Clinical Anatomy of the Ligaments of the Craniocervical Junction

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Joe Iwanaga and R Shane Tubbs

Introduction

The atlantooccipital joint (Figs. 1–4) is an important transitional region that supports and stabilizes the cranium, which is connected to the spine via surrounding ligamentous structures. An injury to this joint is often accompanied by brain injury and can be fatal. A good understanding of the anatomy of this joint is required for the timely diagnosis of an atlantooccipital joint instability and to then intervene via an immediate fixation. We will discuss the normal anatomy of, as well as anatomical variations, within the occipito-atlantoaxial complex and the classification systems used to describe its disruption and clinical significance.

General Bony Anatomy

The craniocervical junction unites both the C1 and C2 vertebrae (Figs. 5 and 6) and the occiput (Figs. 7 and 8). The atlantooccipital joint unites the occipital condyles and the superior articular surfaces (SAS) of the lateral mass of the atlas. The mean length, width, and height of the occipital condyles are 23.6mm, 10.5mm, and 9.2mm, respectively. The occipital condyles can be categorized according to their shapes: oval-shaped in the majority of individuals, S-shaped in a quarter of individuals, and triangular in less than 10% of individuals. The atlanto-axial joint is the articulation between the inferior articular facet of the atlas and the superior articular facet of the axis. This joint allows for head rotation, flexion, extension, and lateral flexion to a lesser degree.

Atlas

The atlas is made up of two lateral masses connected together by an anterior and a posterior arch (Figs. 9–11). The lateral masses bear the weight of the cranium. The SAS of the atlas is concave, thereby forming a framework for the convex occipital condyles, and is on the superior aspect of the lateral mass, which is trapezoid in shape and higher laterally than medially. The surface of the atlantooccipital joint has a C-shape and is concave medially. This joint is reinforced by a joint capsule.

Axis

The axis, which is also known as the second cervical vertebra or C2 vertebra (Figs. 12–13), consists of an odontoid process (dens), body, two lateral masses, two pedicles, two laminae, and a spinous process. This bone allows for axial rotation along with the atlas. It is ossified from five primary and two secondary ossification centers.

Odontoid Process

The fully formed odontoid process (Fig. 14) is a tooth-like/peg-shaped structure with a curved superior surface and which deviates either slightly to the left or to the right in approximately 14% to 26% of the population. It ranges from 15.5mm (± 1.8) in males and 14.6mm (± 1.5) in females, with an antero-posterior diameter of 10.3mm (± 0.7) in males and 9.6mm (± 0.9) in females. According to Lang, the mean transverse diameter of the odontoid process is 11.21mm in comparison to 10.5 and 9.8mm in Japanese males and females, respectively, and the mean height is 15.7mm as opposed to 17.9mm and 16.5mm in Japanese men and women.

The sagittal and transverse diameters are approximately 10.5 and 10mm, respectively. The anterior articular surface of the dens is circular or elliptical and is roughly 10 x 9mm. Tubbs et al., in their study on inclination of the odontoid process in pediatric Chiari I malformation, showed that the posterior angulation (retroflexion) of the odontoid process can be affected by sex: females have higher angulation grades, Chiari I malformation, and other skeletal disorders that affect the craniovertebral junction. It has been speculated that this posterior deviation of the odontoid process arises from a peri-odontoid inflammatory condition that remodels its apical part.

Occipital Bone

The human occipital bone (Figs. 8 and 9), like that of most other mammals, is ontogenetically and functionally distinct from other bones of the cranium. It is one of the first bones of the skull to develop and, anatomically, consists of four parts surrounding the foramen magnum: the basilar, squamous, and two condylar parts. The basilar part or basiocciput is formed from the fusion of four primary cranial vertebrae, which unite with the basisphenoid at the sphenooccipital synchondrosis to become the clivus. The squamous part, also called the supraoccipital, consists of central, right, and left segments; the central segment is separated from the right and left portions by the right and left vertical sutures, which extend from the interparietal–supraoccipital suture to the posterior margin of the foramen magnum. Its concave interior surface forms the lateral and posterior wall of the posterior cranial fossa. Superolaterally, the right and left portions articulate with the inferior angle of the parietal bones on either side at the lambdoid suture and the mastoid part of the temporal bone at the occipito-mastoid suture.

Superoposteriorly, the occipital bone has two protuberances: the internal and the external occipital protuberances (in the region surrounding the torcular Herophili). The occipital bone can have impressions of the inner table that extend into the diploic space, which is occupied in part by the arachnoid granulations. The condylar or exoccipital part forms the lateral borders of the foramen magnum. It lies between the basiocciput and the squamous part of the occipital bone and fuses with them through the synchondrosis in early life.

Clivus

The clivus (Figs. 2 and 3) is a central configuration of the skull base and is, consequently, a significant structure. When addressing the anatomy of the clivus, it is vital to understand its location in terms of adjacent structures. It descends inferiorly from the dorsum sellae to the anterior border of the foramen magnum and the border of the foramen magnum constitutes the posterior boundary of the clivus. The anterior border, however, is not as distinct as it blends with the sphenoid bone, which is adjacent to the sphenoidal sinus. The lateral superiorly boundary of the clivus is the petrooccipital fissure, and inferiorly it is the synchondrosis between the basioccipital and exoccipital divisions of the occipital bone. The lateral borders of the clivus closely approximate to the cranial nerves V through XII, the internal jugular veins, and the inferior petrosal sinuses. The nasopharyngeal surface of the lower aspect of the sphenoid and basioccipital make the inferior border of the clivus, while the basal subarachnoid space, which is anterior to the brainstem, forms the superior border. The medulla oblongata and pons lie adjacent to the posterior surface of the clivus but are separated by the prepontine and perimedullary cistern, while the craniocervical ligaments—the tectorial membrane and superior longitudinal band of the cruciate ligament—all attach to the posteroinferior surface of the clivus. The tectorial membrane is an extension of the posterior longitudinal ligament, which extends from the posterior surfaces of C1–C2 towards the clivus.

The clivus has a concave shape when viewed posterosuperiorly and is more prominent inferiorly at the location of the jugular tubercles, which project on to the lateral inferior margins of the clivus. The fibrous raphe of the pharynx, the muscle of the nasopharynx, and the continuation of the anterior longitudinal ligament of the spinal column are connected to the inferior surface, exocranial, of the clivus. The posterior surface, or endocranial, is smooth, composed of cortical bone, and covered with dura. On a midsagittal cross-section, the clivus is a wedge-shaped bone, which is thicker anteriorly and thinner posteriorly. Close examination of its central portion reveals cancellous bone and a spongiosa structure containing bone marrow, which can be pneumatized to a variable extent by the sphenoidal sinus.

