior
    - Relationship does not change in flexion/extension
  - **Welcher basal angle**
    - Angle between lines drawn along plane of sphenoid bone and posterior clivus
    - Normal < 140°, average 132°
  - **Chamberlain line**
    - Between hard palate and opisthion
    - Odontoid tip ≥ 5 mm above line abnormal
  - **McGregor line**
    - Between hard palate to base of occipital bone
    - Odontoid tip ≥ 7 mm above line abnormal
  - **Clivus canal angle**
    - Junction of Wackenheim line and posterior vertebral body line
    - 180° extension, 150° flexion, < 150° abnormal
  - **McRae line**
    - Drawn between basion and opisthion
    - Normal 35-mm diameter
- **Frontal assessment of CCJ**
  - Lateral masses of C1 and C2 should align
    - Overlapping lateral masses can be normal variant in children
  - **Atlantooccipital joint angle**
    - Angle formed at junction of lines traversing joints
    - 125-130° normal, < 124° may reflect condyle hypoplasia

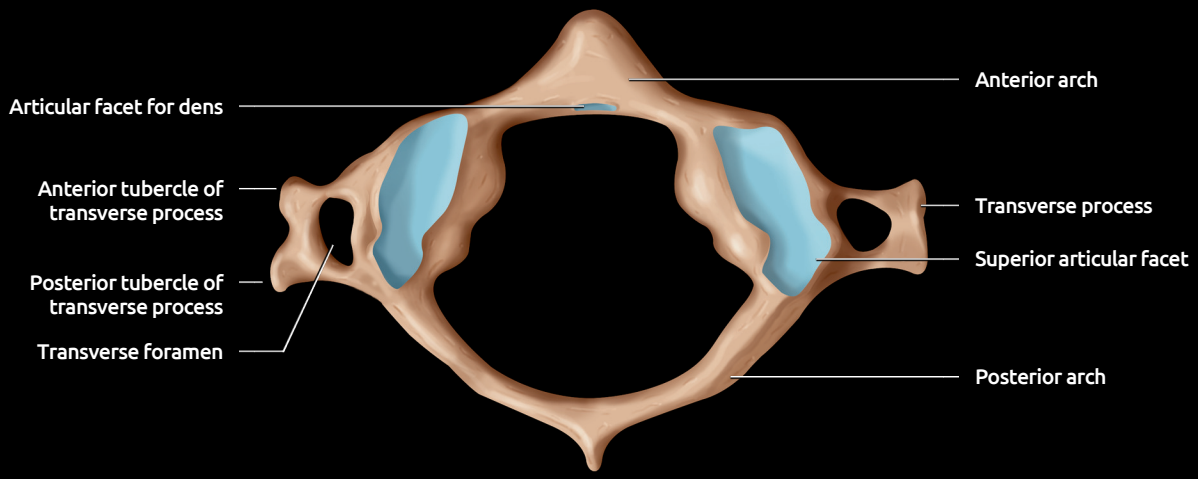
LIGAMENT ANATOMY

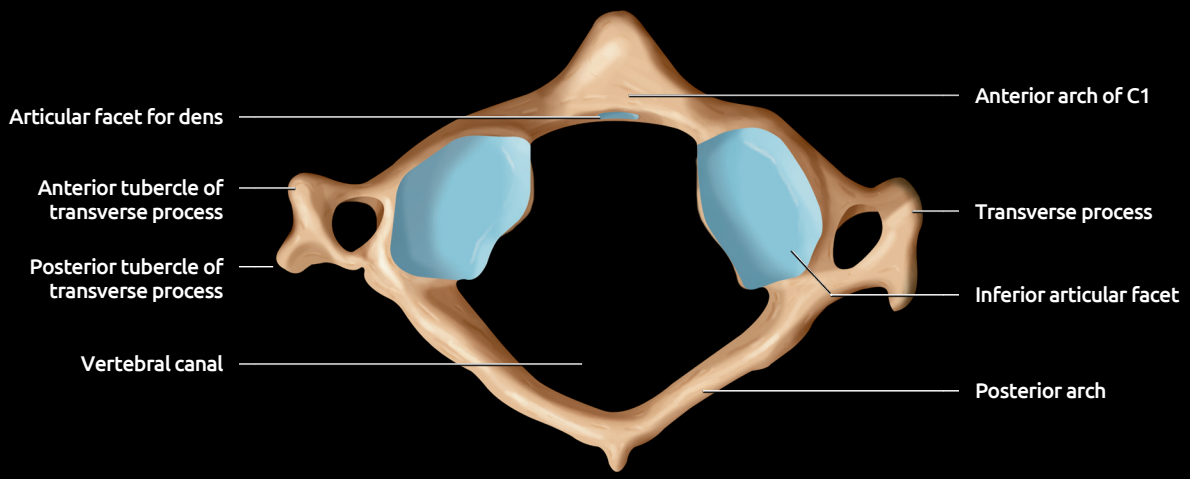




(Top) *Sagittal midline graphic shows the craniocervical junction. The complex articulations and ligamentous attachments are highlighted. The midline atlantoaxial articulations consist of anterior and posterior median atlantoaxial joints. The anterior joint is between the posterior aspect of the anterior C1 arch and the ventral aspect of odontoid process. The posterior joint is between the dorsal aspect of the odontoid process and the cruciate ligament. The midline view shows a series of ligamentous connections to the skull base including the anterior atlantooccipital membrane, apical ligament, superior component of cruciate ligament, tectorial membrane, and posterior atlantooccipital membrane.* **(Bottom)** *Posterior view of the craniocervical junction with posterior elements cut away to define the components of the cruciate ligament and alar ligaments is shown.*

