Surgery of the Cranio-Vertebral Junction

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Preface

This excellent and insightful book details abnormalities and treatments of the craniovertebral junction. It provides an overview of the human anatomy, with an emphasis on biomechanics, including the sagittal balance concept of surgical techniques. Even more so, it describes important perioperative considerations, such as the planning of surgical incisions, anesthesiological considerations, and types of preoperative and intraoperative image guidance.

In particular, the authors thoroughly explain surgery techniques per se. These include the traditional anterior, posterior, and posterolateral approaches, as well as innovative minimally invasive and endovascular approaches.

The last part of the book describes in detail how best to treat many of the wide variety of abnormalities that can afflict the craniovertebral junction. It examines both trauma and tumors, not only extra-axial tumors but also inflammatory tumors and foramen magnum tumors.

The authors close with a review of the vascular abnormalities that can afflict the craniovertebral junction and how best to treat them. Lastly, they discuss infectious metabolic diseases that can affect the craniovertebral junction.

This text is a comprehensive review of craniovertebral surgical techniques, anatomy, and abnormalities. The only aspect not covered is the embryological development of this area of the spine, but the authors do not purport to do so. Other authors have written tomes addressing the treatment of craniovertebral junction abnormalities. In this book, however, the authors describe techniques and provide added information gleaned from the surgical literature published during the past several years. These include the sagittal balance concept applied to the craniovertebral junction; innovative approaches, such as the far-lateral transventricular, the extreme lateral, and the anterolateral approaches; innovative techniques applied to neurosurgery techniques; and recent minimally invasive and endovascular approaches. Subsequently, it provides much information to the reader that can aid diagnosis and treatment considerations to address abnormalities of the craniovertebral junction in the modern arena.

This comprehensive textbook on the management of abnormalities that can present at the craniovertebral junction should be in the library of every surgeon who diagnoses and treats problems in this very complex area of the spine.

Phoenix, AZ, USA — Volker K. H. Sonntag

Contents

Part I

Introduction

Relevant Anatomy of the Craniovertebral Junction

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Elena d'Avella, Luigi Maria Cavallo, Matteo De Notaris, Jose Pineda, Alberto Di Somma, Paolo Cappabianca, and Alberto Prats-Galino

1.1 Introduction

Craniovertebral junction (CVJ) refers to the complex transition from the skull to the spine. Its bony structure consists of the occipital bone, atlas (C1), and axis (C2) (Fig 1.1) [1–3]. The occipital bone surrounds the foramen magnum and has three parts: a squamosal part located behind the foramen magnum, a clival portion located anterior to the foramen magnum, and a condylar part that connects the squamosal and clival parts. The atlas, the first cervical vertebra, is ring shaped and consists of two thick lateral masses situated at the anterolateral parts of the ring connected with short anterior and longer posterior arches. The upper facet of each lateral mass articulates with the occipital condyle that protrudes from the condylar part of the occipital bone (atlanto-occipital joints). The inferior facet of each lateral mass articulates with the superior articular facet of the axis. The axis, the second cervical vertebra, is distinguished by the odontoid process (dens), which projects upward from the body. On the front of the dens is an articular facet that forms a joint with the facet on the back of the anterior arch of the atlas. The body is connected to the lateral mass by short and strong pedicles. Articular facets of the axis extend lateral

