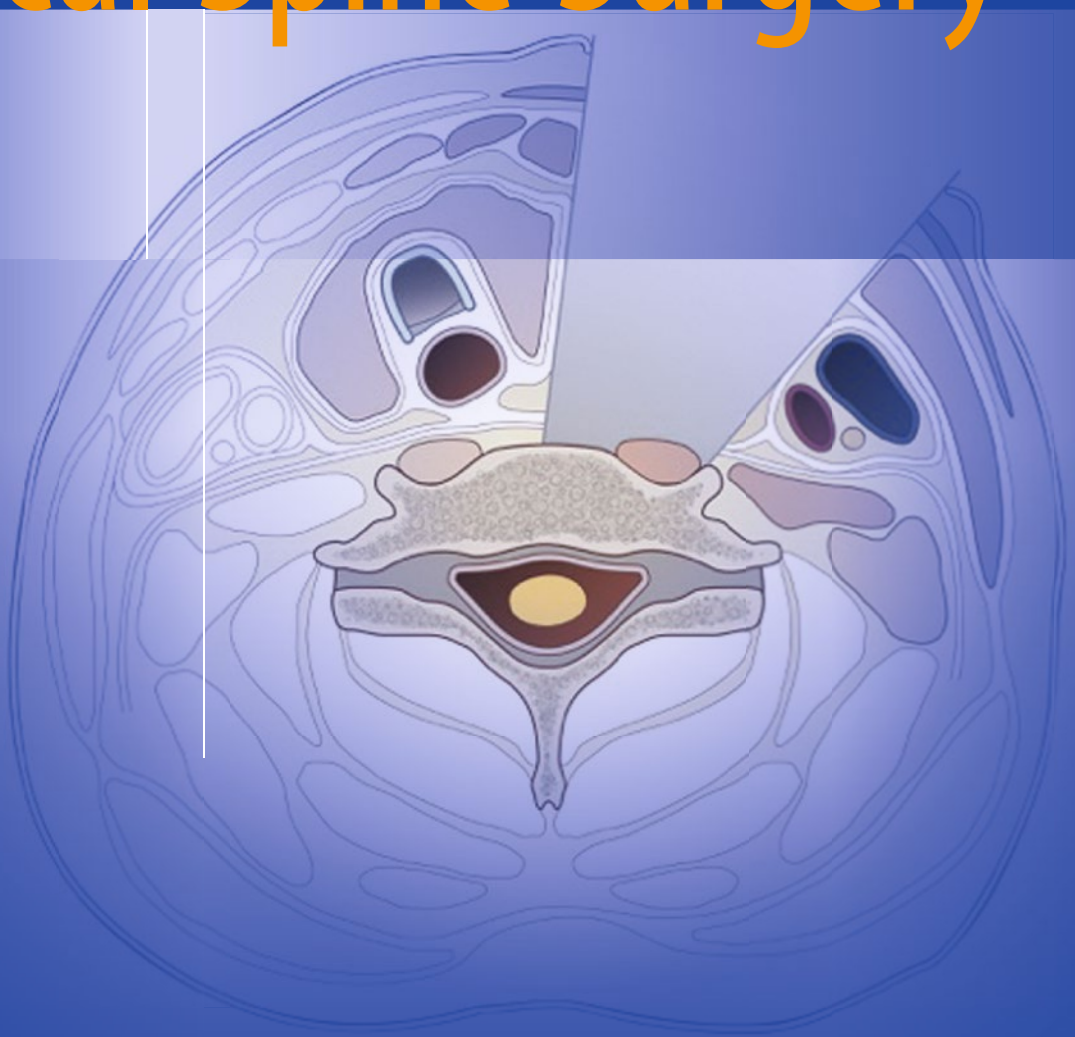
Stefano Boriani · Livio Presutti
Alessandro Gasbarrini
Francesco Mattioli *Editors*

Atlas of Craniocervical Junction and Cervical Spine Surgery



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Contents

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Part I

Anatomy

Anatomy of Craniocervical Junction

1

M. Alicandri-Ciufelli, M. Menichetti, M.P. Alberici, and L. Presutti

1.1 Osseous Anatomy

The craniocervical junction (CCJ) is an osteoligamentous complex between the occiput, atlas and axis, which provides both structural stability and movement [1].

