The suboccipital cavernous sinus

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The authors studied the microsurgical anatomy of the suboccipital region, concentrating on the third segment (V3) of the vertebral artery (VA), which extends from the transverse foramen of the axis to the dural penetration of the VA, paying particular attention to its loops, branches, supporting fibrous rings, and surrounding venous structures. The VA, which extends from the transverse foramen of the axis to the cavernous sinus, this suboccipital complex is here named the "suboccipital cavernous sinus." Its role in physiological and pathological conditions as they pertain to various clinical and surgical implications is also discussed.

KEY WORDS • microsurgical anatomy • function • cavernous sinus • suboccipital cavernous sinus • vertebral artery

The suboccipital region contains the complex of the vertebral artery (VA), its periartrial autonomic neural plexus, its branches, and the adjacent spinal nerves, all of which are cushioned in a venous compartment. This region can be the site of vascular, neoplastic, degenerative, congenital, or traumatic diseases, the operative management of which demands an in-depth understanding of the complex anatomy. We studied the microsurgical anatomy of this region, concentrating on the third segment (V3) of the VA, which extends from the transverse foramen of the axis to the dural penetration by the VA. We also studied the loops, branches, supporting fibrous rings, and surrounding venous structures of the VA, as well as the relationships of these anatomical elements to their surrounding structures. Our study revealed an astonishing anatomical resemblance between this complex and the cavernous sinus. A review of the literature showed a related embryological development and functional and pathological features, as well as similar transitional patterns in the arterial walls of the V3 and the petrous-cavernous internal carotid artery (ICA), namely their loops, branches, supporting fibrous rings, and periartrial autonomic neural plexus; adjacent nerves; and skull base locations. Likewise, a review of the literature showed a related embryological development and functional and pathological features, as well as similar transitional patterns in the arterial walls of the V3 and the petrous-cavernous ICA. Hence, due to its similarity to the cavernous sinus, this suboccipital complex is here named the "suboccipital cavernous sinus." Its role in physiological and pathological conditions as they pertain to various clinical and surgical implications is also discussed.

Materials and Methods

The craniocervical regions of ten cadaver heads (20 sides) were dissected with the aid of an operating microscope (magnification 4–40). The cadavers previously had been embalmed in a formalin solution. The ICAs, the VAs, and the internal jugular veins (IJVs) were dissected, cannulated, and irrigated with saline to remove any residual blood clots in the lumens. Two colored silicone rubber mixes were prepared by first adding red and blue powder paint (Tempera Powder Paint; Sargent Art, Inc., Hazleton, PA) to the liquid solvent poly-di-methylsiloxane (Dow Corning, Inc., Midland, MI). Silicone rubber was then added immediately before administering the injections. The mixture was prepared so that it was sufficiently fluid to allow perfusion of the smaller blood vessels; it solidified after injection. To further ensure adequate perfusion of the microcirculation, we perfused the arteries individually under pressure (by injecting one ICA while clamping the contralateral ICA and both VAs). Forty hours after the injections were given, the cadavers were ready for dissection. In two additional formalin-fixed specimens, the VA, and its surrounding structures were dissected under the microscope, from the transverse foramen of the axis to the dural ring. Serial cross sections were made and embedded in paraffin, and then histological cross sections were cut and stained with hematoxylin and eosin and Masson trichrome. All specimens were examined under the microscope.
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Definitions of abbreviations for figure legends