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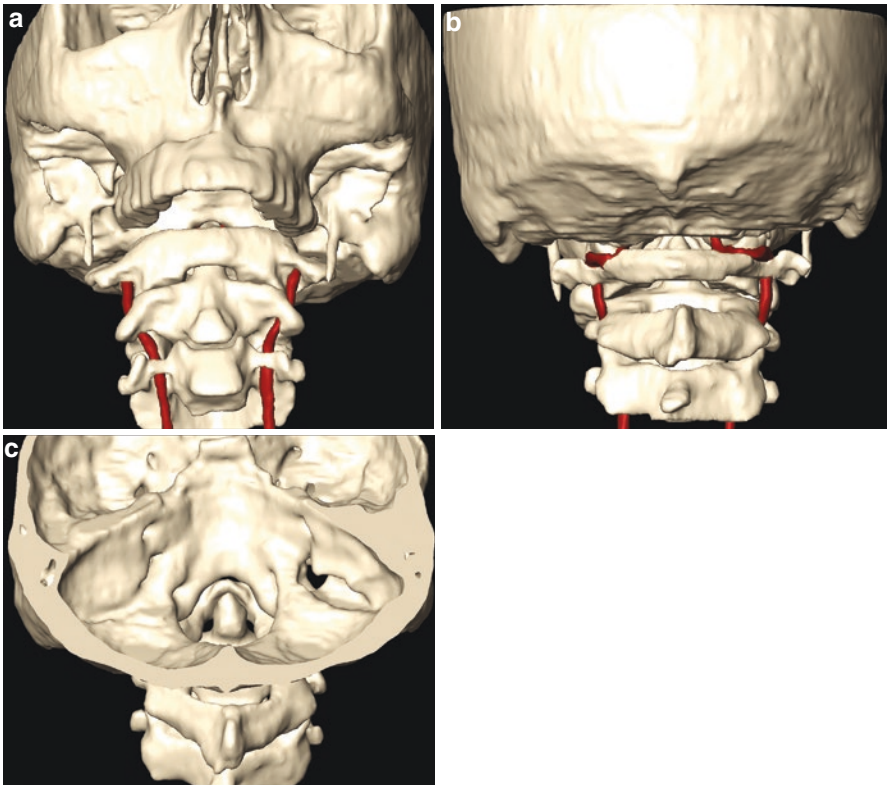

Fig. 1.1 3D anatomical model of the craniovertebral junction (CVJ). Its bony structure consisting in the occipital bone, atlas and axis is shown as seen from an anterior (**a**), posterior (**b**), and superior-posterior intracranial perspective (**c**). The extracranial course of the vertebral artery, which is the major vessel related to the CVJ, is represented

from the body and articulate superiorly with the inferior facets of the atlas [1–5]. Muscles, ligaments, and membranes that provide stability and mobility to the craniovertebral junction support the bony structure of this critical region [2, 5].

Major neurovascular structures are intimately related to the CVJ where they transverse membranous and bony orifices. These include the lower cranial and upper spinal nerves, the caudal brainstem and rostral spinal cord, the vertebral artery and its branches, and the venous drainages through the jugular vein and the vertebral plexus [1, 3, 6, 7]. Anatomy of the vertebral artery will be further detailed in a dedicated chapter.

A thorough understanding of three-dimensional (3D) CVJ anatomy and relations with surrounding neurovascular structures is paramount for the surgical management of pathologies in this region. The aim of this chapter is to describe the relevant anatomy of the CVJ as seen from a posteromedial, posterolateral, anterolateral and anteromedial perspectives. Anatomical dissection through the anteromedial

corridor was carried out by an endoscopic endonasal access whereas posterior and lateral corridors were studied by microscopic vision.

Merging together anatomical information coming from endoscopic and microsurgical investigations with the reconstruction of 3D computed models might provide a 360° full and clear understanding of this complex area, more readily applicable to the operative setting.

1.2 Posteromedial Perspective of the CVJ (Fig. 1.2)

1.2.1 Bony Structures

The posteromedial perspective of the CVJ is focused on the squamosal part of the occipital bone bordering the foramen magnum and on the posterior arch of C1 and C2 (Fig. 1.3).

The posterior surface of the squamosal part of the occipital bone in its medial portion has some relevant protuberances on which muscles of the neck attach: the external occipital protuberance (EOP), situated at the central part of the external surface; the superior nuchal line (SNL) and the inferior nuchal lines (INL) that radiate laterally from the protuberance; the posterior border of foramen magnum (FM); and the midline occipital crest, a vertical ridge that descends from the EOP to the midpoint of the posterior margin of the foramen magnum. The area below and between the superior and inferior nuchal lines is rough and irregular and serves as the site of attachment of numerous muscles. There is great variability in the position of the superior nuchal line, and therefore, it does not reflect the internal position of

