1 Craniovertebral Junction

Nader S. Dahdaleh

Summary
The craniocervical junction is composed of two joints, the atlanto-occipital and atlantoaxial joints along with their surrounding ligamentous and muscular attachments.

Keywords: craniocervical junction, craniovertebral junction, atlas, axis

1.1 Key Points

- The craniovertebral junction (CVJ) is composed of the occiput (O), atlas (C1), and axis (C2) along with the atlantoaxial and atlantooccipital joints (**Fig. 1.1**).
- The CVJ is a very flexible junction accounting for at least 50% of the range of motion of the cervical spine in all planes. The joint orientation determines the direction of motion, and the ligaments determine the biomechanical stability of this junction (**Fig. 1.2**).

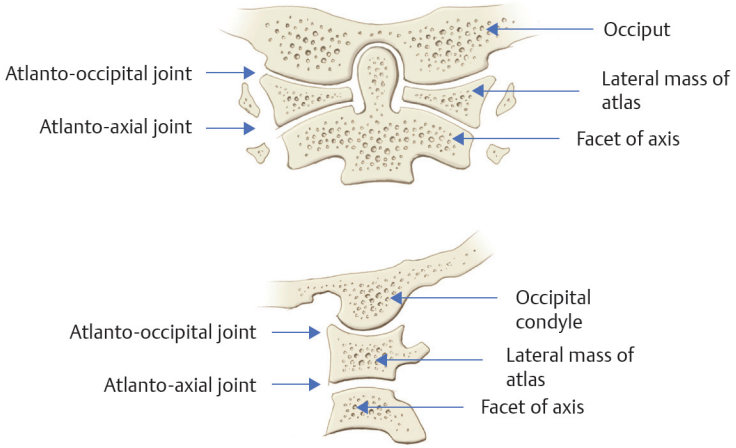

Fig. 1.1 Craniovertebral junction (CVJ) anterior (top) and lateral (bottom) views.

Motion	OC–C1	C1–2
Flexion/Extension	23°–24.5°	10.1°–22.4°
Lateral bending	3.4°–5.5°	6.7°
Axial rotation	2.4°–7.2°	23.3°–38.9°

Fig. 1.2 Craniovertebral junction (CVJ) range of motion.

1.2 Bony Anatomy

- The CVJ consists of the base of the occiput, the atlas (C1), and the axis (C2).
- The foramen magnum boundaries consist of the basion anteriorly, the opisthion posteriorly, and the occipital condyles anterolaterally.
- The atlas (C1) is composed of an anterior arch, a posterior arch, and two lateral masses (**Fig. 1.3**).
- The atlantooccipital joint is cup like in the coronal and sagittal plane allowing for flexion/extension and little axial rotation.
- The C1 anterior tubercle is the attachment site of the anterior longitudinal ligament (ALL) and the longus coli muscle.
- The vertebral artery (VA) and C1 nerve run along the superior lateral groove on C1 (sulcus arteriosus). In less than 15% of the population, the groove is roofed, forming the arcuate foramen.
- The axis (C2) consists of the body, odontoid process (dens), articulating surfaces, pedicles, pars interarticularis lamina, and large, bifid spinous process (**Fig. 1.4**).
- The atlantoaxial joint is convex in orientation allowing for axial rotation about the dens.

1.3 Neural Anatomy

- Cervical nerve roots exit above their corresponding level (e.g., the C2 nerve root exits above the C2 pedicle).
- C1 nerve root: The posterior division (suboccipital nerve) is more prominent than the anterior division. It innervates suboccipital muscles and occasionally branches to the lesser/greater occipital nerve.
- C2 nerve root: Posterior, medial (greater occipital nerve), and lateral divisions innervate suboccipital muscles and scalp from occiput to vertex. It may be sacrificed during atlantoaxial or occipitocervical fusions to enhance the exposure of the lateral mass for lateral mass screw placement and/or to access the atlantoaxial joint for direct arthrodesis.
- The lesser occipital nerve is formed by dorsal divisions of C2 and C3.