1.1.1 Occipital Bone

The occipital bone extends from the clivus anteriorly to the lambdoid suture posteriorly, its embryologic origin being four primary cartilaginous centres laid down in the chondrocranium around the foramen magnum, and a fifth membranous element [2]. The superior nuchal line serves as a rough guide for the location of the transverse sinus, and the inion, found in the midline along this line, approximates the torcular herophili. The insertion of the semispinalis capitis may be the most accurate landmark for the confluence of the sinuses [3].

A fundamental anatomical part of the occipital bone is the foramen magnum, which has three parts:

1. The squamosal portion, located in the dorsal aspect of foramen magnum
2. The basal or clival portion located anterior to the foramen magnum
3. The condylar part that connects the squamosal and the clival parts [4]

The most posterior margin of the foramen magnum is called the opisthion. The most anterior midline of the foramen magnum is termed the basion. The sagittal diameter of the foramen magnum should be 35 ± 4 mm. The transverse diameter at the equator of foramen magnum is slightly less.

The condylar part includes the occipital condyles, which fall just at the level and anterior to the equator of the foramen magnum. The shape of these condyles positioned on either side of the foramen magnum allows the skull to articulate with the cervical spine, whilst the angles prevent excessive axial rotation at the craniocervical junction [5].

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1.1.2 **Atlas** (Fig. 1.1)

The atlas, first cervical vertebra, has its origins in the fourth occipital and first cervical sclerotomes. It is unique among vertebrae in not having a body and is formed from three ossification sites: the anterior arch or centrum and two neural arches which fuse in later life to become a unified posterior arch, thereby completing the osseous ring which surrounds the spino-medullary junction [6]. An appreciation that this ring is incomplete in up to 5% of patients is important if one is to avoid causing a durotomy or spinal cord injury when approaching the craniocervical junction posteriorly [7, 8].

The ring of the atlas consists approximately of one-fifth anterior arch, two-fifths posterior arch, with the remaining two-fifths being contributed by the lateral masses [9]. The longus colli muscles and the anterior longitudinal ligament, which contribute to anterolateral flexion and resistance to hyperextension of the cervical spine respectively, are attached to the anterior tubercle found in the midline on the anterior arch. Two important membranes also arise from this portion of the atlas: the anterior atlanto-occipital membrane, connecting the atlas to the occipital bone, and the anterior atlantoaxial ligament extending from the atlas to the axis immediately inferior. Atlantal lateral masses have both a superior articular facet and an inferior articular facet. These true synovial joints allow articulation with the occipital condyles and the axis, respectively. The atlanto-occipital joints' orientation at caudal angles of 129° from lateral to medial limits the rotation possible, compared with the atlantoaxial joint with a cranially biased angulation of between 130° and 135°, where much greater rotation is possible [10]. A posterior tubercle is found in the midline posteriorly providing attachment for the rectus capitis and the ligamentum nuchae. The posterior atlanto-occipital membrane extends from the superior border of the posterior arch of the atlas to the anterior surface of the rim of the foramen magnum [11, 12].

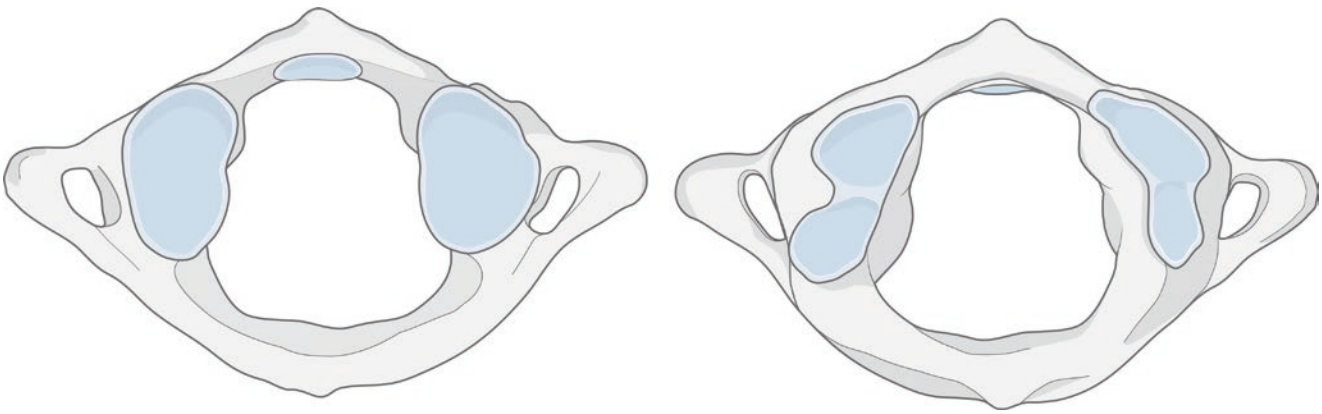

Fig. 1.1 C1 anatomy

1.1.3 **Axis** (Fig. 1.2)

