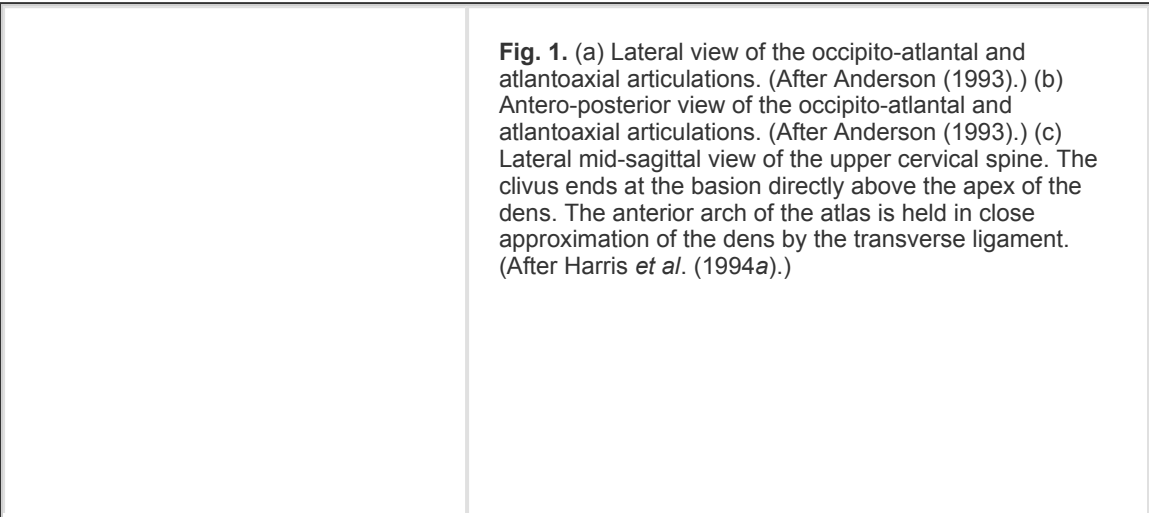# Basic science

*Part of* "3.42 - Upper cervical spine trauma"

Anatomy

The variable anatomy of the upper cervical spine leads to many injury patterns that pose difficulties for treating physicians in their ability to recognize and provide adequate treatment. The upper cervical spine has a large spinal canal, making spinal cord injury less frequent; however, spinal cord injuries, when present, may be associated with mortality secondary to impairment of ventilation. Functionally, the upper cervical spine forms a transition between the cranial vault and the spinal column. The region between the occiput and the axis protects the brainstem, spinal cord, and vertebral arteries, yet maintains a large range of motion. There is little intrinsic bony stability, relationships being maintained by stout ligamentous structures. The vertebral arteries must traverse from their location laterally in the foramen transversarium in C2, move medially to penetrate the posterior occipito-atlantal membrane and then enter the foramen magnum. Despite this tortuous route, injury to the vertebral artery is clinically rare.

Bony anatomy (Fig. 1)

The occipital condyles are paired projections from the caudal surface of the occipital skull base. They are semilunar in shape and form the anterolateral wall of the foramen magnum. Viewed from the anteroposterior direction, they are wedge-shaped, extending more medially than laterally. Together, the two occipital condyles form a cup-like projection that lies in the corresponding concavities of the atlas. The alar ligaments attach to the anteromedial surface of the occipital condyle.