Foramen Magnum

The foramen magnum (Fig. 7) varies in shape in both children and adults. Lang (1991) classified the shapes into five groups as follows: composed of two semicircles (adults 41.2% and children 18.4%); an elongated circle (adults 22.4% and children 20.4%); egg-shaped (adults 17.6% and children 25.5%); rhomboidal (adults 11.8% and children 31.6%); and rounded (adults 7% and children 4%). This author found that the average anteroposterior diameter of the foramen is 3.5cm and the average horizontal diameter 3cm.

General Embryology

The embryological development of the craniocervical junction is a complex process that particularly involves the notochord as an inducer of neuroectodermal differentiation and the paraxial mesoderm, which is a precursor to bone and skeletal muscle in the craniocervical region. A combination of endochondral ossification and the growth of regional sutures is necessary for the formation of the skull base. Elongation of the clivus, and hence the anterior aspect of the foramen magnum, results from growth of the spheno-occipital synchondrosis and sutural growth along the lateral portion of the base. Descent of the occiput via growth from the petro-occipital and sphenopetrosal junctions is important for the formation of bone around the foramen magnum, while the primary determinants of foramen magnum size and area are the basi-exoccipital and exo-supraoccipital synchondroses and the three enchondral parts of the basiocciput, exocciput, and supra-occiput. In contrast to most of the skull and facial bones, which develop from intramembraneous ossification, the cranial base takes the intermediate step of calcification of a previously-arranged cartilaginous network.

In the human embryo, there are 42 somites near the close of the 4th week of gestation. Each somite differentiates in order to form a sclerotome, a dermatome, and a myotome. There are four occipital somites in a human embryo and so there are four corresponding sclerotomes. The sclerotomes migrate ventro-medially and eventually differentiate into vertebral bodies.

Conventionally, the occipital bone and posterior parts of the foramen magnum are formed from an amalgamation of the four occipital sclerotomes. The basiooccipu is derived from the first two occipital sclerotomes, and the third forms the exooccipital bone, which produces the jugular tubercles.

Specific Embryology of the Craniocervical Junction

Somites 1–7 participate in forming the craniocervical junction. The superior four somites are occipital somites 1–4. Ventromedial migration of the sclerotomal cells from somites 1–4 toward the cephalic notochord gives rise to the primary occipital sclerotomes 1–4 (O1–4) (Fig. 15). The hypoglossal nerve rootlets course laterally between the hypochordal bows of the occipital sclerotomes and the C1 spinal nerve between the hypochordal bows of O4 and sclerotome 5 (S5 or first cervical sclerotome). Initially, occipital sclerotomes 1–3 join to form the main portion of the mesenchymal basiocciput. In an embryo of 9mm crown-rump length (CRL: approximately the fifth week of gestation), the hypochordal bows of O4 (proatlas) (Fig. 16) and S5 (atlas) are distinct in the craniocervical junction. The notochord travels from the dorsal to the hypochordal bows. The rostral O1-3 hybrid and O4 join together in an embryo of 9–11mm CRL (approximately the sixth week of gestation) to form a mesenchymal O1-04 hybrid that surrounds the cephalic end of the notochord. This mesenchymal hybrid is termed chordal cartilage after chondrification occurs in gestation. The hypochordal bow of O2 is small, disappears medially, and fuses with the hypochordal bow of O3 laterally. The dorsolateral extensions of the hypochordal bows of O2-O4 create the lateral masses. Further dorsal extension of these masses adds to the development of the exocciput, which is homologous to the neural arch of a typical vertebra. The portion of the exocciput rostral to the hypoglossal nerve and canal is formed from O3 and the caudal portion is formed from O4. Ultimately, the lateral masses of S3 and S4 fuse to create a single exocciput ventral and dorsal to the hypoglossal canal. Loosely-packed sclerotomal cells between the hypochordal bows of the proatlas and atlas correspond to the centrum of the primary sclerotome 5. These contribute to the occipital condyles, laterally, and the tip of the odontoid process of the axis, medially.

The hypochordal bow of O3 degenerates except for its lateral projections, which are exaggerated by fusing with the hypochordal bow of O2 and contribute to the exocciput. At week five of gestation, the hypochordal bow of O3 can be noticed laterally above and anterior to the hypochordal bow of O4. An osseous separation within the hypoglossal canal is formed by the medial remnant of the hypochordal bow of O3, and the median part of the hypochordal bow of O4 remains as a continuous mass across the midline, which begins to fuse with the remainder of the basiocciput rostrally during the mesenchymal stage. After chondrification, its fusion is completed, thereby forming the basion. The hypochordal bow of S5 forms the anterior arch of the atlas and disappears from between the loosely-packed regions of the S5 and S6 sclerotomes. The lateral mass of S5 (C1) encompasses the odontoid process and forms the neural/posterior arch of the atlas, while the lateral mass of S6 forms its neural arch.

Embryology of the Odontoid Process

The odontoid process was once thought to be a displaced body of the atlas, but is now believed to separate from the anterior part of the atlas between the sixth and seventh weeks of gestation and then migrate caudally to fuse with the body of the axis. This important structure originates from the axial portion of the occipital and the upper two cervical sclerotomes, both caudally from the atlas and cephalically from the axis. It is formed from two separate ossification centers that fuse in the midline by the seventh month of gestation (Fig. 17). A secondary ossification center appears at the apex of the odontoid process (ossiculum terminale) between ages three and six years and usually fuses by the beginning of puberty (Fig. 17).

The tip of the odontoid process is originally laid out as the central part of the atlas and then fuses caudally with the cephalic portion of the body of the axis during the development of the vertebral column. This fusion is complete in a child by about the third or fourth year of life. Until then, the junction of the odontoid tip and the axis is a cartilaginous physis. The odontoid process has two lateral primary ossification centers and an apical secondary ossification center. The axis has four articular processes like the rest of the vertebrae: a pair of spherical convex superior and a pair of flat and sagittally aligned inferior articular processes that are individually connected through a long pars interarticularis. Unlike all other vertebral segments, the superior and inferior articular processes of the axis are completely offset from one another in the sagittal plane, which places great strain on the pars interarticularis. This requires the integrity of the axis ring structure to allow for proper cranio-cervical mechanical function and this, in turn, concentrates the stress at a focal point on the narrow waist of the odontoid as the anchoring pivot for the atlanto-axial articulation. This complex arrangement enables the head to rotate substantially and the upper cervical spine to turn quickly. The two primary ossification centers of the odontoid appear in utero and usually fuse in the midline by the eighth month of fetal life. This medially fused primary ossification center then coalesces with the body of the axis by the sixth year of life forming a line, which can usually be seen on radiographs until the eleventh year. This line can be mistaken for a fracture on radiographs and remains throughout life in about one-third of individuals. This area of fusion between the odontoid process and the body of the axis is called the subdental synchondrosis. The secondary ossification center usually fuses with the rest of the odontoid process by the age of twelve years.