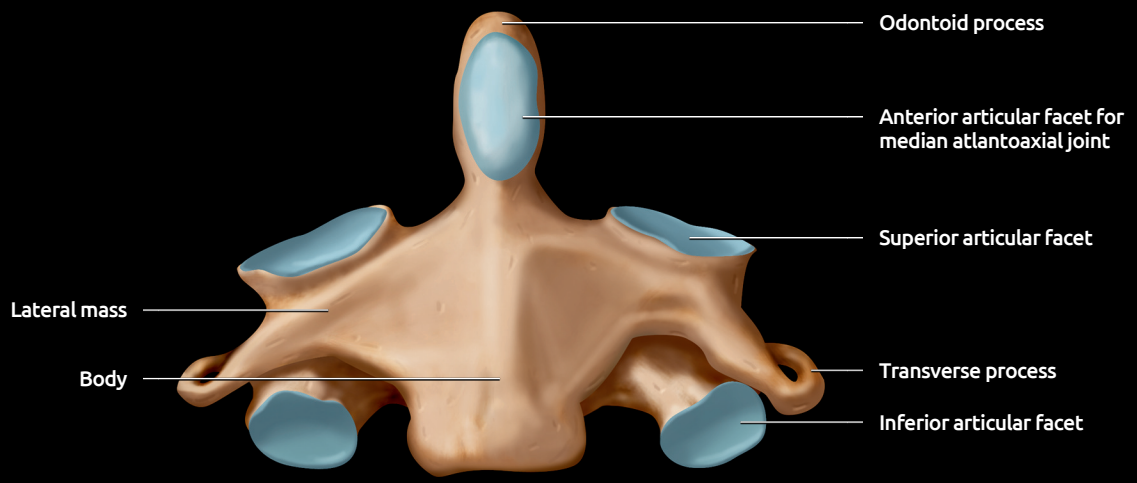
C1 GRAPHICS

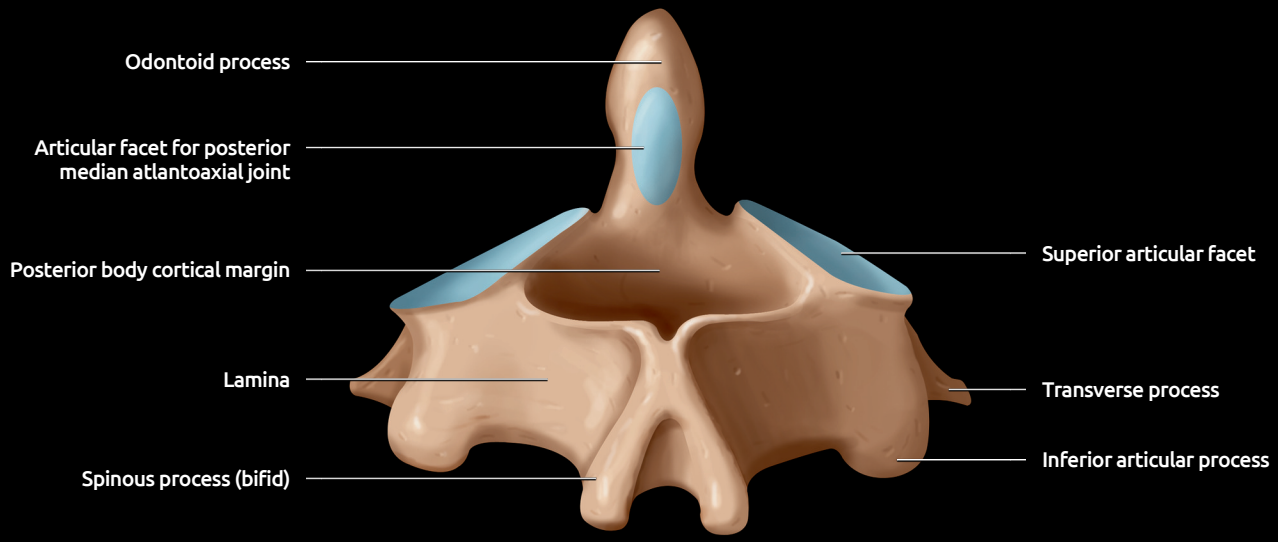




(Top) *Axial graphic shows the atlas viewed from above. The characteristic ring shape is shown, composed of anterior and posterior arches and paired large lateral masses. The superior articular facet is concave anteroposteriorly and projects medially for articulation with the convex surface of the occipital condyle at the atlantooccipital joint. The anterior arch articulates with the odontoid process at the anterior median atlantoaxial joint.* **(Bottom)** *In this atlas viewed from below, the large inferior facet surface is concave mediolaterally and projects medially for articulation with the convex surface of the superior articular facet of C2. The canal of the atlas is ± 3 cm in AP diameter: The spinal cord, odontoid process, and free space for the cord are each about 1 cm in diameter. The size of the anterior midline tubercle of the anterior arch and spinous process of posterior arch are quite variable.*