The axis is the second cervical vertebra, and it is called the epistropheus (literally "to twist") because of its configuration that forms the pivot for the atlas and the head to rotate. The axis is formed from five ossification centres: one in the body, one in each vertebral arch and two in the odontoid process [13]. The odontoid process projects cephalad from its articulation with the axis body. On the ventral odontoid surface is an oval facet, which articulates with the dorsal surface of the anterior arch of the atlas. In the dorsal aspect of the dens, there is a transverse groove over which passes the transverse ligament of the atlas. The axis has a spinous process, which is large and deeply concave on its caudal border, that makes the axis the first bifid vertebra in the cervical spine [4].

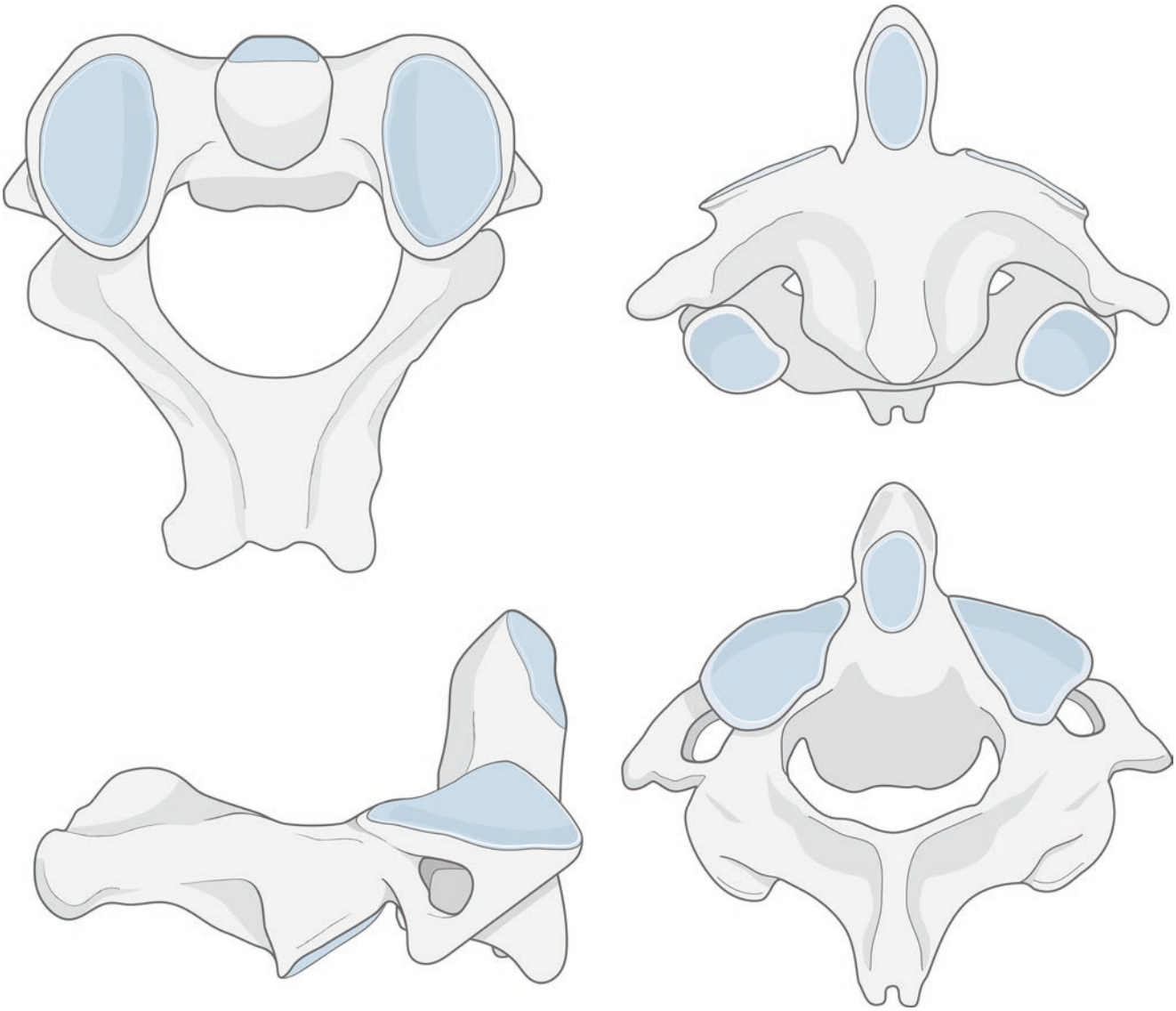

Fig. 1.2 C2 anatomy

1.2 Articular and Ligamentous Anatomy

The CCJ is composed of two major joints: the atlanto-occipital and the atlanto-axial. These joints are responsible for the majority of the movements of the cervical spine and operate on different biomechanical principles. The mechanical properties of the atlanto-occipital joint are primarily determined by bony structures, whereas the mechanical properties of the atlantoaxial joint are mainly determined by ligamentous structures [14, 15]. The prominent movements at the atlanto-occipital joint are flexion and extension. The primary movement at the atlantoaxial joint is axial rotation [16] (Figs. 1.3 and 1.4).