The loose prevertebral zone of the first cervical sclerotomes gives rise to the basal segment of the odontoid process, and that of the second cervical sclerotomes becomes the body of the axis. In essence, after resegmentation, the odontoid process comprises of the apical dental segment from the caudal proatlas, the basal dental segment from the first cervical sclerotomes, and the body of the axis from the second cervical sclerotomes. Chondrification of the respective components occurs simultaneously at various periods during gestation, starting around six weeks, and fusion begins from birth up until the fifth to sixth postnatal year of life; however, the ossification of the dental tip and bony fusion of the upper synchondrosis are not complete until adolescence. The base of the odontoid process is separated during development by an embryological remnant of the C1-2 intervertebral disc, which is a cartilaginous disc that can persist until old age. At birth, the neurocentral synchondrosis, or epiphyseal growth plate, separates the body of the axis from the odontoid process.

These cartilaginous articulations are named the dentocentral (separating the odontoid process from the body) and the neurocentral (separating the odontoid process and body from the neural arches) synchondroses. Synchondroses among the neural arches, body, and odontoid process fuse at between three to six years of age. After six years, the odontoid process fuses with both the body and the neural arches. In adults, the remnant of the dentocentral synchondrosis can be seen on magnetic resonance imaging (MRI) as a hypointense ring between the inferior end of the odontoid and the superior roof of the body of C2. This structure is located in the cancellous bone and should be accepted as the inferior border of the odontoid process in adults. The anatomical level of the dentocentral synchondrosis is well below the superior articulating facets and the indentation of the transverse ligament to the posterior aspect of the odontoid process.

Development of the Occipital Condyle

The occipital condyles are two semilunar prominences with an inward concavity and outward convexity, which appear on the anterolateral region of the foramen magnum. They comprise of a cartilaginous articular facet, which is convex ventrodorsally and mediolaterally, and an osseous portion. The medial region of the condyle tends to be larger than the lateral region. During embryogenesis, the sclerotomic primordia of the occipital condyles are derived from the hypochordal bow of S4 and the loosely-packed region of S5 (Figs. 15 and 16). After chondrification in the occipital region, the basioccipital and exoccipital components are united and the ossification centers appear independently within those segments. The ventral and dorsal regions of the exoccipital and suboccipital ossification centers grow and meet each other but remain separated by a synchondrosis (known as the anterior intraoccipital synchondrosis), which traverses the occipital condyle. As a result, the occipital condyle is divided by a cleft, which corresponds to the unossified anterior intraoccipital synchondrosis; this is seen in children. The region of the condyle anterior to the synchondrosis, or the basioccipital area, is smaller than the region posterior to it: the exoccipital area. The anterior intraoccipital synchondrosis ossifies in a mediolateral direction, a process that begins around one to two years of age and is completed by seven to ten years. From this time, the occipital condyle then presents as a single osseous prominence with a uniform articular facet. Sometimes adults have a transverse division of the articular facet, which can result from the maceration of its midportion.

Occipital Bone Ossification

Ossification of the basioccipital segment proceeds laterally into the ventral portion of each condyle, while ossification of the lateral occipitals simultaneously advances into the dorsal portions of the occipital condyles.

At birth, the basioccipital and lateral occipital bones are separated on each side by a prominent synchondrosis, which normally obliterates between two and four years of age. The lateral occipitals are separated from the supraoccipital segment by the prominent innominate synchondrosis with the bony fusion of these segments taking place between two and four years of age. At birth, the interparietal and supraoccipital segments are fused, apart from laterally, where they are separated by the mendosal sutures.

During the third month another two pairs of centers (secondary interparietal centers) appear anterior to the primary interparietal bone. The medial pair of secondary centers develop first, followed by the lateral pair. These pairs form a meshwork of trabeculae, which rapidly fuse with each other and/or with the upper edge of the primary bone. Around this stage, irregular-shaped areas of ossification can be observed on the external surface of the supraoccipital bone. These areas, which are initially granular and thread-like, develop to form a bony meshwork and then fuse with the lateral part of the primary interparietal bone on each side. Ossification is scattered in the external membranous tissue of the supraoccipital plate and is occasionally connected to the supraoccipital bone by a thin trabeculae.

The occipital bone is formed from the union of four primary cartilaginous centers, which are laid down on the chondrocranium around the foramen magnum, and from a fifth membranous element. The four cartilaginous components are the basioccipital, the lateral or exoccipitals, and the supraoccipital (the inferior squama below the suture). The mendosal suture is an accessory suture of the occipital bone that is situated somewhat superior to the transverse sinus, which develops in the region of the posterior lateral (mastoid) fontanelle, between the developing interparietal and supraoccipital bones, and runs horizontally from the medial portion of the lambdoid suture. Its fusion begins before birth and is completed between the second and fourth years. The membranous component gives rise to the interparietal bone (the superior squama above the mendosal suture). In this study, fetuses at nine weeks of gestation had a single median ossification center in the cartilaginous basiocciput ventral to the notochord and in each lateral occipital cartilage around the hypoglossal canal. In all specimens, the supraoccipital segment was also ossified from a single focus in the tectum synoticum. At twelve weeks gestation, both the interparietal and supraoccipital segments are fused in the midline but remain separated laterally by the mendosal sutures.