\[ a = \text{muscular artery of V}_3 \]
\[ acv = \text{anterior condylar vein} \]
\[ ar = \text{anterior ramus} \]
\[ av = \text{anterior vertebrobasilar vein} \]
\[ c = \text{condyle} \]
\[ C_{3n} = \text{C-3 nerve} \]
\[ C_{2n} = \text{C-2 nerve} \]
\[ d = \text{diameter} \]
\[ dm = \text{digastric muscle} \]
\[ dr = \text{discal ring} \]
\[ il = \text{inferior lateral loop} \]
\[ im = \text{inferior medial loop} \]
\[ ist = \text{inferior suboccipital triangle} \]
\[ j = \text{jugular bulb} \]
\[ jv = \text{jugular vein} \]
\[ kcv = \text{knee of condylar vein} \]
\[ lr = \text{lateral ring} \]
\[ m = \text{membrane of suboccipital cavernous sinus} \]
\[ ma = \text{muscular artery} \]
\[ mon = \text{major occipital nerve} \]
\[ ms = \text{muscular layers} \]
\[ n = \text{vertebra} \]
\[ oa = \text{occipital artery (OA)} \]
\[ om = \text{oblique capsular inferior muscle} \]
\[ osm = \text{oblique capsular superior muscle} \]
\[ ov = \text{occipital vein} \]
\[ pam = \text{posterior atlantooccipital membrane} \]
\[ panp = \text{periarterial autonomic neural plexus} \]
\[ pcv = \text{posterior condylar vein} \]
\[ pma = \text{posterior meningeal artery} \]
\[ pr = \text{posterior ramus} \]
\[ rl = \text{retroglidial ligament} \]
\[ rma = \text{radicular arteries} \]
\[ rppam = \text{rectus posterior major muscle} \]
\[ rppam = \text{rectus posterior minor muscle} \]
\[ scs = \text{suboccipital cavernous sinus} \]
\[ secm = \text{semispinalis cervicis muscle} \]
\[ sem = \text{semispinalis capitis muscle} \]
\[ sli = \text{superior lateral loop} \]
\[ sml = \text{superior medullary loop} \]
\[ splcm = \text{splenius cervicis muscle} \]
\[ spinm = \text{splenius capitis muscle} \]
\[ ss = \text{sigmoid sinus} \]
\[ sst = \text{superior suboccipital triangle} \]
\[ stm = \text{sternocleidomastoid muscle} \]
\[ v = \text{vein} \]
\[ vavp = \text{vertebral artery venous plexus (VAVP)} \]
\[ vvp = \text{vertebral venous plexus (VVP)} \]

The VA is divided into four segments: 1) the pretransverse segment (V\(_1\)), which extends from the origin of the VA to the transverse foramen of the C-6 vertebra; 2) the transverse segment (V\(_2\)), which extends from the transverse foramen of C-6 to the transverse foramen of the axis; 3) the suboccipital segment (V\(_3\)), which continues from the transverse foramen of the axis to the dural penetration of the VA; and 4) the intracranial segment (V\(_4\)), which continues intracranially to the junction with the contralateral VA to form the basilar artery. We subdivided the V\(_3\) into two parts: a horizontal (V\(_{3h}\)), which is cushioned in a venous compartment, and a vertical (V\(_{3v}\)), which is surrounded by a venous plexus.

Measurements for the following anatomical structures were obtained with the aid of a microscope: the width of the V\(_{3h}\) at the intersection with the anterior ramus of the C-2; the width of the V\(_{3h}\) at the origin of the muscular artery; the diameters of the branches of the VA at the sites of origin; the height of the C-1 transverse foramen at the midpoint; and the distances between the midline and the V\(_{3h}\) at three levels: 1) the distal (dural) ring; 2) the intersection with the C-2 anterior ramus; and 3) the upper level of the transverse foramen of the atlas. The measurements of the structures were obtained by using calipers and stainless-steel micrometers; the amounts are conservative and can be assumed to be larger in vivo. The range and mean statistical values were also obtained.

**Results**

We examined the anatomical features of the suboccipital region as they appeared in layers from the superficial to the deep tissues, as follows: 1) the muscular layers; 2) the posterior atlantooccipital membrane; 3) the venous structures; 4) the spinal nerves; and 5) the V\(_{3h}\) segment of the VA with its loops, branches, and supporting fibrous rings.

**Muscular Layers**

The V\(_{3h}\) is covered by three layers of muscles: superficial, intermediate, and deep, as noted in previous anatomical descriptions. A rich suboccipital venous plexus is located between the intermediate and deep muscular layers. At the occipitoatlantal interspace, the muscles of the deep layer, namely the obliquus capitis superior and inferior muscles and the rectus capitis posterior major muscle, create the superior suboccipital triangle.