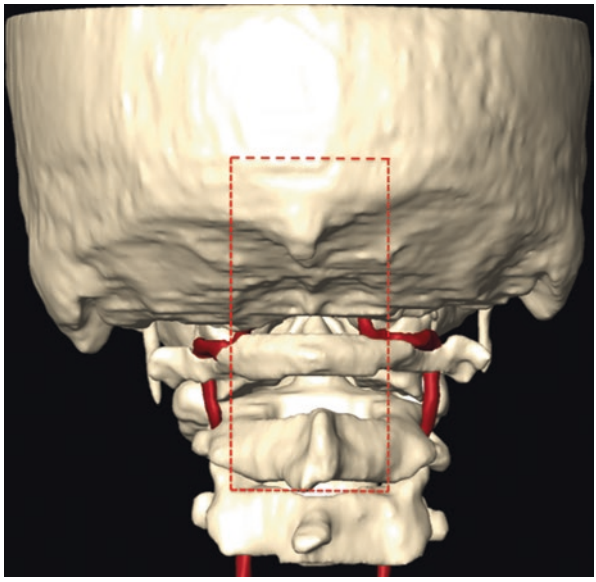

Fig. 1.2 3D anatomical model of the CVJ as seen from a posterior view. The area corresponding to the posteromedial perspective is highlighted with red dotted lines