C1 Ossification

The atlas usually forms from three primary ossification centers and no secondary ones. The posterior arch arises from the lateral dense zone of the first cervical sclerotome. In contrast, the anterior arch is formed from the hypochordal bow of the first cervical sclerotome. Interestingly, this is the only area of the spine where the hypochordal bow or cells similar to it are involved in the formation of the vertebral column. The posterior arch usually fuses by five years of age and the anterior arch typically fuses before eight years. The anterior and posterior ossification centers are separated by the right and left neurocentral synchondroses, and the two posterior ossification centers are separated by the posterior synchondrosis. The neurocentral synchondroses typically do not fuse until age five to eight years. In contrast, the posterior synchondrosis shows fusion at age three to five years. The anterior arch of the C1 vertebra shows progressive ossification in only 20% of infants through six to twenty-four months. Most infants have cartilaginous anterior arches. The most common finding in the anterior arch is a single ossification center; although up to four can exist. Fusion and ossification of the anterior arch are typically complete by six to eight years. Overall, there are many patterns of C1 ossification. Up to 25% of children younger than eight years show multiple ossification centers at the anterior arch of the atlas. This anterior arch ossification can be delayed past two years of age. Incomplete ossification of the anterior arch of the atlas vertebra is not uncommon. It also shows that variant ossification patterns are more common in anterior than posterior arches.

Proatlas: Key to the Craniocervical Junction

The term proatlas comes from the field of comparative anatomy. It is considered a rudimentary or vestigial vertebral structure in some animals. It is found between the atlas and the occipital bone in non-human animals such as some rodents, reptiles, and dinosaurs.

In humans, the proatlas (Fig. 16) fuses with the upper three occipital sclerotomes to constitute the occipital bone and the dorsal part of the foramen magnum. It is, therefore, not usually observed as a separate structure in man. However, there are instances in which proatlatal remnants have been noted in humans. On occasion, an additional vertebra will appear in front of the atlas, hence the name proatlas. The proatlas does not usually exist in adult humans, but parts of it can appear owing to a failure of regression in the embryonic structures.

Zoologists would consider this a reversionary or regressive variation. As such, the human proatlas could be regarded as an atavistic structure. This is because the occipital bone is usually formed by including vertebrae that are normally separate in lower vertebrates in the cranium of mammals. However, another hypothesis states that this variation does not represent a general tendency to the increased shortening of the vertebral column.

A number of structures are derived from the fourth occipital sclerotome. The anterior tubercle of the clivus is derived from the hypocentrum of the proatlas. The terminal portion of the dens and the apical ligament are similarly formed from the centrum of this structure. In other words, the apex of the odontoid process of the axis is derived from the proatlas. The neural arch segment of the proatlas differentiates into two separate regions. The ventral portion creates the anterior margin of the foramen magnum, the occipital condyle, and the midline third occipital condyle, while the caudal portion gives rise to the lateral atlantal masses and the superior portion of the posterior arch of the atlas. Finally, some authors consider the lateral sections of the proatlas condense to give rise to the cruciate and alar ligaments.

Two families of developmental control genes have been implicated in the formation of structures in the craniocervical junction. It has been proposed that the homeobox (Hox) gene cluster on chromosome 6 and the paired box (Pax) genes on chromosome 2 are crucial for the development of cervical vertebrae. Experiments using transgenic mice with gain-of-function mutations, due to the introduction of genomic sequences of the Homeobox-1.1 gene under the control of a chicken β-actin promoter, resulted in manifestations of the proatlas. Additionally, there were malformations of the basiooccipital bone, atlas, and axis. These mice also had craniofacial abnormalities and were nonviable after birth. Mutations of the *Paired box-1* gene also caused variations of the upper cervical vertebra, although these were slightly different from those caused by altered homeobox genes.

Craniocervical Junction Ligaments in General

The craniocervical junction contains the complex transition from the skull to the spine. It comprises of two joints, the atlantooccipital and the atlantoaxial joints, and houses the spinal cord, multiple cranial nerves, and many important blood and lymphatic vessels that supply the head and neck. This junction must protect its contents while simultaneously allowing for significant mobility. The two most prominent, and arguably the most important, ligaments of the craniocervical junction are the transverse and alar ligaments (Fig. 18). These have been the focus of much study, but the other accessory ligaments (Fig. 19) of the craniocervical junction have remained largely undescribed and are absent from many textbooks devoted to this topic. A possible reason is the detailed dissection needed to view the ligaments or a lack of knowledge about their morphology. Regardless of the reason, it is important to study and know these small ligaments in order to understand the craniocervical junction and the complications that arise from injury to the area.

The occipitoatlantoaxial joints and their ligaments have lymphatic drainage into the retropharyngeal nodes. Retrograde infection may affect the synovial lining of some of these joints and the attached ligaments, resulting in neck stiffness and instability. The posterior ascending artery (Fig. 20) continues cranially, supplies the tectorial membrane, and crosses the alar and transverse ligaments on their dorsal surfaces.

Suggested Reading

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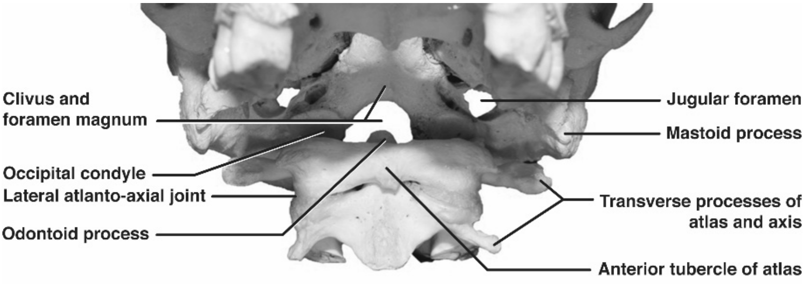

Figure 1: Anterior view of the bony parts of the craniocervical junction.

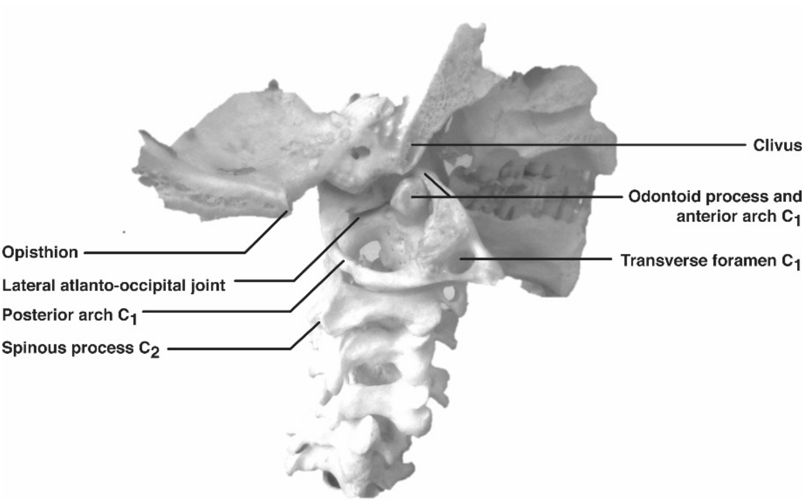

Figure 2: Posterolateral view of the bony parts of the craniocervical junction.