**Posterior Atlantooccipital Membrane**

The posterior atlantooccipital membrane, located ventral to the latter is the venous compartment that contains the V\(_{3h}\), the muscular artery of the V\(_{3h}\), the posterior meningeal artery of the V\(_{3h}\), the periorbital autonomic neural plexus, and the C-1 nerve branching into anterior and posterior rami. In the atlantoaxial region, the obliquus capitis inferior and the semispinalis and splenius cervicis muscles delineate the inferior suboccipital triangle. This triangle contains the V\(_{3h}\), the periorbital autonomic neural plexus, the muscular and radiculomuscular arteries of the V\(_{3h}\), the VA venous plexus (VAVP) around the V\(_{3h}\), and the C-2 nerve branching into anterior and posterior rami (Fig. 1 right).

**Suboccipital Venous Structures**

The venous structures in the suboccipital region are: 1) the suboccipital venous plexus; 2) the venous compartment cushioning the V\(_{3h}\); 3) the VAVP around the V\(_{3h}\); and 4) the vertebral venous plexus (VVP) related to the spine.
Photographs of the suboccipital region after reflection of the superficial and deep muscular layers. Left: Photograph showing the suboccipital venous plexus located on the deep muscular layer. The muscles of the first and second layers are reflected: semispinalis capitis muscle (sem) superiorly and sternocleidomastoid (stm) and splenius capitis (spm) muscles laterally. The major occipital nerve (mon) arises here from the posterior ramus of C-2 nerve and ascends to pierce the sem. Note also the OA (oa) and the occipital vein (ov), the latter of which connects the mastoid emissary vein and the suboccipital venous plexus. Right: Photograph showing the deep muscular layer (right side). The obli­quus capitis superior (osm), obliquus capitis inferior (oim), and rectus capitis posterior major (rpmam) muscles create the superior suboccipital triangle (sst). The oim, splenius cervicis (spcm), and semispinalis cervicis (secm) muscles create the inferior suboccipital triangle (ist). Note also the OA, the rectus capitis posterior minor muscle (rpmim), and the digastric muscle (dm).

The suboccipital venous plexus is located between the intermediate and deep muscular layers (Fig. 1) and continues inferiorly into the deep cervical vein. The suboccipital venous plexus communicates with the following structures: 1) the venous compartment cushioning the V₃h via the anastomotic vein that passes through the foramen of the posterior atlantooccipital membrane (Fig. 2); 2) the VAVP around the V₃v; 3) the VVP (the suboccipital venous plexus), which communicates with both the VAVP and the VVP via the anastomotic vein at the atlantooccipital interspace (Fig. 3 upper), and 4) the transverse sigmoid sinus via the mastoid emissary and occipital veins (Fig. 1).

We found that the venous compartment in the sub­occipital region, bordered proximally by the lateral (periosteal) ring, distally by the distal (dural) ring, inferiorly by the posterior arch of the atlas, ventrally by the dura and the capsule of the atlantooccipital condylar joint, and dorsally by the posterior atlantooccipital membrane, is a structure strikingly similar to the cavernous sinus. It is surrounded by a fibrous membrane and contains and cushions the V₃h, the muscular artery of the V₃h, the posterior meningeal artery, the periarterial autonomic neural plexus, and the C-1 nerve branching into anterior and posterior rami (Fig. 1 lower left). It communicates with 1) the contralateral sinus via the internal VVP; 2) the occipital sinus via the marginal sinus; 3) the jugular bulb and vein via, first, the anterior condylar vein, which accompanies the hypoglossal nerve and meningeal branch of the ascending pharyngeal artery along the hypoglossal canal (anterior condylar canal); second, the posterior condylar vein, which exits from the posterior condylar canal at the condylar fossa located posterior to and above the occipital condyle; third, the lateral condylar vein, which connects the jugular vein and the venous compartment cushioning the V₃h and is lateral to the occipital condyle (Fig. 3 upper); and 4) the suboccipital venous plexus via the anastomotic vein coursing through the foramen of the atlantooccipital membrane.