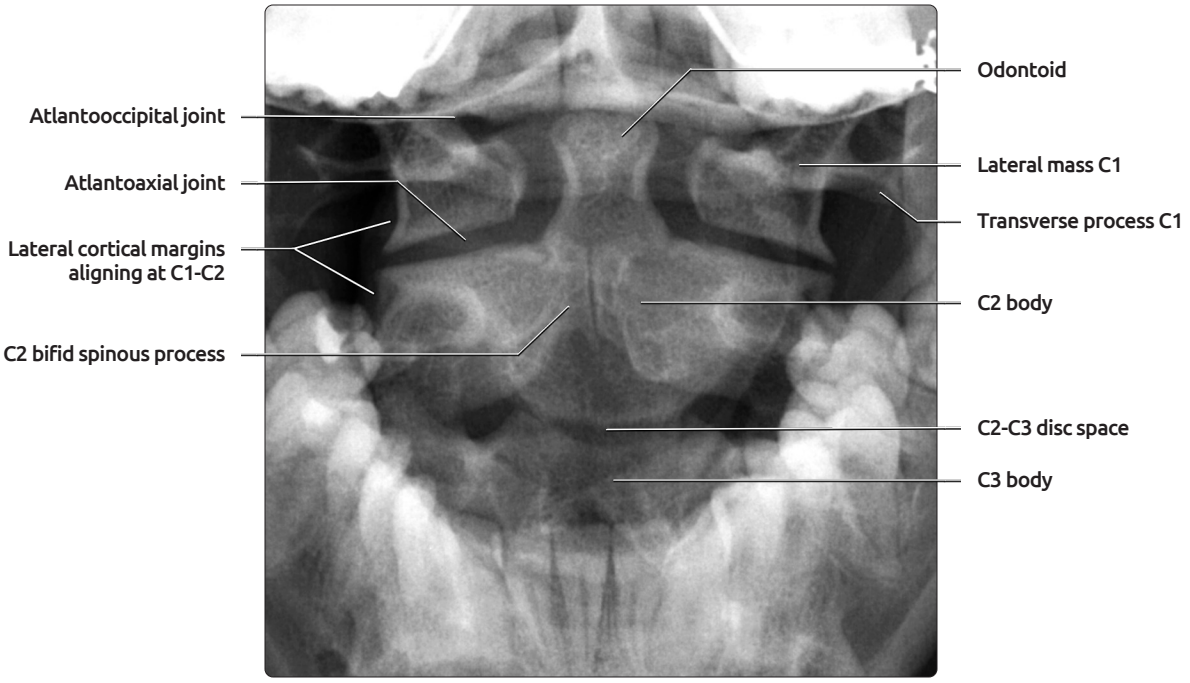
C2 GRAPHICS

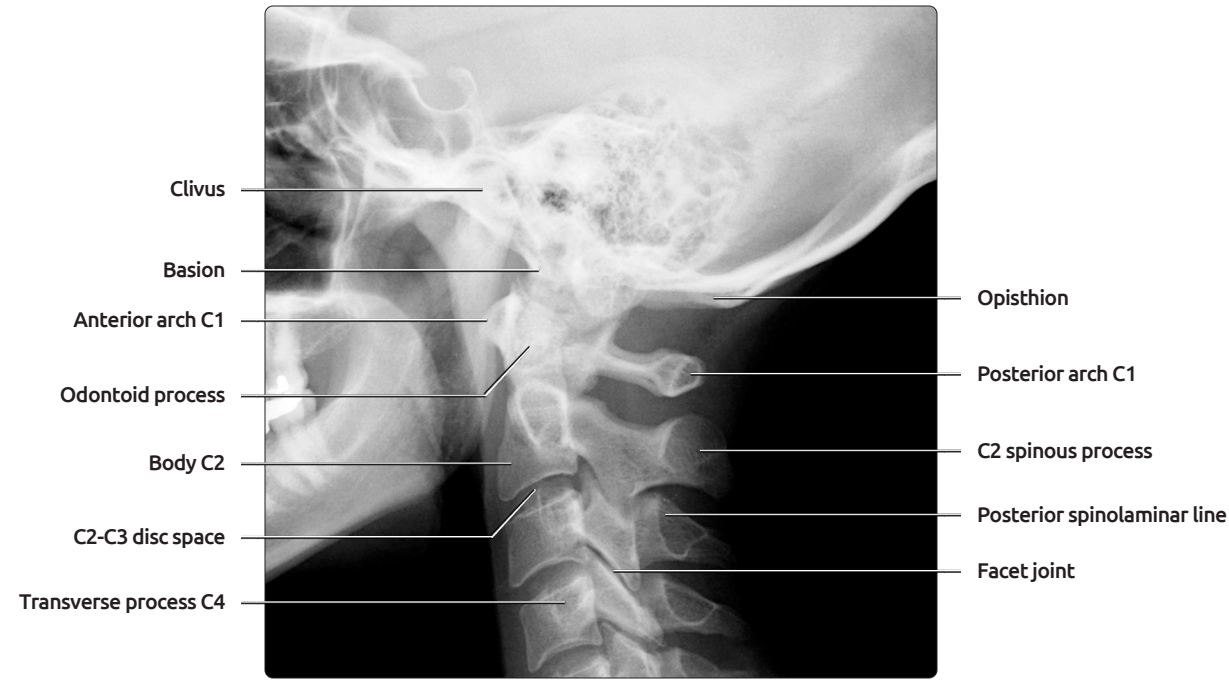




(Top) *In this atlas viewed from the anterior perspective, the odontoid process is the "purloined" embryologic centrum of C1, which is incorporated into C2, giving C2 its unique morphology. The C2 body laterally is defined by large lateral masses for articulation with the inferior facet of C1. The elongated pars interarticularis of C2 ends with the inferior articular process for articulation with the superior articular facet of C3.* **(Bottom)** *The atlas viewed from the posterior perspective shows that the odontoid process has anterior and posterior joints for articulation with C1. The anterior median joint articulates with the C1 arch, while the posterior median joint (shown here) involves the transverse ligament.*