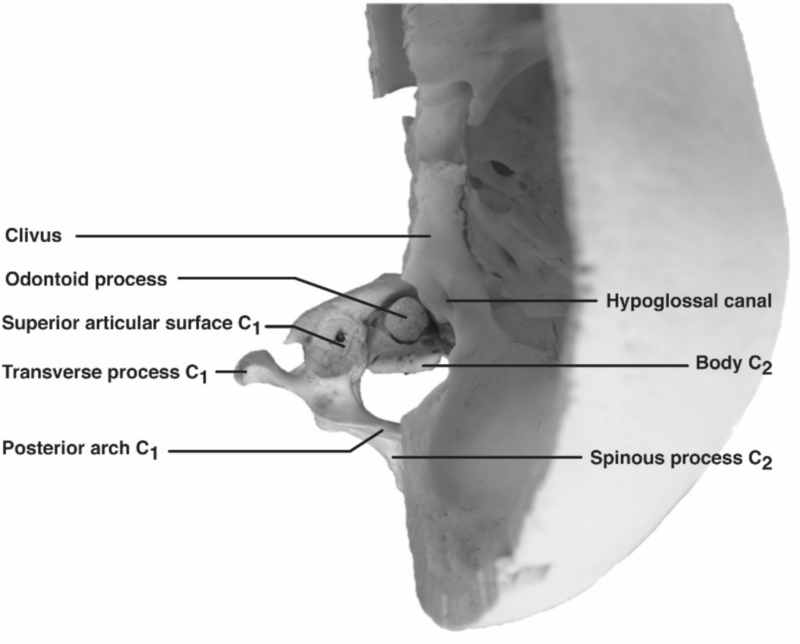

Figure 3: Superior view of the bony parts of the craniocervical junction.

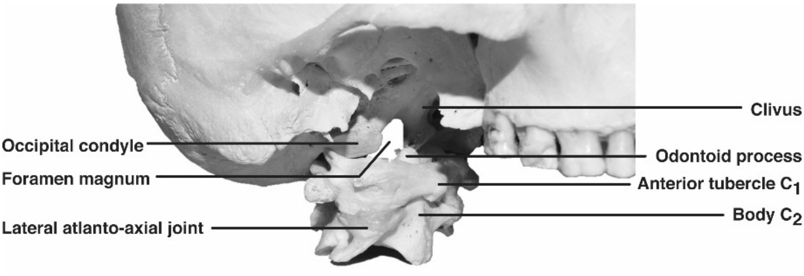

Figure 4: Anterolateral view of the bony parts of the craniocervical junction.

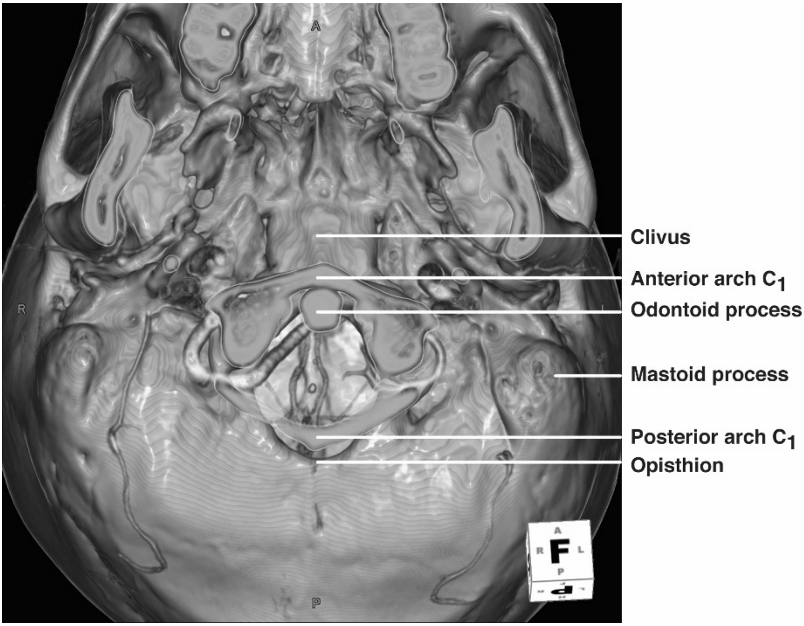

Figure 5: Inferior view of the craniocervical junction via 3D reconstructed CT angiogram. Note the occiput posteriorly, the dens anteriorly and the atlas with left and right vertebral arteries leaving the transverse foramina to course over the sulcus for the vertebral arteries.

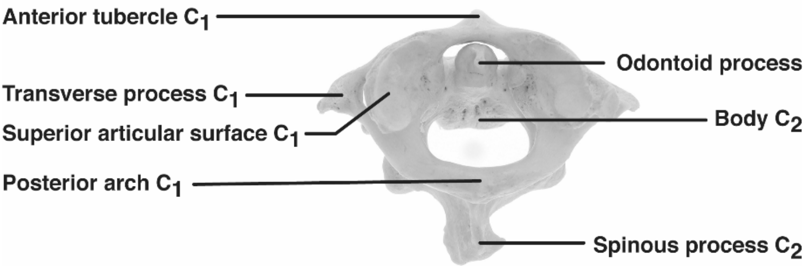

Figure 6: Bone specimens of the atlas and axis articulated and seen from a superior view.

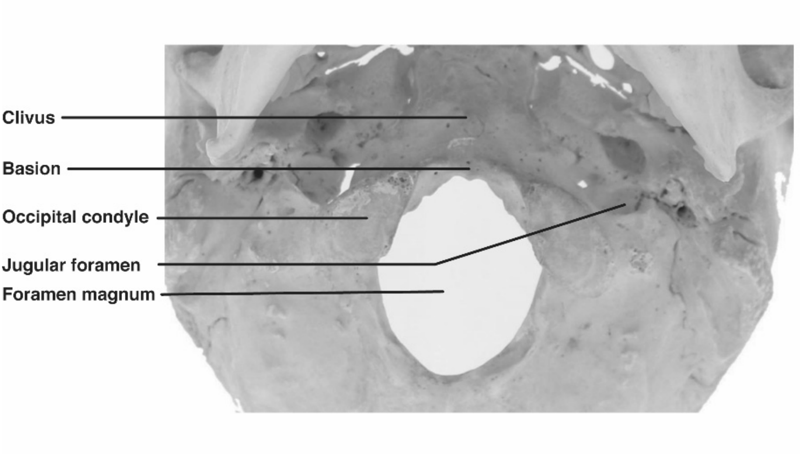

Figure 7: Inferior view of the skull base and a focus on the occipital bone in this region. Note the occipital condyles and the anterior third of the foramen. Also note the clivus extending anterosuperiorly.