The suboccipital venous compartment cushioning the V₃h continues below the transverse foramen of the atlas, gradually becoming the VAVP (the venous plexus around the V₃v). This plexus has a number of venous trunks (average four, range three–six) mutually interconnected by venules and located predominantly at the medioposterior aspect of the V₃v (Fig. 3 lower right). It communicates with the VVP and the suboccipital venous plexus (Fig. 3 upper). More distally, the VAVP continues below the axis as two or three vertebral veins that merge into one trunk that enters the brachiocephalic vein.

The internal VVP, a rich venous network, is contained within the dural leaflets at the occipitoatlantal interspace. It is an inferior continuation of the occipital and marginal dural sinuses, as well as of the basilar venous plexus. At the atlantoaxial interspace, this plexus has an external component (external VVP) located predominantly around the axis and continuing farther below it. It connects the two contralateral venous compartments around the V₃h at the occipitoatlantal interspace and the two contralateral VAVPs at the atlantoaxial interspace (Figs. 3 upper and 4).

**Spinal Nerves**

Two spinal nerves, the C-1 and the C-2, are adjacent to the V₃.

The C-1 Nerve. Exiting extradurally at the inferior aspect of the V₃h is the C-1 nerve (Fig. 4); both the artery and the exiting nerve are encircled by the distal ring. The C-1 nerve is located in the depth of the superior suboccipital triangle and within the sulcus of the VA of the posterior arch of the atlas, where it divides into anterior and posterior rami. The anterior ramus continues below the
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**FIG. 2.** Photograph revealing the right side of posterior atlantooccipital membrane (pam). The pam is stretched between the occipital bone and the atlas. Close to its lateral border, it displays a foramen of the posterior atlantooccipital membrane (dots). Coursing throughout this foramen are the muscular artery of V₃h (a), the anastomotic vein (v), and the branches of the posterior ramus of C-1 nerve (n). The rpmam is in position, whereas the oim and rpmim muscles are reflected inferiorly. The OA is more lateral.

V₃h passes between the obliquus capitis superior and rectus capitis anterior muscles, and contributes to the cervical plexus. The posterior ramus exits through the foramen of the posterior atlantooccipital membrane, branching out and innervating the suboccipital muscles (Fig. 2).

**The C-2 Nerve.** At the occipitoatlantal interspace, in the depth of the inferior suboccipital triangle, the C-2 nerve (Fig. 4) exits extradurally and divides into anterior and posterior rami. The anterior ramus is attached to the V₃v with a fibrous adhesion (Fig. 3 lower right); it curves around the artery ventral to the posterior intertransverse muscle and contributes to the cervical plexus. The posterior ramus courses posteriorly below the inferior obliquus muscle and divides into a medial branch (the major occipital nerve) and a lateral branch, the latter of which innervates the suboccipital intermediate muscular layer.

**Vascular Loops of the V₃ Segment**

The V₃ possesses four vascular loops (Fig. 4). The first, the inferior medial loop, which directs the artery laterally and slightly posteriorly, appears at the transverse foramen of the axis. The next loop, the inferior lateral loop, continues immediately, directing the artery upward and slightly anterior toward the transverse foramen of the atlas. The third, the superior lateral loop, is located at the point where the V₃v turns into a horizontal position (V₃h) in the sulcus of the posterior arch of the atlas. In two arteries (20%), this bone groove was transformed into the canal by the bone ring. The fourth loop, the superior medial loop, surrounds the condyle of the atlas and brings the V₃ to its dural foramen. This part of the V₃ is connected to the capsule of the atlantooccipital articulation by the retroglenoid ligament, a strong and wide fibrous adhesion.

At the atlantoaxial interspace, the V₃v is intersected dorsally by the anterior ramus of the C-2 nerve, which is attached to the artery by fibrous adhesion (Fig. 3 lower right). A fine periarterial autonomic neural plexus encircles the V₃ in its entire length (Fig. 5).