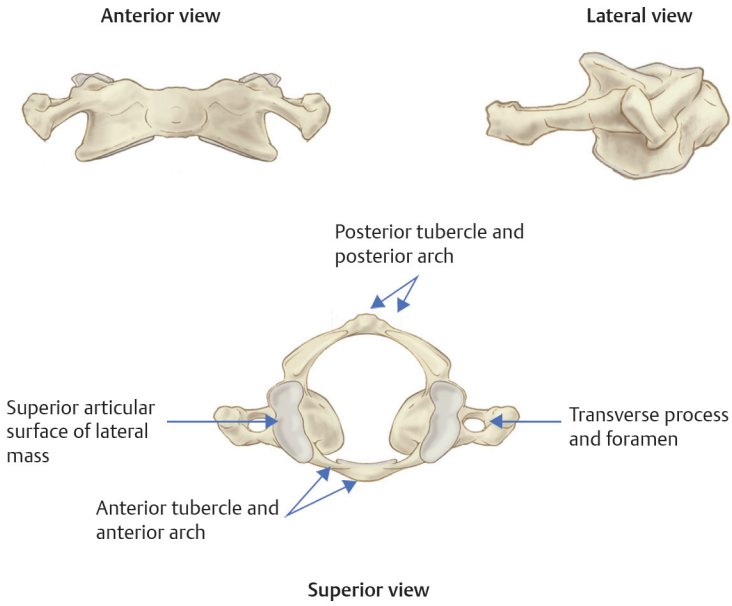

Fig. 1.3 The atlas.

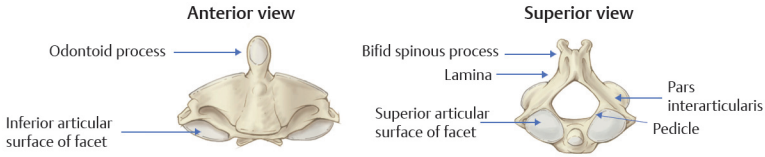

Fig. 1.4 The axis.

1.4 Vascular Anatomy

- The voluminous vertebral venous plexus that surrounds the horizontal portion of the V3 segment of the VA is encased in the suboccipital fascia. If the planes of dissection are respected, the plexus can be preemptively coagulated during exposure of the CVJ.
- The VA leaves the C2 transverse foramen (becoming V3). It takes a 45 degrees lateral projection and ascends (vertical portion of V3) into the C1 transverse foramen.

- The VA then courses medially (horizontal portion of V3) along the C1 sulcus arteriosus and then anteriorly through the atlantooccipital membrane, where it becomes intradural (beginning of V4 segment).
- Blood is supplied to the CVJ primarily through branches of the vertebral and occipital arteries.
- Blood supply to the CVJ emanate from extensions of the VA from the subaxial spine. The anterior and posterior ascending arteries branch from the VA at C2–C3, entering the vertebral column supplying the axis before anastomosing to form the apical odontoid arcade that supplies the atlas and dens.

The occipital artery completes the superior portion of the arcade.

- Lymphatic drainage of the CVJ is through retropharyngeal and deep cervical nodes.

1.5 Muscular Anatomy (Table 1.1)

- Muscular layers:
  - Superficial:
    - Trapezius.
    - Sternocleidomastoid.
  - Intermediate:
    - Splenius capitis.
  - Deep:
    - Semispinalis capitis.
  - Deepest (suboccipital muscles and triangle): The following muscles comprise the borders of the suboccipital triangle:
    - Rectus capitis posterior major and minor: Medial.
    - Obliquus capitis superior: Lateral.
    - Obliquus capitis inferior: Inferior.

1.6 Ligamentous Anatomy (Table 1.2)

The anterior ligaments can be divided into four layers. From anterior to posterior[1,2]:

- 1st layer: Atlantooccipital membrane.
- 2nd layer: Apical and alar ligaments.
- 3rd layer: Cruciate ligament (superior curx, transverse atlantal, and inferior crux).
- 4th layer: Tectorial membrane (continuation of PLL).

The biomechanical stability of the CVJ is primarily derived from its ligamentous attachments. The ligaments that contribute the most to its stability are

Table 1.1 Craniovertebral junction musculature: their attachments and modes of action