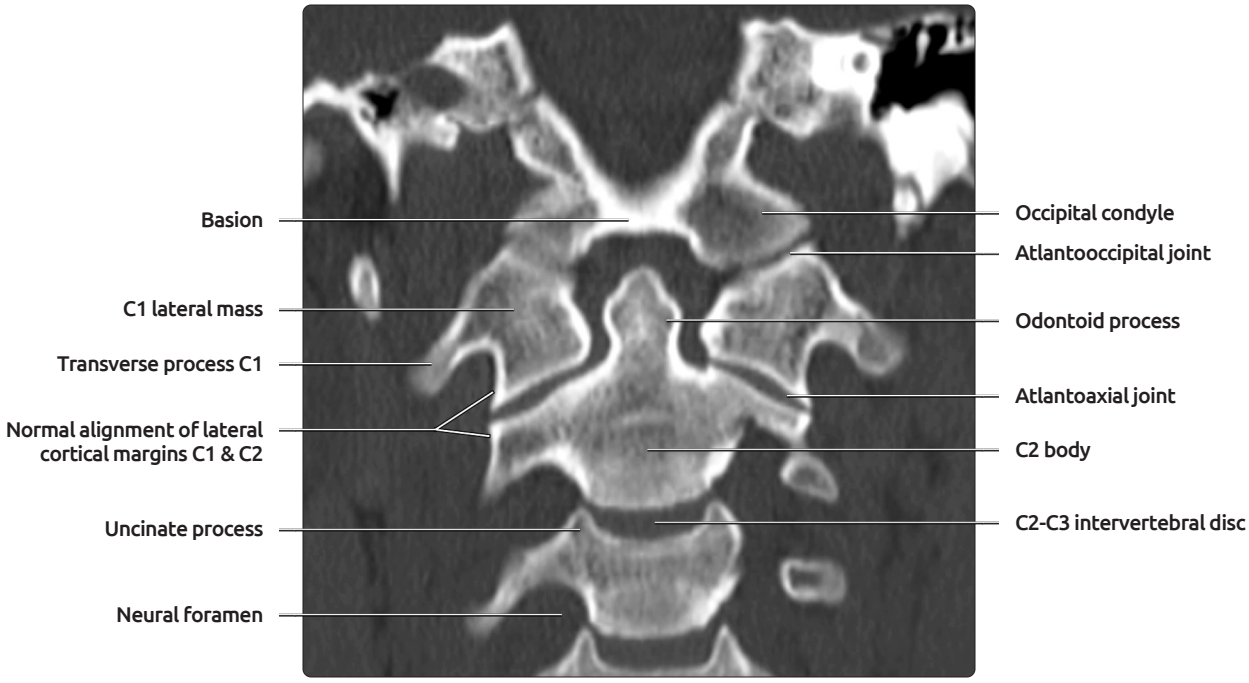
RADIOGRAPHY

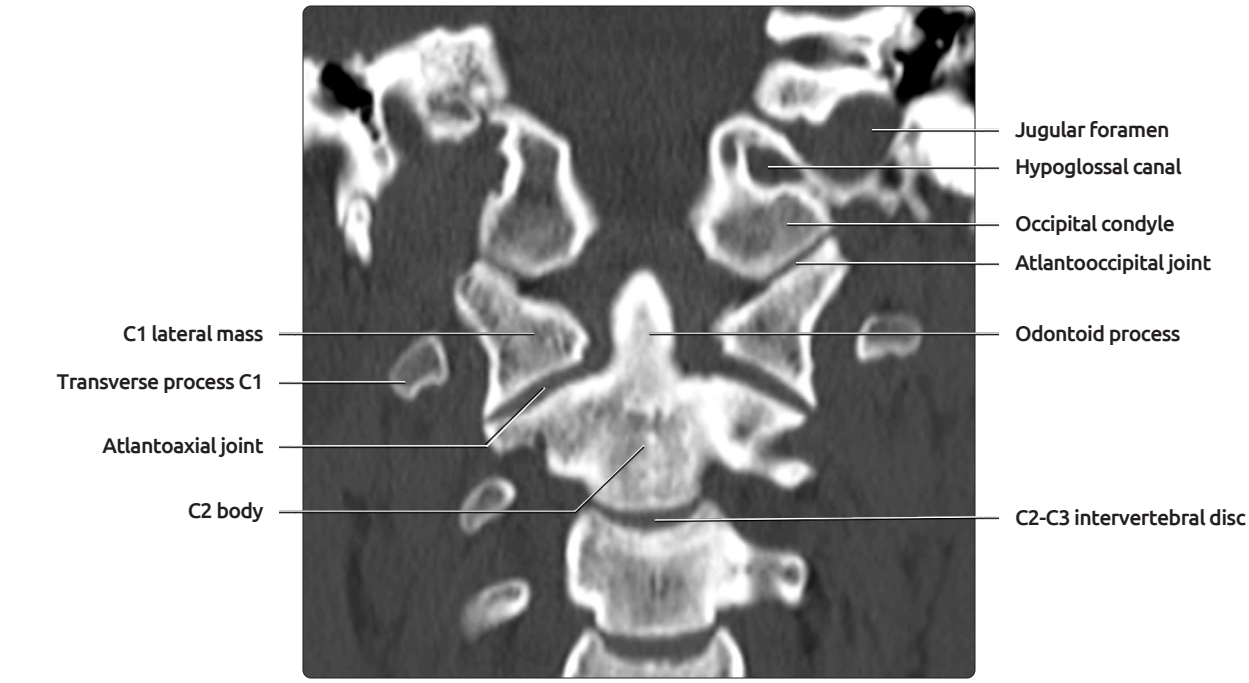




(Top) *AP open-mouth view shows the odontoid process. With proper positioning, the odontoid process is visualized in the midline with symmetrically placed lateral C1 masses on either side. The medial space between the odontoid and C1 lateral masses should be symmetric as well. The lateral cortical margins of the C1 and C2 lateral masses should align. The atlantooccipital and atlantoaxial joints are visible bilaterally with smooth cortical margins. The bifid C2 process should not be confused for fracture.* **(Bottom)** *In this lateral radiograph of craniocervical junction, there is smooth anatomic alignment of the posterior vertebral body margins and the posterior spinolaminar line of the posterior elements. The anterior arch of C1 should assume a well-defined oval appearance with sharp margination between the anterior C1 arch and the odontoid process.*