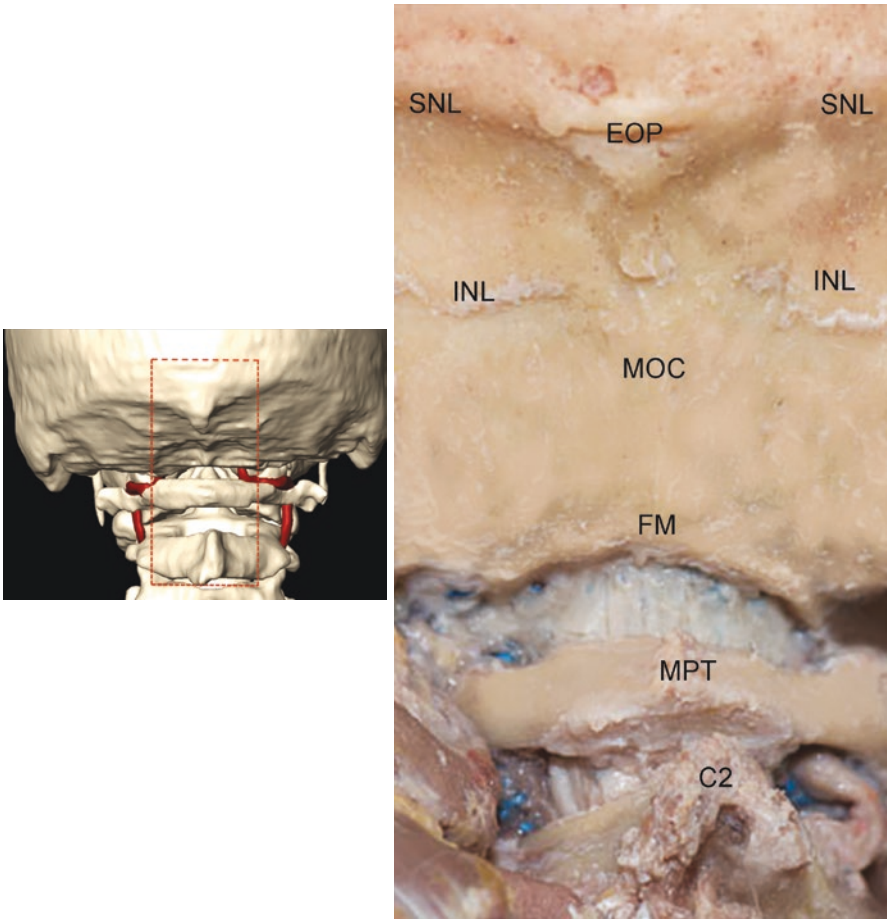

Fig. 1.3 The posteromedial perspective of the CVJ is focused on the squamosal part of the occipital bone bordering the foramen magnum and on the posterior arch of C1 and C2. On the left side of the image, the 3D model is for anatomical reference for the area of interest. The posterior surface of the squamosal part of the occipital bone in its medial portion has some relevant protuberances on which muscles of the neck attach: the external occipital protuberance; the superior nuchal line and the inferior nuchal lines; the posterior border of foramen magnum; the midline occipital crest. The area below and between the superior and inferior nuchal lines is rough and irregular and serves as the site of attachment of numerous muscles. On the posterior arch of the atlas is the median posterior tubercle, which substitutes the spinous process of any other vertebra. The posterior arch of the axis distinguishes by harboring the thickest lamina than on any other cervical vertebrae and a large spinous process serving as an attachment point of important suboccipital triangle muscles and the nuchal ligament. *C2* spinous process of the axis; *EOP* external occipital protuberance; *FM* posterior border of foramen magnum; *INL* inferior nuchal line; *MOC* midline occipital crest; *MPT* median posterior tubercle of the atlas; *SNL* superior nuchal line

transverse sinus accurately. The relation of confluence of the sagittal sinus with the transverse sinus (torcular Herophili) to EOP is more consistent [2, 4, 8].

On the posterior arch of the atlas is the median posterior tubercle, which substitutes the spinous process of any other vertebra. The posterior arch of the axis distinguishes by harboring the thickest lamina than on any other cervical vertebrae and a large spinous process serving as an attachment point of important suboccipital triangle muscles and the nuchal ligament [1, 5].

1.2.2 Muscular Relationships (Fig. 1.4)

The trapezius is the most superficial muscle that is encountered when exploring the CVJ through a posteromedial corridor. It extends from the medial half of the SNL, the EOP, and the spinous processes of the cervical and thoracic vertebrae and converges on the shoulder to attach to the scapula and the lateral third of the clavicle. In a deeper layer, the splenius capitis is exposed in its medial half running to the spinous processes of the lower cervical and upper thoracic vertebrae. Deep to the splenius capitis, the semispinalis capitis begins medially at the midline occipital crest in the area between the superior and inferior nuchal lines and attaches below to the upper thoracic and lower cervical vertebrae (Fig. 1.5) [4, 8, 9]. In the next layer, along the posteromedial corridor, the rectus capitis posterior minor can be seen extending from the medial part and below the inferior nuchal line to the tubercle of the posterior arch of the atlas (Fig. 1.6) [6, 10].

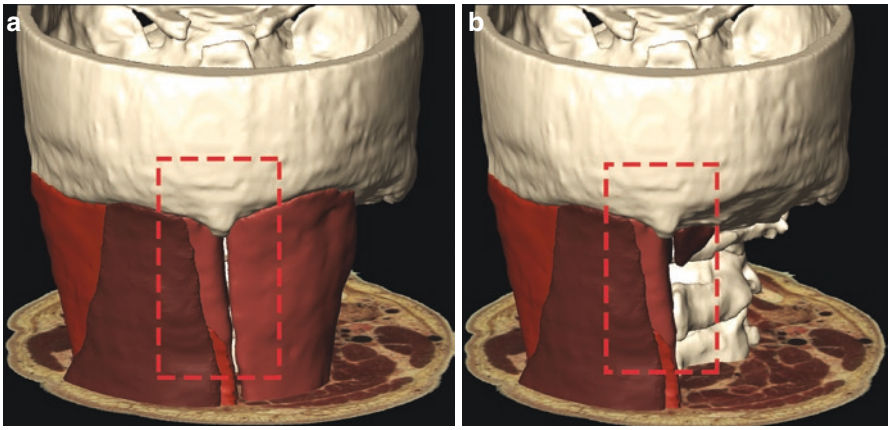

Fig. 1.4 3D model of the muscular layers visible through a posteromedial perspective to the CVJ. The anatomical area of interest is limited by the red dotted lines. The superficial layer (**a**) is represented by the trapezius muscle (dark brown), splenius capitis muscle (dark orange), and semispinalis capitis (light brown). On the right half of the picture, trapezius and splenius capitis muscles have been removed, revealing the semispinalis capitis muscle. The deep muscular layer (**b**) is represented by rectus capitis posterior minor muscles (dark brown), exposed after the removal of the superficial layer muscles on the left side of the picture