Muscle	Attachments	Action
Trapezius	Origin: Occipital bone, the ligamentum nuchae, and the spinous processes of T01–T12 Insertion: Lateral third of the clavicle and the scapula (acromion and scapular spine)	Stabilize and move the scapula
Sternocleidomastoid muscle (SCM)	Origin: Sternum, clavicle Insertion: Temporal bone (mastoid process), occipital bone	Contralateral head rotation, neck flexion
Splenius capitis	Origin: Lower half of the nuchal ligament and the spinous processes of C7–T3 vertebrae Insertion: Temporal bone (mastoid process), occipital bone	Unilaterally: Lateral bending and rotation of head to ipsilateral side Bilaterally: Extension of the head and cervical spine
Semispinalis capitis	Origin: Transverse and articular processes of C4–C7, transverse processes of T1–T6 Insertion: Between superior and inferior nuchal lines of occipital bone	Unilaterally: Lateral bending and rotation of head to ipsilateral side Extension, rotation, and lateral bending of head and cervical spine
Rectus capitis posterior major and minor	Origin: Posterior tubercle of atlas (minor), spinous process of C2 (major) Insertion: Medial part of inferior nuchal line of occipital bone	Bilateral contraction at the atlantooccipital joint: Head extension Unilateral contraction at the atlantoaxial joint: Head rotation (ipsilateral)
Obliquus capitis superior muscle of occipital bone (between superior and inferior nuchal lines)	Origin: Transverse process of atlas Insertion: Occipital bone (between superior and inferior nuchal lines)	Bilateral contraction at atlantooccipital joint: Head extension Unilateral contraction at atlantoaxial joint: Head lateral flexion (ipsilateral)

(Continued)

Table 1.1 (*Continued*)

Muscle	Attachments	Action
Obliquus capitis inferior	Origin: Spinous process and lamina of axis Insertion: Inferior aspect of the tip of the transverse process of the atlas	Rotation at the atlantoaxial joint

Table 1.2 Principal craniovertebral junction ligaments: their attachments and modes of action

Ligament	Attachments	Action
Apical	Odontoid tip (superiorly) to basion in apical cave	No significant function
Alar (paired)	Occipital–alar: Odontoid tip to occipital condyles Atlantoalar: Odontoid tip to lateral masses of atlas	Limit axial rotation and lateral bending on contralateral side and may limit anterior displacement of atlas. If transverse ligament ruptures, becomes primary ligament preventing atlantoaxial subluxation.
Cruciate	Superior: Posterior odontoid to upper clivus Inferior: Posterior odontoid to posterior surface of C2 body Transverse component: Medial tubercles of C1 lateral masses to posterior dens	Transverse component is the primary stabilizing ligament of the AAJ by keeping odontoid locked against anterior ring of C1, preventing anterior subluxation of atlas on axis. Permits axial rotation. Superior and inferior limbs offer minimal stability.
Tectorial	Posterior aspect of vertebral bodies, superiorly to IAC; continuation of PLL	Limit extension and flexion with little to no impact on stability. Prevents odontoid from compression of ventral cervical spinal cord.
ALL	Anterior aspect of vertebral bodies	Limits hyperextension, distraction.
Accessory atlantoaxial	C2 body laterally to medial C1 lateral masses	No biomechanical studies available. May mimic alar ligament function.

Table 1.2 (*Continued*)

Ligament	Attachments	Action
Capsular	O–C1 and C1–C2 articulating facets	Stabilizes natural motion of facet joints.
Anterior and posterior	Anterior: Anterior C1 tubercle to anterior rim of foramen magnum	AAO: May limit extension of atlantooccipital joint (AOJ). Limited studies. PAO: No significant role in stability.
Atlantooccipital membranes	Posterior: C1 posterior arch to posterior rim of foramen magnum	
Lateral atlantooccipital ligament	Anterolateral aspect of C1 transverse process to jugular process of occipital bone	No biomechanical studies available. May limit lateral flexion of contralateral side.
Barkow ligament	Horizontal band attaching anteromedial aspect of the occipital condyles to the attachment of the alar ligaments	May limit extension of O–C1 joint. May inhibit lateral displacement of a unilateral occipital condyle fracture. The transverse ligament must be intact for the Barkow ligament to function properly.
Atlantodental ligament	Horizontal band attaching anterior base of the dens to internal aspect of anterior arch of the atlas	Helps maintain predental space (along with transverse and alar ligaments). Limits axial rotation before alar ligaments. Limits posterior displacement of dens before transverse ligament.
Nuchal ligament	Cephalic extension of the supraspinous ligament extending from C7 spinous process to inion	Restricts hyperflexion of the cervical spine.

Abbreviations: AAJ, atlantoaxial joint; AAO, atlantooccipital joint; ALL, anterior longitudinal ligament; IAC, internal auditory canal; O, occiput; PAO, posterior atlantooccipital membrane; PLL, posterior longitudinal ligament.