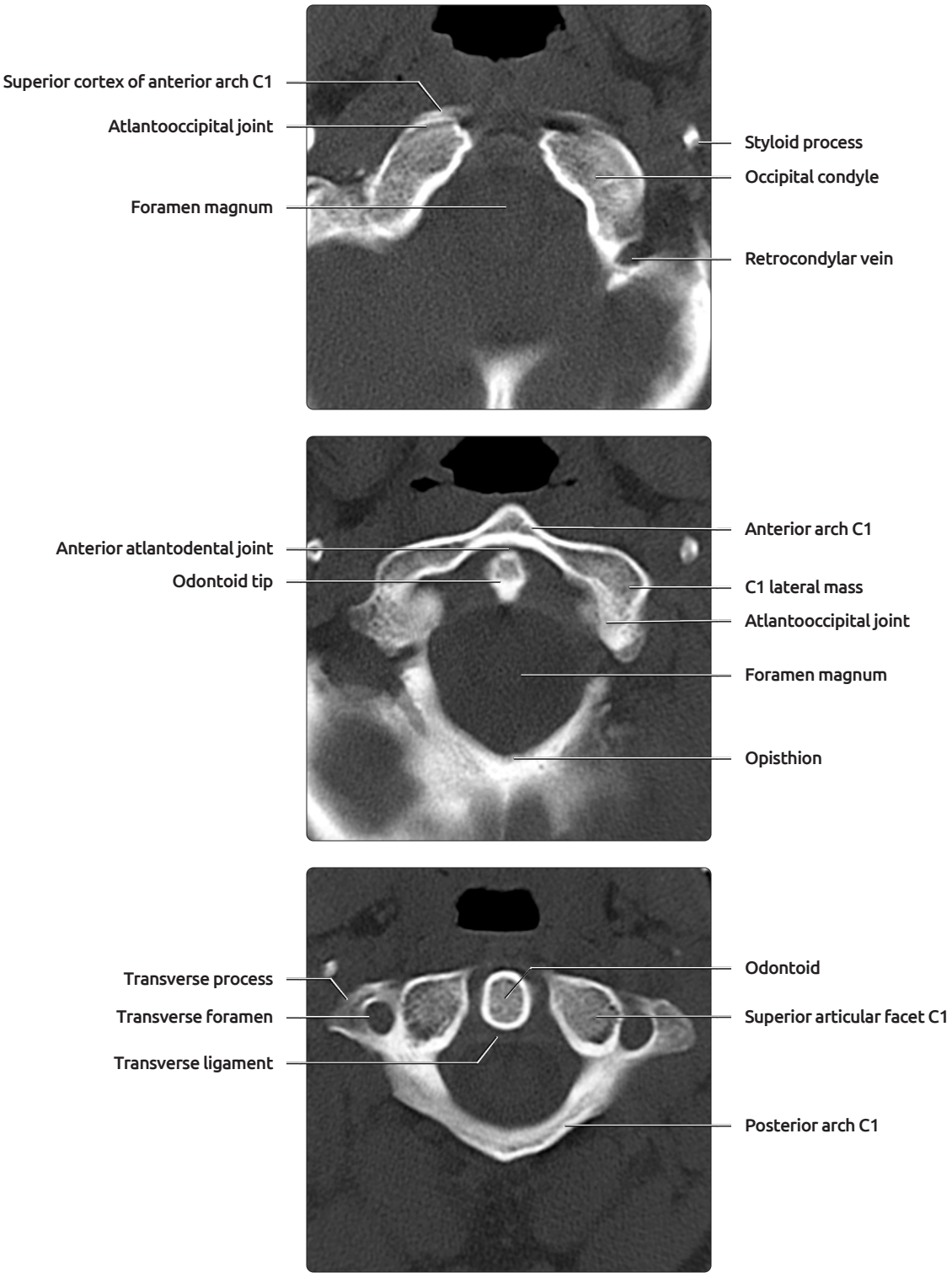
CORONAL BONE CT





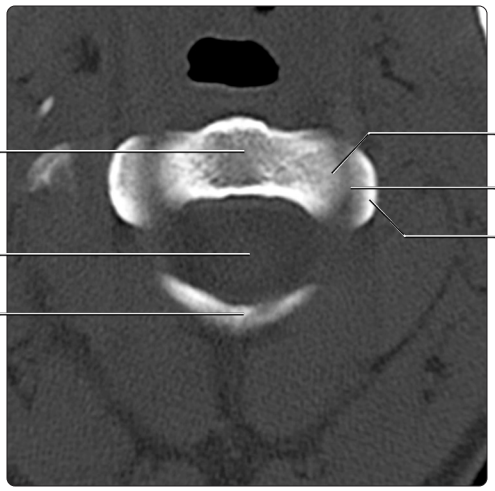
(Top) *The 1st of 2 coronal bone CT reconstructions of the craniocervical junction presented from anterior to posterior is shown. The odontoid process is visualized in the midline as a sharply corticated bony peg with symmetrically placed lateral C1 masses on either side. The lateral cortical margins of the C1 lateral masses and the C2 lateral masses should align. The atlantooccipital and atlantoaxial joints are visible bilaterally with even joint margins and sharp cortical margins.* **(Bottom)** *The more posterior view of the craniocervical junction shows that both the atlantooccipital joints are now well defined with smooth cortical margins, sloping superolateral to inferomedial. The atlantoaxial joints are smoothly sloping inferolateral to superomedial.*

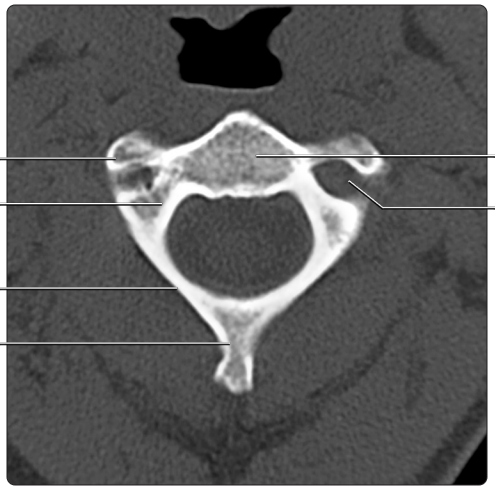
AXIAL BONE CT