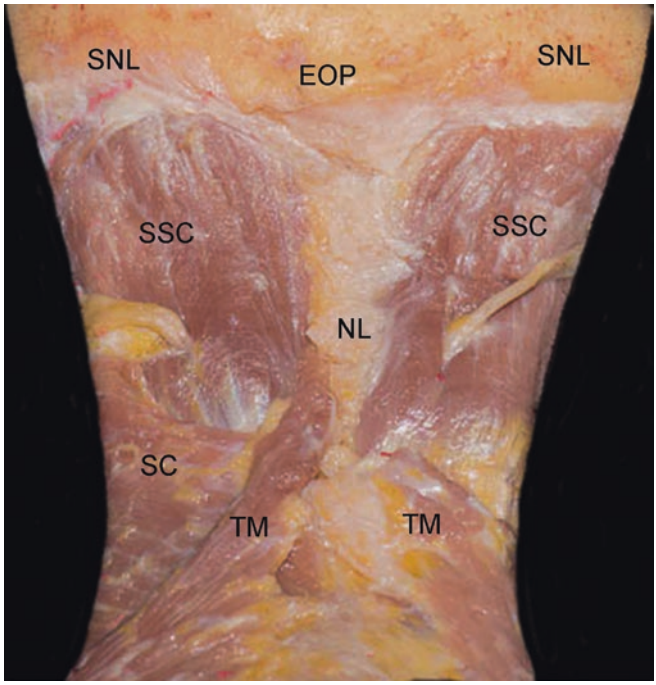

Fig. 1.5 Posteromedial perspective of the CVJ: muscular relationships. Trapezius is the most superficial muscle. It extends from the medial half of the superior nuchal line, the external occipital protuberance, and the spinous processes of the cervical and thoracic vertebrae and converges on the shoulder to attach to the scapula and the lateral third of the clavicle. Here, it has been partially resected in its rostral part to expose in a deeper layer the splenius capitis in its medial half, running to the spinous processes of the lower cervical and upper thoracic vertebrae. On the right side of the picture the splenius capitis has been resected. Deep to the splenius capitis, the semispinalis capitis begins medially at the midline occipital crest in the area between the superior and inferior nuchal lines and attaches below to the upper thoracic and lower cervical vertebrae. In the midline, the nuchal ligament forms a septation dividing the posterior neck muscles on the left and right sides. Moreover, some of these muscles attach medially to this structure. The nuchal ligament extends from the spinous process of the cervical vertebrae to the external occipital protuberance. *EOP* external occipital protuberance; *NL* nuchal ligament; *SC* splenius capitis; *SNL* superior nuchal line; *SSC* semispinalis capitis; *TM* trapezius muscle

In the midline, the nuchal ligament forms a septation dividing the posterior neck muscles on left and right sides. Moreover, some of these muscles attach medially to this structure. The nuchal ligament extends from the spinous process of the cervical vertebrae to the EOP [11].

1.2.3 Extradural Structures

The posterior border of the foramen magnum and the upper border of the posterior arch of the atlas are connected by the posterior atlanto-occipital membrane (PAOM)