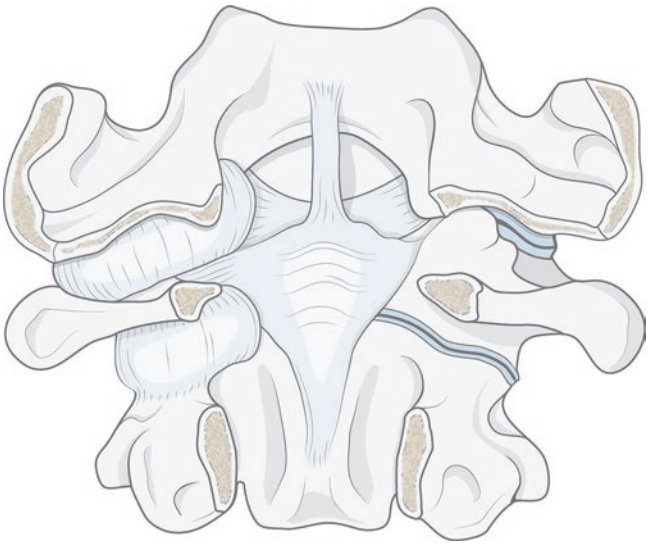

Fig. 1.3 Ligaments of upper cervical spine, posterior view

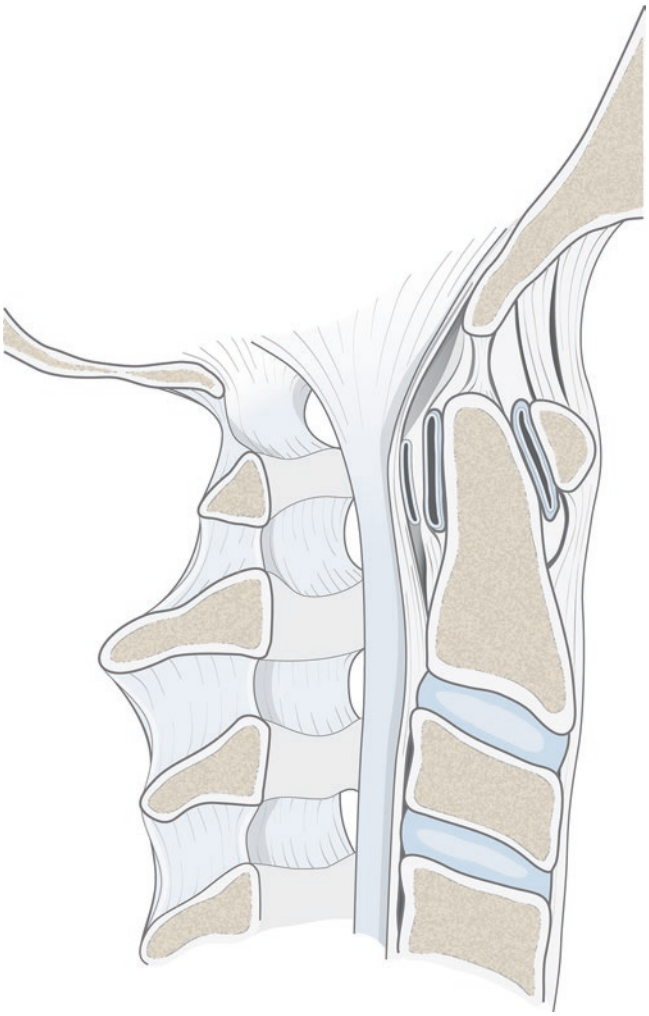

Fig. 1.4 Ligaments of upper cervical spine, sagittal view

1.2.1 Transverse Ligament

The transverse ligament of the atlas is the key component of the cruciform ligament and is one of the most important ligaments in the body. It is the largest, strongest and thickest craniocervical ligament (mean height/thickness 6–7 mm) [17]. The superior and inferior limbs of the cruciform ligament are extremely thin and offer no known craniocervical stability, whilst the transverse ligament maintains stability at the CCJ by locking the odontoid process anteriorly against the posterior aspect of the anterior arch of C-1, and it divides the ring of the atlas into two compartments: the anterior compartment houses the odontoid process, and the posterior compartment contains primarily the spinal cord and spinal accessory nerves. The transverse ligament runs posterior to the odontoid process of C-2 and attaches to the lateral tubercles of the atlas bilaterally. A synovial capsule is located between the odontoid process and the transverse ligament.

The ligament also has a smooth fibrocartilaginous surface to allow the odontoid process to glide against it [4]. The tectorial membrane, epidural fat and dura mater are located dorsal to the transverse ligament [17].

1.2.2 Alar Ligament

The alar ligament attaches the axis to the base of the skull, from the lateral aspects of the odontoid process to the anterolateral part of the foramen magnum and/or on the medial aspect of the occipital condyles [18–20].

1.2.3 Transverse Occipital Ligament

The transverse occipital ligament (TOL) is a small accessory ligament of the CCJ that is located posterosuperior to the alar ligaments and the odontoid process. It attaches to the inner aspect of the occipital condyles, posterosuperior to the alar ligament, superior to the transverse ligament, and extends horizontally across the foramen magnum [21].

Dvorak et al. [18] stated that the TOL is only present in about 10 % of the population, whereas Lang [1] identified the TOL in approximately 40 % of their specimens. The discrepancies in the occurrence of the TOL in specimens could be due to its proximity and similar morphology to the alar ligament that makes it difficult to distinguish the two easily.

1.2.4 Accessory Atlantoaxial Ligament

The accessory atlantoaxial ligament is an important but often ignored ligament that inserts medially into the dorsal surface of the axis and courses laterally and superiorly to insert on the lateral mass of the atlas, posterior to the transverse ligament [22, 23].