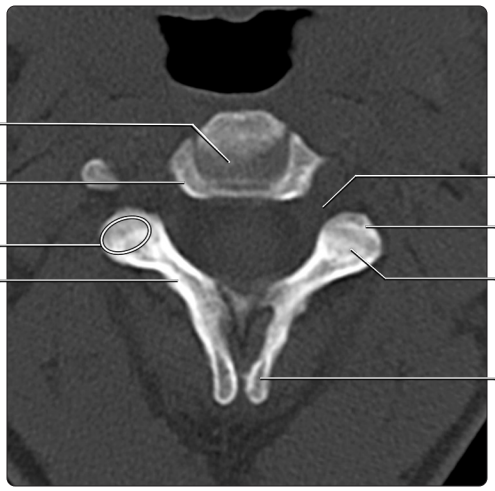


(Top) *The 1st of 6 axial bone CT images through the craniocervical junction presented from superior to inferior is shown. The anterolateral margin of the foramen magnum is formed by the prominent occipital condyles, which articulate with the superior articular facets of the C1 lateral masses.* **(Middle)** *This more inferior image of the craniocervical junction shows that the anterior arch of C1 is now well defined with the odontoid process of C2 coming into plane. The atlantooccipital joint is seen in oblique section and therefore has poorly defined margins. The odontoid is tightly applied to the posterior margin of the C1 arch, held in place by the strong transverse component of the cruciate ligament.* **(Bottom)** *Image at the level of the atlas shows the unique morphology of the C1 body, defined with its large transverse process, with a transverse foramen and ring shape.*