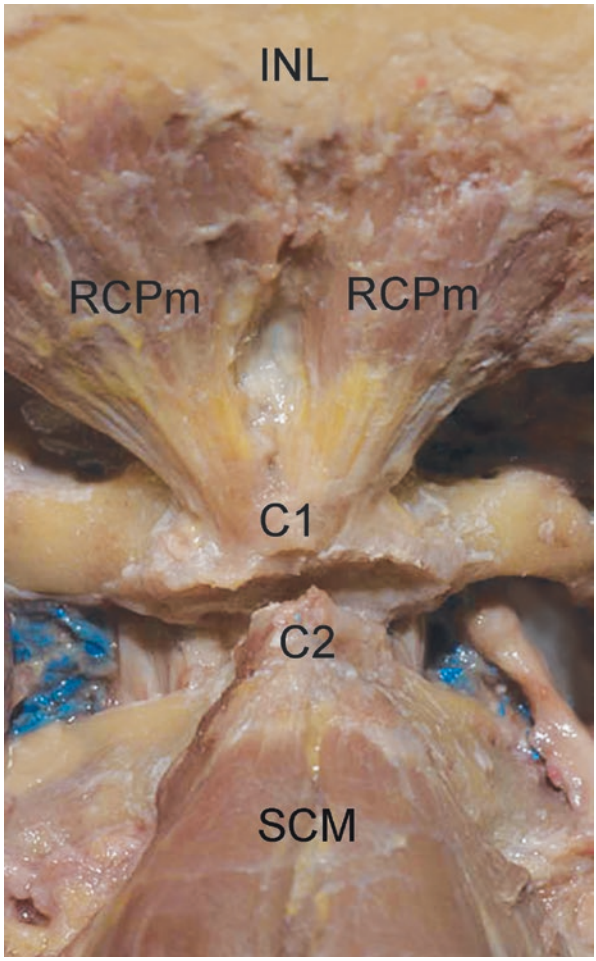

Fig. 1.6 Posteromedial perspective of the CVJ: muscular relationships. The deepest layer of muscle consists of the rectus capitis posterior minor muscles. The muscles extend from the medial part and below the inferior nuchal line to the tubercle on the posterior arch of the atlas. *C1* median posterior tubercle of the atlas; *C2* spinous process of the axis; *INL* inferior nuchal line; *RCPm* rectus capitis posterior minor muscle; *SCM* semispinalis cervicis muscle

that runs adjacent to the rectus capitis posterior minor posteriorly and the dura mater anteriorly. Connection or interdigitation of the PAOM with both the rectus capitis posterior minor muscles and the spinal dura mater can be observed. The PAOM is continuous inferiorly with a thin membrane named the posterior atlanto-axial membrane, which is attached above to the lower border of the posterior arch of the atlas and below to the upper edges of the laminae of the axis, in series with the ligamentum flavum [4, 12]. The posterior opening of the FM is wider posteriorly than anteriorly and transmits the medulla (Fig. 1.7).

The venous channels in the dura mater surrounding the foramen magnum in its posteromedial aspect are the marginal sinus and the occipital sinus. The marginal sinus is located between the layers of the dura in the rim of the foramen magnum. It communicates posteriorly with the occipital sinus. The occipital sinus courses in the cerebellar falx [9, 13].

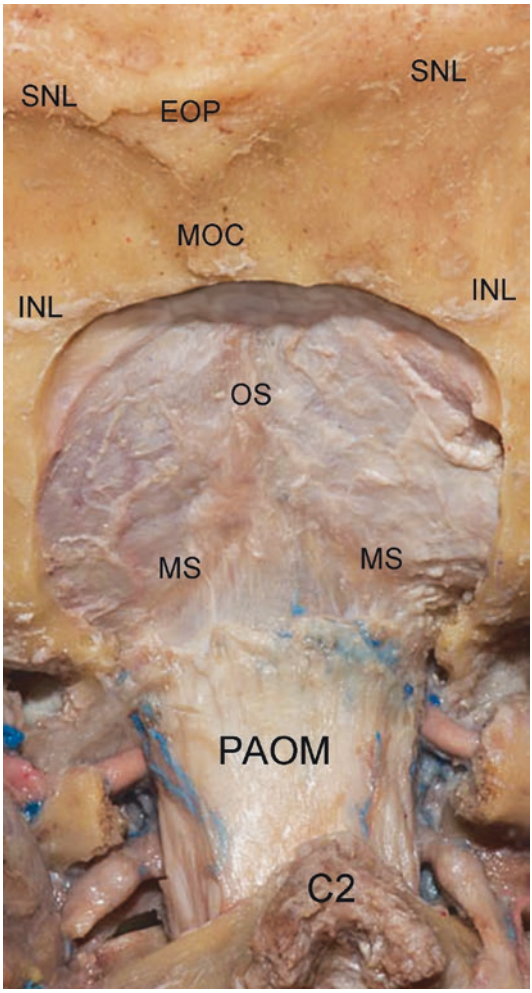

Fig. 1.7 Posteromedial perspective of the CVJ. The middle portion of the squamosal part of the occipital bone and the posterior arch of the atlas have been removed. The posterior border of the foramen magnum has been opened. The posterior border of the foramen magnum and the upper border of the posterior arch of the atlas are connected by the posterior atlanto-occipital membrane that runs adjacent to the rectus capitis posterior minor posteriorly and the dura mater anteriorly. The venous channels in the dura mater surrounding the foramen magnum in its posteromedial aspect are the marginal sinus and the occipital sinus. The marginal sinus is located between the layers of the dura in the rim of the foramen magnum. It communicates posteriorly with the occipital sinus. The occipital sinus courses in the cerebellar falx. *C2* spinous process of the axis; *EOP* external occipital protuberance; *INL* inferior nuchal line; *MOC* middle occipital crest; *MS* marginal sinus; *OS* occipital sinus; *PAOM* posterior atlanto-occipital membrane; *SNL* superior nuchal line