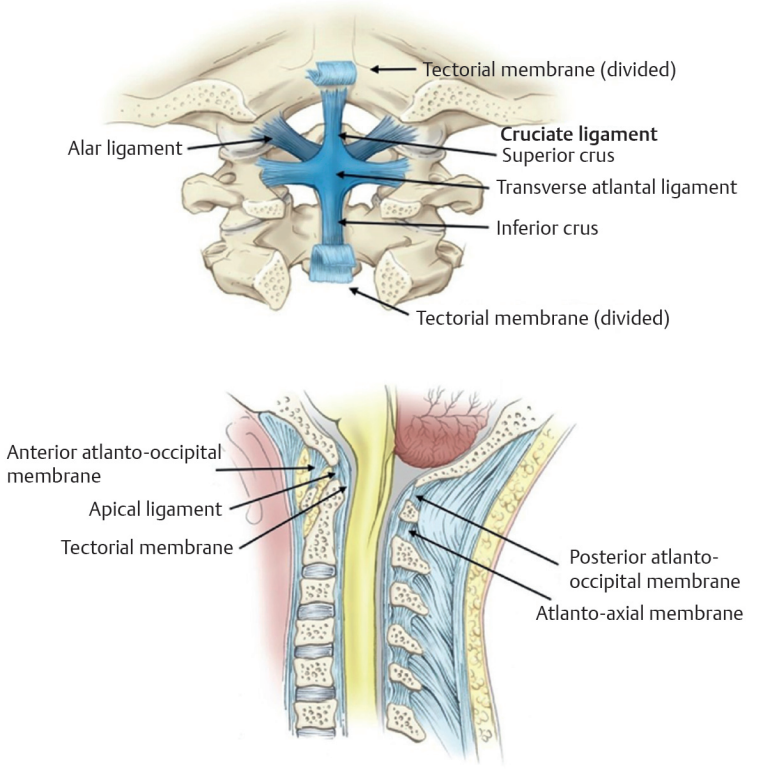

Fig. 1.5 Craniovertebral junction (CVJ) ligaments.

the paired alar ligaments which limit axial rotation and lateral bending, the transverse atlantal ligaments which limit flexion and extension of the atlantoaxial joint, and the facet capsular ligaments (**Fig. 1.5**).

1.7 Surgical Pearls

- While exposing the posterior arch of C1, monopolar cautery should be used with caution and not beyond 7 mm on both sides of the midline lateral to the posterior tubercle. Following that a dissector (Penfield number 1) is used to complete the subperiosteal dissection laterally. This is an effort to avoid heat injury to the VA coursing in the sulcus arteriosus.
- The vertebral venous plexus around C2 ganglion may cause considerable bleeding, which should not be mistaken for VA injury. Patience and the use

of hemostatic agents (e.g., Gelfoam, Floseal) are placed while exposing the other side is attempted.
- Vascular imaging such as a computed tomography angiography (CTA) or magnetic resonance angiography (MRA) is key in understanding the location, course, and dominance of the vertebral arteries.
- While placing C1 lateral mass screws, aiming at a bicortical purchase is important to improve screw pullout strength. However, the screw tip must not be more than 2 to 3 mm beyond the anterior cortex. This is in order to avoid an injury to the structures ventral to the C1 anterior arch such as the oropharynx, carotid artery, and hypoglossal nerve.

Common Clinical Questions

1. How many ossification centers C1 and C2 are formed from?
2. What forms the continuation of the posterior longitudinal ligament (PLL) at the CVJ?
3. What persistent carotid–vertebrobasilar anastomoses may be encountered in the CVJ?
4. The fourth sclerotome, the proatlas, is a precursor to which structures?

Answers to Common Clinical Questions

1. C1 is formed by the fusion of three ossification centers and C2 is formed by the fusion of four ossification centers by the age of 6 to 8 years.
2. Tectorial membrane.
3. Proatlantal intersegmental artery and persistent hypoglossal artery.
4. Anterior tubercle of clivus, apical ligament, apex of dens, occipital condyles, U-shaped part of foramen magnum, alar and cruciate ligaments, superior portion of the posterior arch, and lateral masses of the atlas.

References

1. Menezes AH, Traynelis VC. Anatomy and biomechanics of normal craniovertebral junction (a) and biomechanics of stabilization (b). Childs Nerv Syst. 2008; 24(10):1091–1100
2. Lopez AJ, Scheer JK, Leibl KE, Smith ZA, Dlouhy BJ, Dahdaleh NS. Anatomy and biomechanics of the craniovertebral junction. Neurosurg Focus. 2015; 38(4):E2