Tubbs et al. [24] suggested that this ligament could be more appropriately named the accessory atlantal-axial-occipital ligament, to underline its anatomical attachments.

1.2.5 Lateral Atlanto-Occipital Ligament

The lateral atlanto-occipital (LAO) ligament is another ligament of the CCJ that has been neglected in the literature.

It runs just lateral to the anterior atlanto-occipital membrane, attaching to the anterolateral aspect of the transverse process of the atlas and inserting onto the jugular process of the occipital bone [25, 26]. This ligament runs immediately posterior to the rectus capitis lateralis muscle and has fibres that extend in the opposite direction to the muscle (i.e. muscle runs lateral to medial and ligament runs medial to lateral).

1.2.6 Barkow Ligament

Barkow ligament has been rarely described. It is a horizontal band attaching onto the anteromedial aspect of the occipital condyles anterior to the attachment of the alar ligaments. This ligament is located just anterior to the superior aspect of the dens with fibres travelling anterior to the alar ligaments, but there is no attachment to these structures.

Barkow ligament, present in 92 % of studied cases [20], inserts anterior to the alar ligaments and is often adherent to the anterior atlanto-occipital membrane. Its primary function is thought to be in resisting extension of the atlanto-occipital joint, acting synergistically with the anterior atlanto-occipital membrane to achieve this.

1.2.7 Apical Ligament

The apical ligament, also known as the middle odontoid ligament or suspensory ligament, attaches the tip of the odontoid process to the basion. The ligament runs in the triangular area between the left and right alar ligaments known as the supraodontoid space (apical cave) [27] and travels just posterior to the alar ligaments and just anterior to the superior portion of the cruciform ligament.

1.2.8 Tectorial Membrane

The tectorial membrane is a thin structure at the CCJ that serves as the posterior border to the supraodontoid space [27]. It runs posterior to the cruciform ligament, and the accessory atlantoaxial ligament runs along its lateral border. The tectorial membrane is composed of 2–3 distinct layers

that run the length of the ligament and then fuse together at the posterior longitudinal ligament.

The outermost layer is the widest and attaches as far laterally as the hypoglossal canals. The second layer is thicker and runs from the clivus to the body of the axis. A small bursa is often present between the two layers over the odontoid process. The third layer is the deepest and is discontinuous as it attaches to the clivus above and then becomes frayed in the area over the odontoid apex.