**Fibrous Rings**

In the transverse foramen of the atlas, a fibrous periosteal ring, herein described as the lateral ring, surrounds the venous compartment that cushions the V₃h, the periarterial autonomic neural plexus, and the V₃ (Fig. 3 upper left).

At the point where the VA penetrates the dura is a dural ring, herein described as the distal ring; it encircles 1) the VA; 2) the periarterial autonomic neural plexus; 3) the C-1 nerve (located below the artery); and 4) the extradural origin (present in 10% of specimens) of the posterior or spinal artery at the posteromedial aspect of the ring (Fig. 6).

**Tables 1, 2, and 3 provide the measurements obtained.**

#### TABLE 1

**Comparison of VA widths (in millimeters) in 10 cadaveric heads***

<table>
<thead>
<tr>
<th>V₃ Subdivision</th>
<th>Width: Lt</th>
<th>Width: Rt</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Range</td>
<td>Mean</td>
</tr>
<tr>
<td>V₃v (intersection w/ anterior ramus of C-2 nerve)</td>
<td>4.0-6.1</td>
<td>4.8</td>
</tr>
<tr>
<td>V₃h (origin of the muscular artery)</td>
<td>3.2-5.2</td>
<td>4.2</td>
</tr>
</tbody>
</table>

*The VA was larger on the left side in seven samples (70%) and on the right side in three samples (30%).

#### TABLE 2

**Comparison of the height of the transverse foramen of the atlas at the midportion in 10 cadaveric heads***

<table>
<thead>
<tr>
<th>Side</th>
<th>Range</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>left</td>
<td>5.0-8.5</td>
<td>6.4</td>
</tr>
<tr>
<td>right</td>
<td>4.9-7.6</td>
<td>6.3</td>
</tr>
</tbody>
</table>

*The height of the transverse foramen of the atlas was greater on the left side in seven samples (70%) and on the right side in three samples (30%).

#### TABLE 3

**Distances (in millimeters) between the midline and the V₃v and V₃h parts of the V₃ at different levels***

<table>
<thead>
<tr>
<th>Level</th>
<th>Distance: Lt</th>
<th>Distance: Rt</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Range</td>
<td>Mean</td>
</tr>
<tr>
<td>V₃v (intersection w/ anterior ramus of C-2 nerve)</td>
<td>27.4-36.1</td>
<td>30.8</td>
</tr>
<tr>
<td>V₃h (distal ring)</td>
<td>11.2-19.2</td>
<td>14.7</td>
</tr>
<tr>
<td>V₃h (upper border of the transverse foramen of the atlas)</td>
<td>24.0-36.6</td>
<td>31.4</td>
</tr>
</tbody>
</table>

*The mean distances from the midline to the V₃h were larger on the left side, whereas those to the V₃v were the same on both sides.
Arterial Branches of the V₃ Segment

The V₃h and the V₃v each have two constant branches. These branches are described below.

Muscular Artery of V₃v. This artery arises ventral to the anterior ramus of the C-2 nerve and communicates further ventrally with the branches of the ascending pharyngeal artery (Fig. 7 left). In 90% of the samples it was the same size on both sides; in 10% it was larger on the left side (mean diameter 0.4 mm).

Radiculomuscular Artery of V₃v. This artery arises below the transverse foramen of the atlas and gives rise to the radiculomedullary branch, which accompanies the C-2 nerve laterally, vascularizing the C-2 ganglion, the C-2
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Fig. 4. Photograph completely revealing the V, after the removal of the atlas and axis (except the spinous process). The V, has four vascular loops: inferior medial loop (iml); inferior lateral loop (ill); superior lateral loop (sll); and superior medial loop (sml). Note also the marginal dural venous sinus (ms), the sigmoid sinus (ss), the IJV (jv), and the C-1 (C1n), C-2 (C2n), and C-3 (C3n) nerves.

nerve, and the spinal cord; and the muscular branch, which accompanies the posterior ramus of the C-2 nerve (Fig. 7). This artery was found to be the largest branch of the V, It was the same width on both sides in all the specimens (mean diameter 1 mm).