Fig. 1. (a) Lateral view of the occipito-atlantal and atlantoaxial articulations. (After Anderson (1993).) (b) Antero-posterior view of the occipito-atlantal and atlantoaxial articulations. (After Anderson (1993).) (c) Lateral mid-sagittal view of the upper cervical spine. The clivus ends at the basion directly above the apex of the dens. The anterior arch of the atlas is held in close approximation of the dens by the transverse ligament. (After Harris *et al*. (1994*a*).)
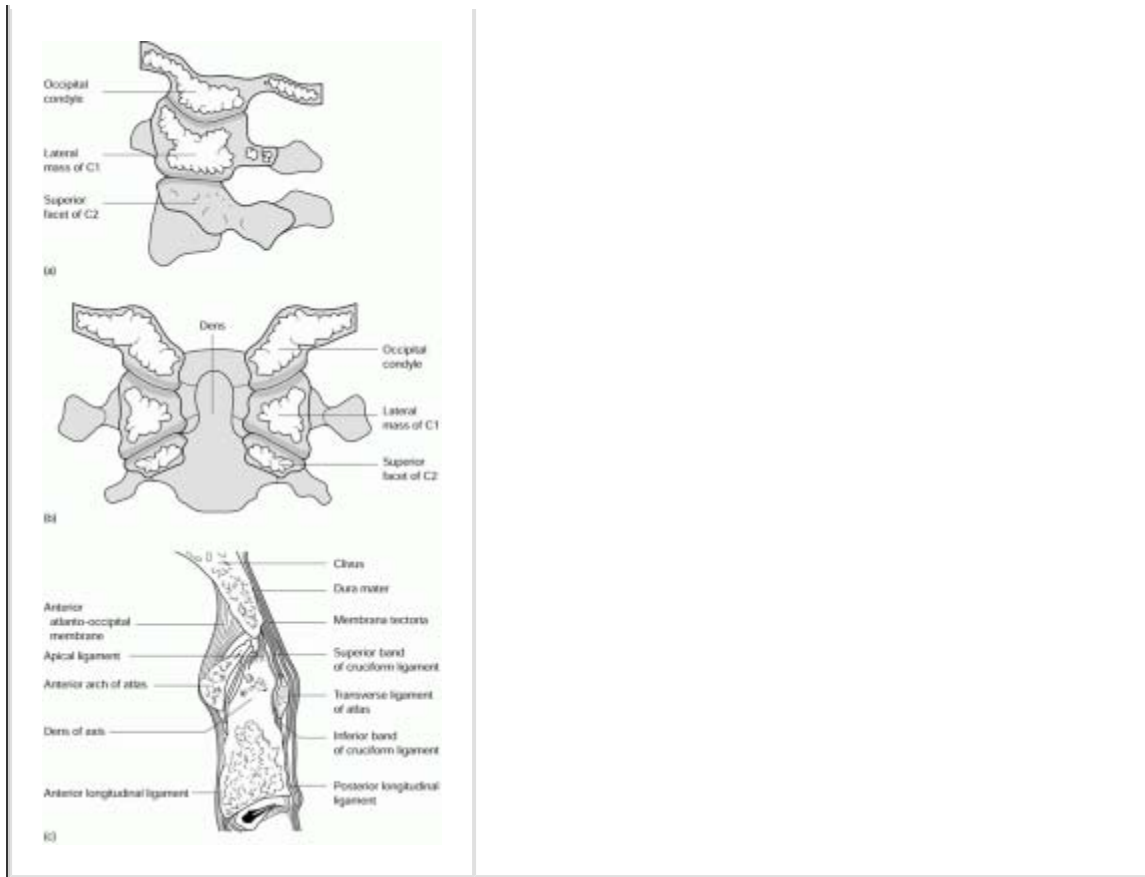
The atlas is a ring-like structure formed from two large lateral masses that are connected by anterior and posterior arches. The anterior arch is short and normally lies directly anterior to the odontoid process. The posterior atlas arch is longer and thinner. It is further weakened by a groove along the