Nerves and vessels often run between the different layers of the tectorial membrane [27]. Descriptions of the tectorial membrane are insufficient and inconsistent regarding the anatomy and function.

1.2.9 Posterior Atlanto-Occipital Membrane

The posterior atlanto-occipital (PAO) membrane is a broad, thin ligament that attaches to the posterior arch of the atlas inferiorly to the posterior rim of the foramen magnum superiorly. It is continuous with the posterior atlantoaxial membrane and then the ligamentum flavum inferiorly [28]. This structure has been noted by several authors to extend laterally over the atlanto-occipital joint capsules [29]. The PAO membrane runs adjacent to the rectus capitis posterior minor muscle posteriorly and the spinal dura mater anteriorly. Several authors have noted connection or interdigitation of the PAO membrane with both the rectus capitis posterior minor muscle and the spinal dura mater [30–32].

1.2.10 Anterior Atlanto-Occipital Membrane

The anterior atlanto-occipital (AAO) membrane is a thin structure that attaches the anterior aspect of the atlas to the anterior rim of the foramen magnum [19, 20, 27–32]. It is located just posterior to the prevertebral muscles of the neck and anterior to Barkow ligament. Tubbs et al. [20] observed a connection of Barkow ligament to the midline onto the AAO membrane. The AAO membrane also serves as the anterior wall of the supraodontoid space, which houses the alar, apical and Barkow ligaments, as well as fat and veins [27].

1.2.11 Nuchal Ligament

The nuchal ligament is the cephalic extension of the supraspinous ligament, extending from the C-7 spinous process to the inion of the occipital bone. With the shorter spinous processes of the cervical vertebrae and the lordotic curve of the cervical spine, this ligament forms a midline septation dividing the posterior neck muscles on left and right sides. Moreover, some of these muscles attach medially to this structure.

1.3 Muscular Anatomy

The muscles of the craniocervical junction do not limit movements of the joints. It was felt that they only had a minor role in motion of the CVJ. Their principle function is one of initiating and maintaining movement of the craniocervical region [33]. They have been grouped into those that cause extension, flexion, abduction, adduction and rotation.

The muscles involved with the C1–C2 complex on the anterior aspect are the recti capitis anterior and lateralis, both stretching from the anterior aspect of the transverse process of C1, respectively, to the inferior surface of the basilar occipital bone. The longus capitis extends from the inferior surface of the basilar occipital bone and clivus to its attachment on the transverse processes of the third to sixth cervical vertebrae. The longus colli is placed anterior to the vertebral column and covered by the longus capitis in its superior aspect. It is divided in three parts and attaches to the transverse processes of the cervical and first thoracic vertebrae, as well as to the anterior aspect of the bodies of the first thoracic vertebrae.

On the posterior aspect, the short and thick bifid spinous process of C2 gives attachment to three muscles (Fig. 1.5):

- Semispinalis cervicis, extending from the second to fifth cervical spines to the transverse processes of the upper five or six thoracic vertebrae
- Inferior oblique, extending to the transverse process of C1 and forms the inferior limit of the suboccipital triangle

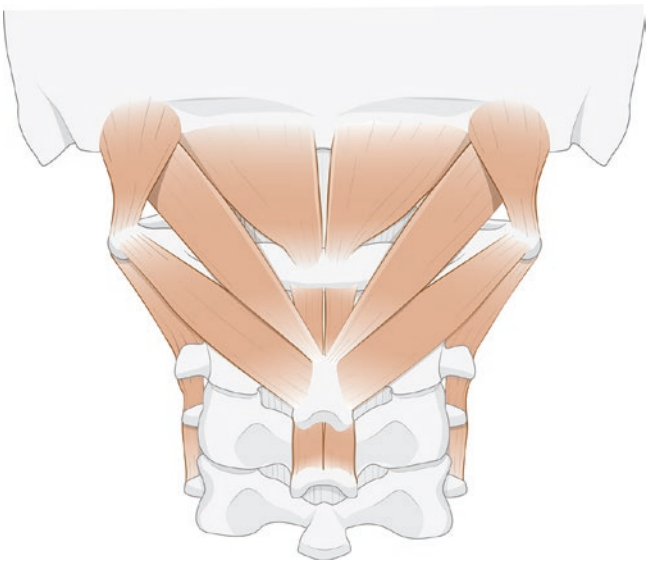

Fig. 1.5 Short neck muscles, posterior view