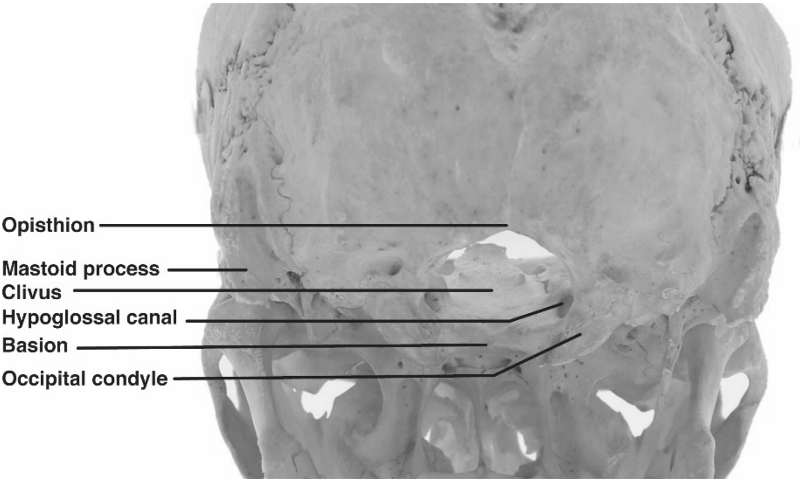

Figure 8: Posterior view of the occipital bone. Again, note the occipital condyles and the extension anterosuperiorly of the clivus.

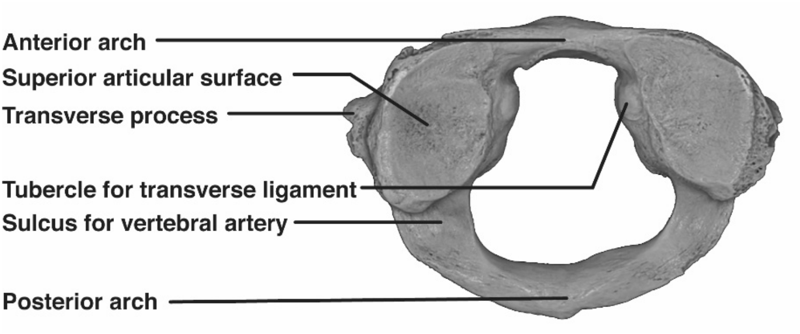

Figure 9: Micro CT of the superior aspect of the atlas.

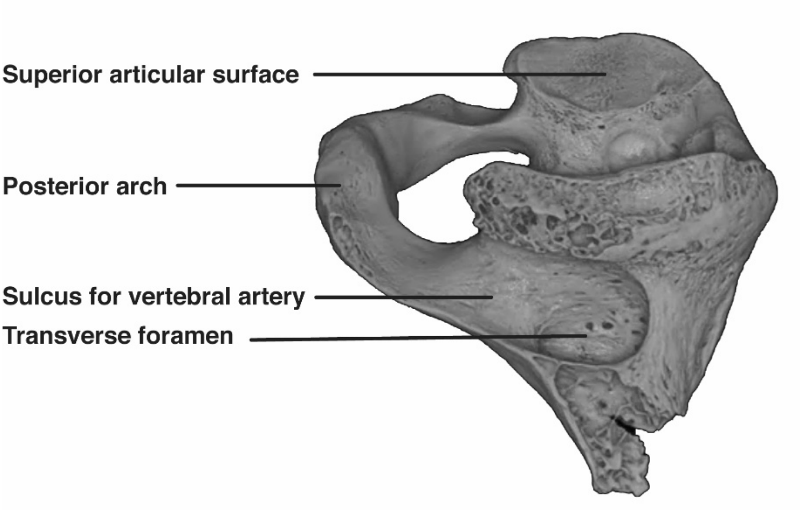

Figure 10: Micro CT of the right lateral aspect of the atlas.

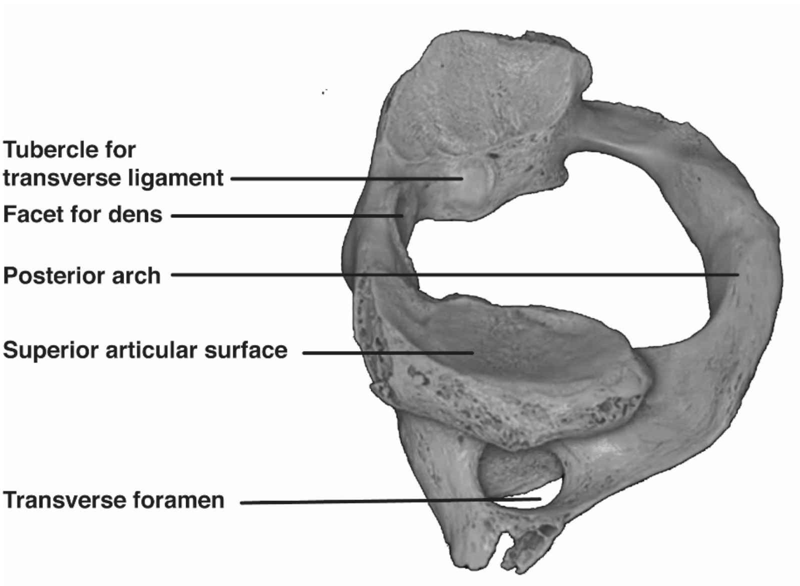

Figure 11: Micro CT of the left lateral aspect of the atlas.

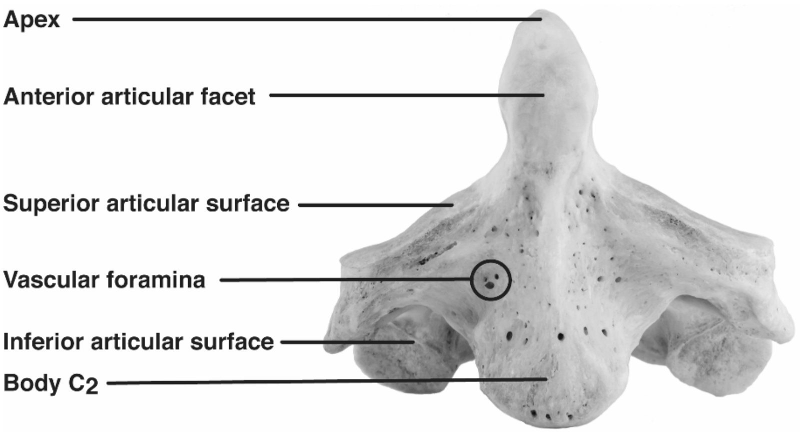

Figure 12: Anterior view of the axis.