superior surface through which the vertebral arteries pass. Viewed ventrally, the lateral masses of the atlas are trapezoidal in shape, with the base lateral. Therefore it has a concave cranial surface, in which the occipital condyle is normally located. The atlas does not have a true spinous process but a small
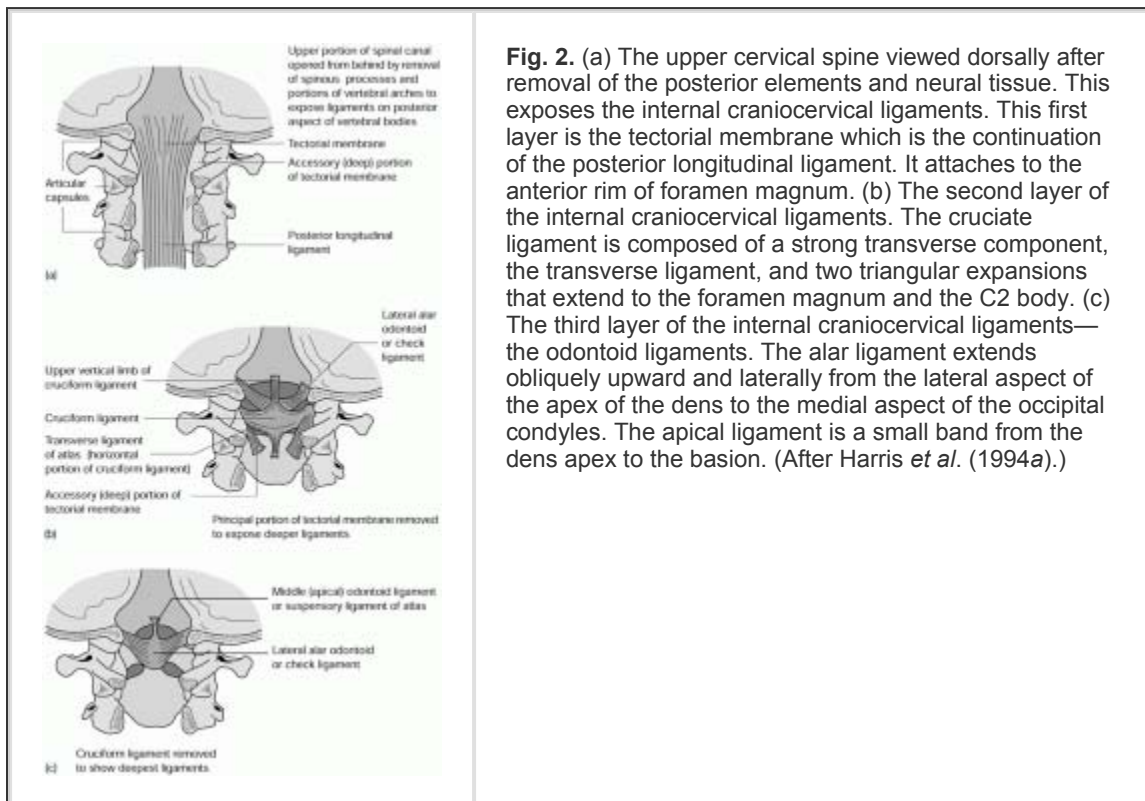
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tubercle is present in the midline. Paired tubercles lie on the medial surface of the lateral masses for attachment of the transverse ligament. The caudal surface of the atlas lateral masses and the cranial surface of the axis lateral masses are slightly convex which facilitates rotational motion. Laterally, the atlas has a transverse process and foramen transversarium through which passes the vertebral artery.