AXIAL BONE CT

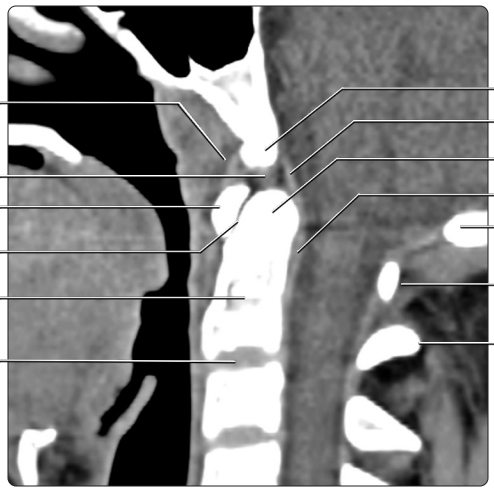


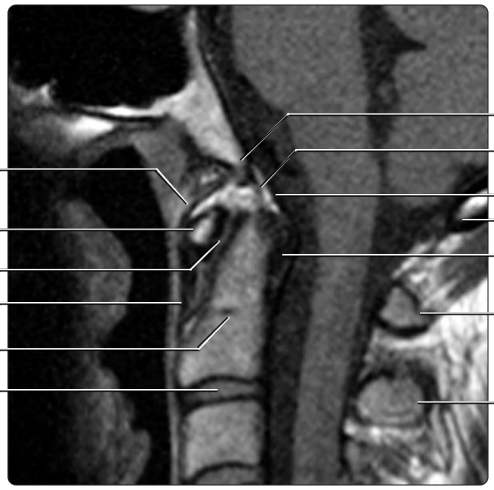


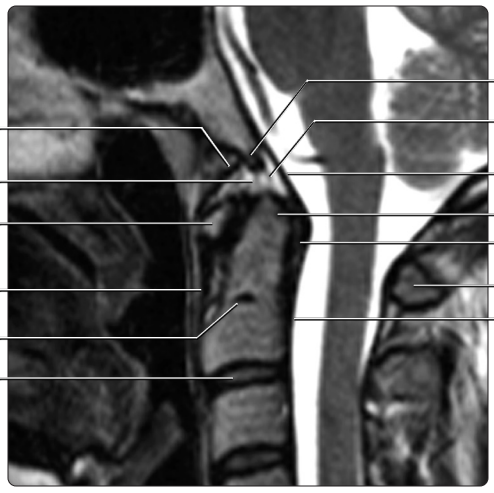


(Top) *In this image through the lateral atlantoaxial joints, this section defines the junction of the odontoid process with the body of C2. The obliquely oriented atlantoaxial joints are partially seen with the C1 component lateral to the joint space and the C2 component medial.* **(Middle)** *This image through the inferior C2 body level shows a large C2 vertebral body and vertebral arch formed by gracile pedicles and laminae.* **(Bottom)** *This image through the C2-C3 intervertebral disc level shows the C2-C3 neural foramen well defined with the posterior margin formed by the superior articular process of C3. The spinous process of C2 is large and typically bifid. The C2-C3 disc assumes the characteristic cervical cup-shaped morphology bound by uncinate processes.*

SAGITTAL CT & MR

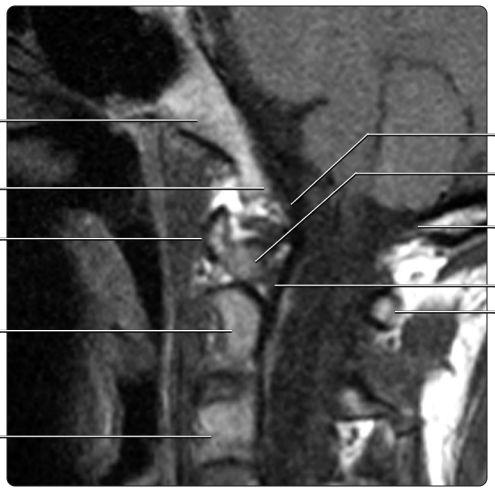


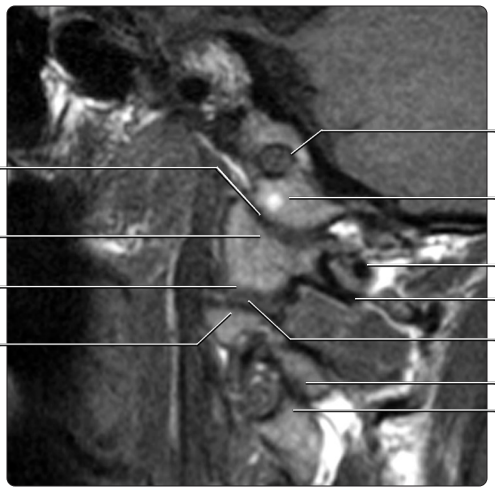




(Top) *Sagittal midline CT reformat shows the ligamentous structures visible at the craniocervical junction. The apical ligament is visible as a linear band between the odontoid tip and clivus. The tectorial membrane is the superior extension of the posterior longitudinal ligament. The anterior atlantooccipital membrane is the extension of the anterior longitudinal ligament.* **(Middle)** *Sagittal T1 MR midline image shows the craniocervical junction. The atlantodental interval is well defined by the adjacent low signal cortical margins of the C1 anterior arch and the odontoid process. The cruciate ligament is a low signal band dorsal to the odontoid.* **(Bottom)** *Sagittal T2 MR shows the craniocervical junction. The tectorial membrane, superior extension of the cruciate ligament, apical ligament, and anterior atlantooccipital membranes are evident.*