1.2.4 Intradural Anatomy (Fig. 1.8)

Through a posteromedial perspective, the medulla can be exposed, occupying the foramen magnum. The medulla blends indistinguishably into the spinal cord at a level arbitrarily set to be at the upper limit of the dorsal and ventral rootlets forming the first cervical nerve. Posteromedially, the spinal cord is divided by the posteromedian sulcus into symmetrical halves. Each half is occupied by the posterior funiculus. At the upper cervical level, the surface of the posterior funiculus is divided by another shallow longitudinal furrow, the posterior intermediate sulcus, into the fasciculus gracilis medially and the fasciculus cuneatus laterally. Superiorly, the posterior surface of the medulla is composed in the midline of the inferior half of the fourth ventricle and laterally by the inferior cerebellar peduncles. Inferiorly the posterior surface is composed of the gracile fasciculus and tubercle medially, and the cuneate fasciculus and tubercle laterally [2, 8, 14].

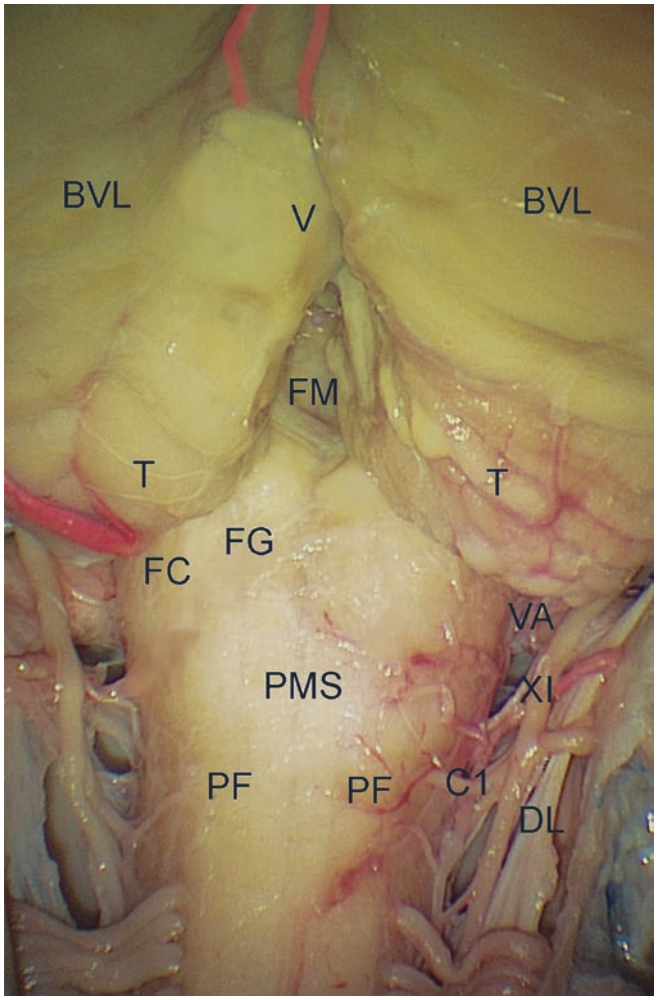

Fig. 1.8 Posteromedial intradural perspective of the CVJ. The medulla is exposed where it blends indistinguishably into the spinal cord at a level arbitrarily set to be at the upper limit of the dorsal and ventral rootlets forming the first cervical nerve. The spinal cord is divided by the posteromedian sulcus into symmetrical halves. Each half is occupied by the posterior funiculus. At the upper cervical level, the surface of the posterior funiculus is divided by another shallow longitudinal furrow, the posterior intermediate sulcus, into the fasciculus gracilis medially and the fasciculus cuneatus laterally. The posteromedial aspect of the cerebellum related to the foramen magnum consists in the lower part of the hemispheres (formed by the tonsils and the biventral lobules) and the lower part of the vermis (formed by the nodule, uvula, and pyramid). Between the tonsils, the foramen of Magendie communicates with the fourth ventricle. The vertebral artery in its third segment (V3) pierces the posterior atlanto-occipital membrane, then dura mater, to enter the posterior fossa. As the artery pierces the dura, it is encased in a fibrous tunnel that binds the posterior spinal artery, dentate ligament, first cervical nerve, and the spinal accessory nerve to the vertebral artery. The C1 nerve root passes through the dura mater on the lower surface of the vertebral artery. The accessory nerve is the only cranial nerve that passes through the foramen magnum, between the dentate ligament and the dorsal spinal roots. *BVL* biventral lobule of the cerebellar hemisphere; *C1* dorsal root of the first cervical nerve; *DL* dentate ligament; *FC* fasciculus cuneatus; *FG* fasciculus gracilis; *FM* foramen of Magendie; *PF* posterior funiculus; *PMS* posteromedial sulcus; *T* tonsil; *V* vermis; *VA* vertebral artery; *XI* accessory nerve