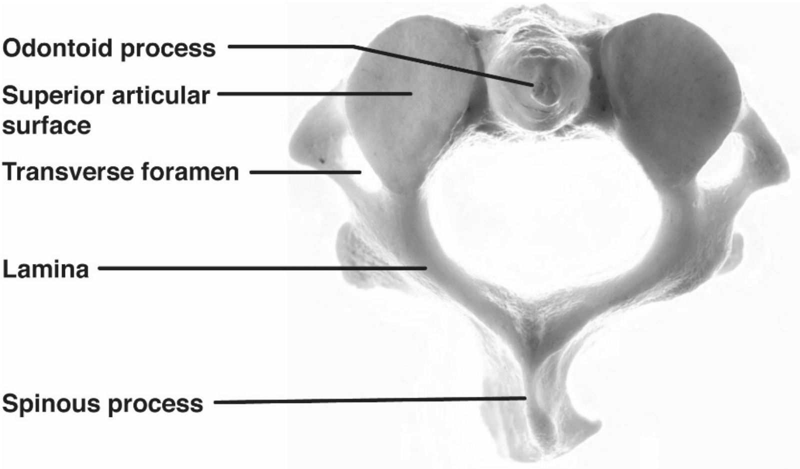

Figure 13: Superior view of the axis.

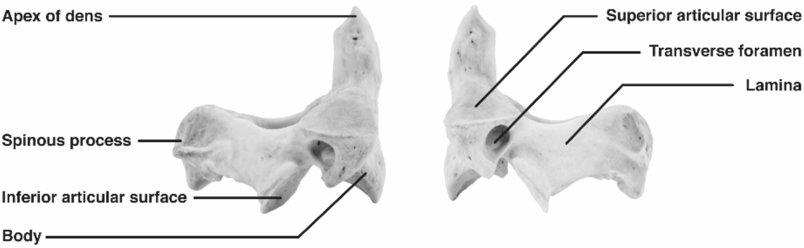

Figure 14: Right and left lateral views of the axis.

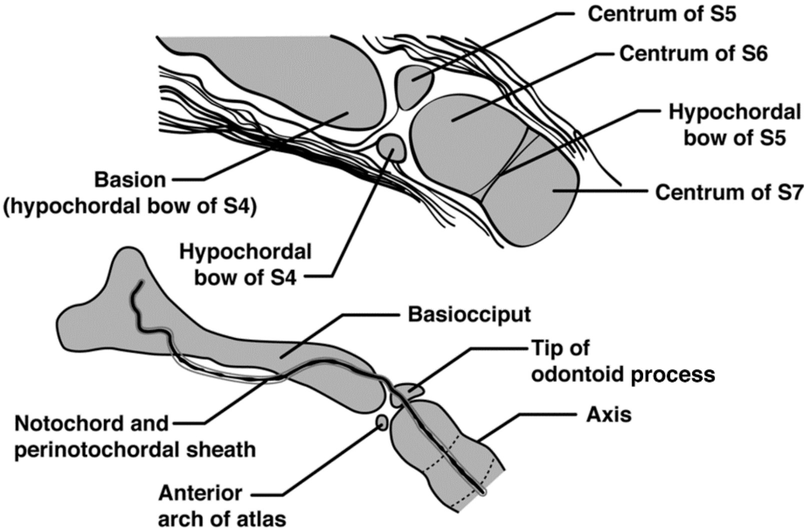

Figure 15: Embryogenesis of the craniocervical junction. The upper and lower images show the mesenchymal/chondrified and osseous stages of the craniocervical junction, respectively. In the lower image, the original fetal position of the notochord is superimposed on the components of the craniocervical junction. Note that the hypochordal bow of S4 contributes to the basion, and the centrum of S5 to the tip or apophysis of the odontoid. Normally, the centra of S5-7 fuse to form the dens and body of the axis. Failure of fusion leads to the formation of an independent center for chondrification and ossification in the S5 centrum and results in the tip of the odontoid being isolated, giving rise to os terminale persistens. On the other hand, if mesenchymal fusion and chondrification of the dens occur normally, the tip of the odontoid can be separated from the dens by an intervening synchondrosis derived from the vestigial remnant of the S5 hypochordal bow. The notochord has an S-shaped course through the basiocciput and passes through the os terminale persistens; it is located on the ventral surface of the basiocciput at its midportion and runs obliquely within its rostral and caudal parts.