SAGITTAL T1 MR





(Top) *The 1st of 3 parasagittal T1 MR images shown from medial to lateral through the atlantooccipital joint is shown. This image extends through the lateral cortical margin of the odontoid, which is incompletely visualized. The anterior arch of C1 is obliquely visualized as it curves posterolaterally. The lateral extension of the cruciate ligament and the transverse ligament is prominent.* **(Middle)** *The relationship of the occipital condyle, C1 lateral mass + the atlantoaxial joint is highlighted in this image. The articular surface of occipital condyle is convex, and the superior facet of C1 is concave allowing for flexion/extension.* **(Bottom)** *More lateral image of the craniocervical junction shows the atlantooccipital joint and atlantoaxial joints with sharp, smooth cortical margins.*

TERMINOLOGY

Synonyms

- Uncovertebral joint (joint of Luschka)
- C1 (atlas), C2 (axis)

Definitions

- Subaxial cervical spine = C3-C7

GROSS ANATOMY

Overview

- Consists of 7 vertebrae (C1-C7)
  - **Craniocervical junction (CCJ)**: C1, C2, & articulation with skull base constitute craniocervical junction
  - **Subaxial spine**: C3-C7
    - C3-C6 typical cervical vertebrae
    - C7 has features that differ slightly from C3-C6

Components of Subaxial Cervical Spine

- **Bones C3-C7**
  - **Body**
    - Small, broader transversely than in AP dimension
    - Posterolateral edges of superior surface are turned upward = uncinate process
  - **Vertebral arches**
    - Pedicle: Delicate, project posterolaterally
    - Lamina: Thin and narrow
    - Vertebral foramen: Large, triangle-shaped
  - **Transverse processes**
    - Project laterally and contain foramen for vertebral artery
    - Anterior and posterior tubercles are separated by superior groove for exiting spinal nerve
  - **Articular processes**
    - Superior and inferior articular processes with articular facets oriented ~ 45° superiorly from transverse plane
    - Form paired osseous shafts posterolateral to vertebral bodies = articular pillars
  - Spinous process: Short and bifid
  - **C7 unique features**
    - Spinous process: Long, prominent
    - Transverse process: Short and project inferolaterally compared with T1 spinous processes, which are long & project superolaterally
- **Intervertebral foramen**
  - Oriented anterolaterally below pedicles at ~ 45° to sagittal plane
- **Joints**
  - Intervertebral disc
    - Narrowest in cervical region
    - Thinner posteriorly than anteriorly
    - Do not extend to lateral margins of vertebral bodies in cervical spine → joints of Luschka
  - **Uncovertebral joint** (joints of Luschka)
    - Oblique, cleft-like cavities between superior surfaces of uncinate processes & lateral lips of inferior articular surface of next superior vertebra
    - Lined by cartilaginous endplate of vertebral body
    - No true synovial lining present; contains serum, simulating synovial fluid
    - Uncinate process develops during childhood with uncovertebral joint forming by fibrillation and fissuring in fibers of annulus fibrosus
  - **Facet (zygapophyseal) joints**
    - Facet joints oriented ~ 45° superiorly from transverse plane in upper cervical spine; assume more vertical orientation toward C7
    - Formed by articulation between superior & inferior articular processes = articular pillars
    - Form 2 sides of flexible tripod of bone (vertebral bodies, right and left articular pillars) for support of cranium
- **Ligaments**
  - Anterior & posterior longitudinal, ligamentum flavum, interspinous & supraspinous ligaments
  - Additional ligaments of CCJ include apical, alar, and cruciate ligaments
- **Biomechanics**
  - Subaxial cervical spine shows free motion range relative to remainder of presacral spine
    - Cervical extension checked by anterior longitudinal ligament & musculature
    - Cervical flexion checked by articular pillars & intertransverse ligaments

IMAGING ANATOMY

Lateral Assessment of Subaxial Spine

- Principles apply equally to radiography, CT, or MR
- **Prevertebral soft tissues**: Distance between air column and anterior aspect of vertebral body
  - Adults: < 7 mm at C2 & < 22 mm at C6
  - Child: < 14 mm at C6
- Bony alignment
  - **Anterior vertebral line**: Smooth curve paralleling anterior vertebral cortex
    - Less important than posterior cortical line
  - **Posterior vertebral line**: Smooth curve paralleling posterior vertebral cortex
    - Translation > 3.5 mm is abnormal
    - Flexion and extension allow physiological offset < 3 mm of posterior cortical margin of successive vertebral bodies
  - **Spinolaminar line**: Smooth curve from opisthion to C7 formed by junction of laminae with spinous processes
  - **Spinous process angulation**: Cervical spinous processes should converge toward common point posteriorly
    - Widening is present when distance is > 1.5x interspinous distance of adjacent spinal segments

Frontal Assessment of Subaxial Spine

- Lateral masses: Bilateral smooth undulating margins
- Spinous processes: Midline
  - Lateral rotation of 1 spinous process with respect to others is abnormal
- Interspinous distance: Symmetric throughout
  - Interspinous distance 1.5x distance of level above or below is abnormal