The posteromedial aspect of the cerebellum related to the foramen magnum consists in the lower part of the hemispheres (formed by the tonsils and the biventral lobules) and the lower part of the vermis (formed by the nodule, uvula, and pyramid). The cerebellar surface above the posterior part of the foramen magnum has a deep vertical depression, the posterior cerebellar incisura, which contains the falx cerebelli and extends inferiorly toward the foramen magnum. The vermis is folded into and forms the cortical surface within this incisura. The vermian surface within the incisura is composed of the pyramid in its upper half and of the uvula that projects downward between the tonsils. Inferiorly, the posterior cerebellar incisura is continuous with the vallecula cerebelli, an opening between the tonsils that extends upward through the foramen of Magendie into the fourth ventricle. Each tonsil is an ovoid structure that is attached along its superolateral border to the remainder of the cerebellum. The superior pole faces the inferior half of the roof of the fourth ventricle. The anterior surface of each tonsil faces and is separated from the posterior surface of the medulla by the cerebello-medullary fissure. This fissure extends superiorly to the level of the roof of the fourth ventricle and the lateral recesses of the fourth ventricle. The dorsal wall of the fissure is formed by the uvula in the midline and the tonsils and biventral lobules laterally. The ventral wall is formed by the inferior medullary velum and tela choroidea. The inferior medullary velum is a thin sheet of neural tissue that blends into the ventricular surface of the nodule medially and stretches laterally across the superior pole of the tonsil. The tela choroidea, from which the choroid plexus projects, forms the lowest part of the roof of the fourth ventricle [4, 5, 14, 15].

The vertebral artery in its third segment (V3) pierces the PAOM, then dura mater, to enter the posterior fossa. As the artery pierces the dura, it is encased in a fibrous tunnel that binds the posterior spinal artery, dentate ligament, first cervical nerve, and the spinal accessory nerve to it. The C1 nerve root passes through the dura mater on the lower surface of the vertebral artery. The posterior spinal artery arises from the posteromedial surface of V3 initial just outside or inside the dura mater. In the subarachnoid space, it courses medially between the accessory nerve and the dentate ligament. At the lower medulla, it divides into an ascending branch that supplies the gracile and cuneate tubercles, the rootlets of the accessory nerve, and the choroid plexus near the foramen of Magendie, and a descending branch that supplies the superficial part of the dorsal half of the cervical spinal cord. It anastomoses with the posterior branches of the radicular arteries that enter the vertebral foramen at lower levels. The descending branch gives rise to collateral branches, which course medially across the posterior surface of the spinal cord and join to form an artery that course in the posterior midline [2, 16, 17].

The posterior meningeal artery arises from the posterosuperior surface of the vertebral artery. Its origin may be intra- or extradural and supplies the dura mater of the posterior and posterolateral part of the posterior cranial fossa [4, 17].

The median posterior spinal vein, which courses along the posteromedian spinal sulcus, is continuous above with the main vein on the posterior surface of the medulla and the median posterior medullary vein, which courses along the posteromedian medullary sulcus. The transverse medullary and transverse spinal veins