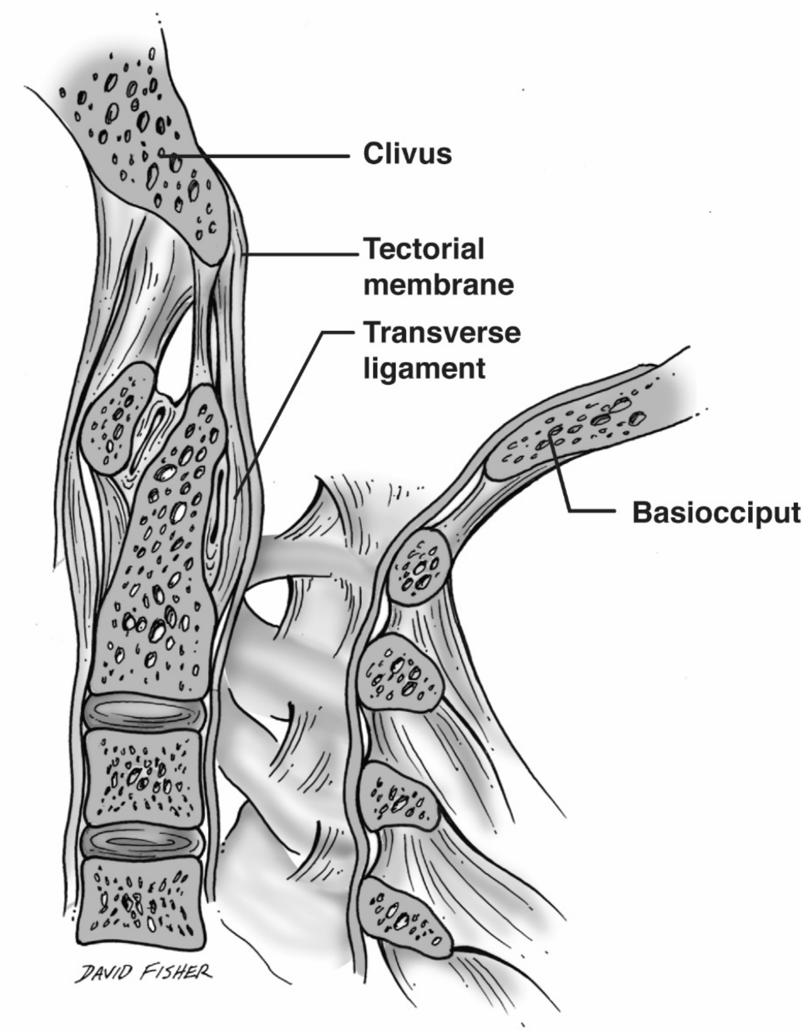

Figure 19: Schematic drawing of the craniocervical junction and its ligaments in sagittal section.

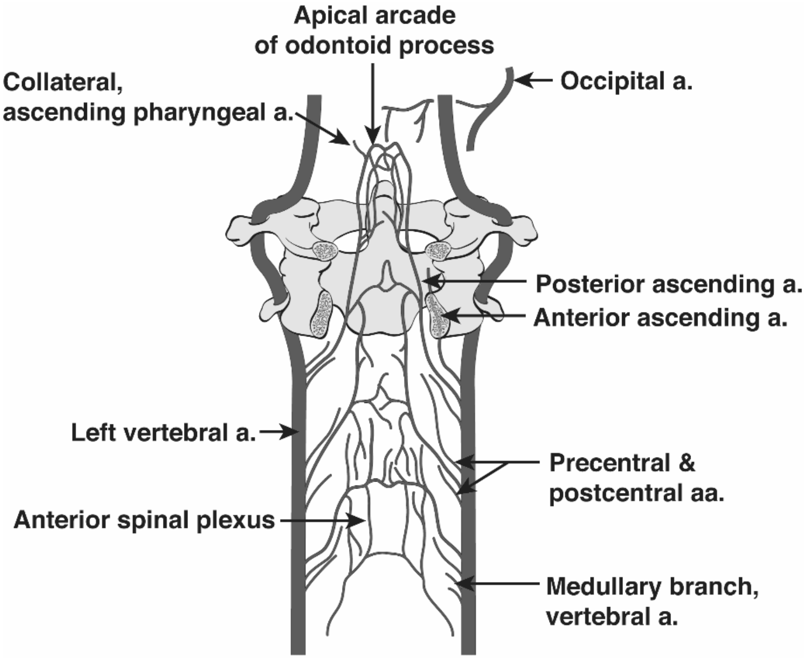

Figure 20: Illustration of the blood supply of the craniocervical junction with contributions from the ascending pharyngeal, a branch of the external carotid artery, the occipital artery, which is also a branch of the external carotid artery, and the vertebral artery, which is the first branch of the subclavian artery. The posterior ascending artery is shown and plays an important role in supplying the ligaments in this region as well as the related bone.

The Ligaments and Joints Connecting the Head with the Spinal Column from Morris' *The Anatomy of the Joints*

R Shane Tubbs

Editor's note: **Sir Henry Morris (1844–1926) (Fig. 1) was an eminent anatomist and surgeon born in Petworth, Sussex, and the son of a local surgeon. He was educated at Epsom College, University College, London and Guy's Hospital, where he qualified in 1861. He joined Middlesex Hospital in 1870 and eventually became the head surgeon of the cancer wards. He had a special interest in urological surgery and published several texts on this topic.**

This excerpt from his historical and now often forgotten 1879 text (*the Anatomy of the Joints)***, specifically the portions dealing with the craniocervical junction, is presented here and has been heavily edited to bring the descriptions up-to-date with regard to both language and current anatomical terminology. The figures have been derived from Bevan et al. (1899).**

When considering how the head is united to the spine, it is impossible to avoid taking into account the union of the axis with the atlas, not only because the *atlas with the head* rotates upon the axis, but also because the ligaments, whereby these rotary movements are rendered secure, is a part of the apparatus between the axis and atlas. In addition, the ligaments which check rotation, as well as other very strong ligaments, pass between the axis and occiput, and so provide for the security of the union in a manner that the ligaments extending from the atlas to the occiput alone could not do. Moreover, the characters of the atlas, which are all modified to allow for the requisite movements of the head upon it, together with the head upon the axis have been excluded from the general description of the ligaments and joints that connect the other vertebrae together.

In the following description, the articulations between the occiput and atlas with their ligaments will first be described; then those between the atlas and the axis; and finally, the ligaments which extend between the axis and occiput.

The articulations between the occiput and atlas are imperfect hinge joints, and those between the lateral masses of the atlas and axis are arthrodial joints. Additionally, between the anterior portion of the atlas and the odontoid process, there is a lateral ginglymoid joint, which is completed by the transverse portion of the cruciform ligament.

The ligaments passing between the atlas and axis, and those connecting the atlas and occiput, are mediate and immediate. The capsular ligaments are immediate: i.e., they hold together parts of the bone which are in contact with one another. The anterior and posterior ligaments are mediate: i.e., they pass between bony parts which are not in contact. Further, the ligaments which connect the atlas and occiput, and those which connect the atlas and axis are for the most part external to the spinal canal; certainly, with the exception of the transverse ligament, they can be examined without dividing the bones or operating the canal. Although it must be admitted that the capsular ligaments of each set of joints must also be seen from within in order to be completely viewed.

However, the ligaments that most strongly connect the head to the spine, and which serve to retain it in position during the rotary and nodding movements, pass from the axis and other cervical vertebrae to the occiput. They are all contained within the spinal canal and can only be examined or dissected after laying open the canal. To do this, the posterior elements of the axis, the posterior arch of the atlas, and the portion of the occipital bone which bounds the foramen magnum posteriorly, as well as the spinal dura mater and the medulla oblongata, and upper part of the spinal cord, must all be removed.

The Articulations between the Atlas and Occipital Bone

Class, Diarthrosis. Subdivision, Ginglymo-arthrodia.

The Occipital Bone.—It is through this bone, which is situated at the lower and back part of the cranium, fused with the sphenoid into one mass, and is locked together by means of deep serrations or rough edges with the parietal and temporal bones, that the whole weight of the skull is borne and transmitted to the spine.