The axis is the largest of the cervical vertebrae and it is notable for a large cranial projection from the vertebral body, the odontoid process. The odontoid process or dens is angled slightly backwards and varies in internal diameter from 6 to 10 mm (Heller *et al.* 1992). This is an important dimension and determines the size and the number of screws that can be placed for treatment of odontoid fractures. This is best measured on an individual basis by preoperative CT or MRI. The superior facets that articulate with the atlas are lateral to the dens, while the inferior facets that articulate with C3 lie posterior to the C2 body. The superior facets are horizontal, whereas the inferior facets are sloped

upward at 30° to 40°, similar to those of the lower cervical spine. The superior and inferior facets of the axis are connected by a small tubular bone known as the pars interarticularis. The lamina of the axis are large and overlie or shingle the C3 lamina. The large bifid C2 spinous process is usually easily palpated.

Ligamentous anatomy (Fig. 2)

The ligaments of the upper cervical spine are essential to maintain stability. They span from the occiput to C2 and bypass the atlas, which acts merely as a bushing or washer. This unique relationship facilitates atlantoaxial rotation. The ligaments of the upper cervical spine can be categorized as external and internal craniocervical ligaments (Werne 1957).

Fig. 2. (a) The upper cervical spine viewed dorsally after removal of the posterior elements and neural tissue. This exposes the internal craniocervical ligaments. This first layer is the tectorial membrane which is the continuation of the posterior longitudinal ligament. It attaches to the anterior rim of foramen magnum. (b) The second layer of the internal craniocervical ligaments. The cruciate ligament is composed of a strong transverse component, the transverse ligament, and two triangular expansions that extend to the foramen magnum and the C2 body. (c) The third layer of the internal craniocervical ligaments—the odontoid ligaments. The alar ligament extends obliquely upward and laterally from the lateral aspect of the apex of the dens to the medial aspect of the occipital condyles. The apical ligament is a small band from the dens apex to the basion. (After Harris *et al*. (1994*a*).)

External craniocervical ligaments

The external craniocervical ligaments include the ligamentum nuchae, the anterior and posterior occipito-atlantal and atlantoaxial membranes, and the joint capsules of the atlantoaxial and occipito-atlantal articulations. The ligamentum nuchae is a strong condensation of fibers attached to the posterior tubercles of the spinous processes of C2 to T7 and to the external occipital protuberance. Ligamentum flava is not present above C2. Instead, thin posterior occipito-atlantal and atlantoaxial membranes are present which provide little protection during surgical dissection. Loose capsules enclose the diarthrodial atlantoaxial and occipito-atlantal joints.

Internal craniocervical ligaments

The internal craniocervical ligaments lie within the spinal column and stabilize the occipitocervical articulation. They form in three layers and are located anterior to the spinal cord. Most dorsal is the tectorial membrane which lies directly anterior to the ventral dura. This is a broad flat ligament that is a continuation of the posterior longitudinal ligament. It covers the dorsal surface of the dens and attaches to the anterior aspect of the foramen magnum. Lying under the tectorial membrane is the cruciate ligament. The strong horizontal component of the cruciate ligament is the transverse ligament which attaches to the tubercles on the anteromedial surface of the atlas. A synovial membrane is present between the transverse ligament and the dens. Vertical triangular bands extend from the transverse ligament, forming the cruciate shape, and attaches to the occiput at the foramen magnum and to the axis body. The odontoid ligaments are the most ventral structures and consist of the alar ligaments and the apical ligament. On each side, an alar ligament extends from the lateral dens tip to the anterior medial surface of the occipital

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condyle. The apical ligament is a small band that extends between the dens apex and the anterior rim of the foramen magnum.

Biomechanics and kinematics

The occipitocervical articulation is highly complex kinematically and biomechanically. The atlanto-occipital and atlantoaxial joints are coupled and should be considered together. Many of the ligamentous structures that stabilize one level have similar effects on the other. Also, injuries at one location are frequently associated with occult injuries adjacently. This occipito-atlantal articulation has an onerous biomechanical requirement to maintain stability, given the large head size, and yet allow motion. The range of motion between the occiput and the atlas is up to 25° of flexion and extension, 5° of lateral bending to each side, and 5° of rotation to each side (Werne 1957; White and Panjabi 1990). The atlantoaxial joint accounts for 50 per cent of overall head–neck rotation or approximately 40° to each side. Additionally, there is up to 20° of flexion–extension and 5° of lateral rotation at the atlantoaxial joint.

Biomechanically, the occipitocervical articulation is stabilized by the alar ligaments and tectorial membrane. In cadaveric studies, vertical diastasis between the occiput and atlas is limited to less than 2 mm by these structures (Werne 1957). Flexion of the occiput on the atlas is checked by impaction of the basion to the dens tip. Occipital extension is limited by the tectorial membrane. The alar ligaments are important in preventing excessive contralateral atlantoaxial rotation and lateral bending. Anteroposterior translation of the occiput on the atlas is limited because the occipital condyles lie in the concavities of the atlas and cannot translate forward because the tectorial membrane and alar ligaments hold them downward. The atlantoaxial joint is stabilized by the transverse ligament and the anterior arch of C1 which encloses the dens. Normally the atlas pivots about the dens. Excessive rotation to one side is prevented by the contralateral alar ligament. Posterior translation of the atlas is prevented by impaction of the anterior arch of the atlas and the dens.