Muscular Artery of V,h. This artery courses posteriorly through the foramen of the posterior atlantooccipital membrane, vascularizes the muscles of the deep muscular layer and surrounding tissue, and communicates with the branches of the OA (Fig. 7 right). In 70% of the samples it was the same size on both sides; in 30% it was larger on the right side (mean diameter 0.5 mm).

Posterior Meningeal Artery of V,h. This artery arises at the superior surface of the V,h (at the superior medial loop) and vascularizes the neighboring portion of the posterior fossa dura, the falx cerebelli, the posterior portion of the tentorium, and the adjacent squama of the temporal bone (Fig. 6). The diameters on the two sides were the same in 70% of the samples, larger on the right side in 20%, and larger on the left side in 10% (mean diameter 0.8 mm).

In addition to these consistent branches, we found an arterial branch entering the posterior condylar canal (average diameter 0.4 mm) in two V,h parts (10%), and an extradural origin of the posterior spinal artery (average diameter 1 mm) in two other V,h parts (10%).

Discussion

The V, segment of the VA and its relation to the surrounding venous structures showed striking similarities to the petrous–cavernous ICA and its surrounding venous structures (Fig. 8). The cavernous sinus in the lateral sellar compartment was named by Winslow, who in 1732 compared it to the corpus cavernosum of the penis. This misnomer has been widely accepted, despite controversy concerning the term.\(^5\) Parkinson\(^6\) in particular has been a strong advocate for the term “lateral sellar compartment.” Parkinson\(^6\) and Dolenc\(^3\) are credited with providing detailed microsurgical anatomical studies of the cavernous sinus space and with pioneering surgery in this region. Because of the similarities between it and the suboccipital venous compartment that cushions the V, at the occipitoatlantal interspace, we posit that the most appropriate term for the latter is the suboccipital cavernous sinus.

Our review of the literature reveals that these similarities were also noticed in 1964 by Zolnai,\(^7\) who stated that “between the atlas and the foramen magnum exists the venous atlantooccipital sinus, which encircles the VA, and is similar to the cavernous sinus by its structure” and that because the sinus completely encircles the VA, it may be mistaken for the artery itself. In 1969 Yaşargil\(^8\) noted that the ICA enters the bony petrous carotid canal accompanied by two veins (one each on the convex and concave sides) and continues into the cavernous sinus, in which the veins communicate with the surrounding venous structures. Similarly, he stated, the VA is enveloped within its canal by the venous plexus, which communicates with the VVP. The arterial walls in both ICA and VA at these segments gradually transform from extracranial to intracranial patterns, losing their elastic, collagenous, and muscular elements, thus becoming thinner. Both arterial segments are encircled by periarterial autonomic neural plexuses. Other authors have outlined the similar embryological development of the ICAs and VAs,\(^9\) as well as the uniform development of the cranial venous system and its drainage pathways.\(^10\)

The similarities between the anatomical complexes of the petrous–cavernous ICA and the suboccipital (V,) segment of the VA far exceed the traits noted above. For one, both are exclusive brain blood suppliers, entering intracranial compartments after significant portions of their lengths have been cushioned in venous compart-
communications, "loop" is the preferred term. They can be divided into four types according to their shapes. The degrees of curvature of the inferior medial and the inferior or lateral loops (first and second contours) appear to be related to aging. The retroglenoid ligament, which connects the superior medial loop (fourth contour) to the atlantooccipital articulation (Fig. 7 right), may be ossified, making surgical dissection of the artery more difficult. At the interval between 0.5 cm before and 0.5 cm after the piercing of the dura, the thicknesses of the adventitial and medial arterial coats are drastically diminished, and the elastic fibers in the media and external elastic lamina of the VA are grossly reduced. The dura at the occipitoatlantal interspace is thicker and contains the internal VVP within its leaflets (Figs. 3 upper center and 4).

The Vp is surrounded by the periarterial autonomic neural plexus (Fig. 6). It is formed by the unmyelinated nerve fibers arising from cervical ganglia (predominantly inferior) and upper cervical nerves and consists of fine branching and communicating nerves that are directed lengthwise and diagonally in the adventitia, continuing around the Vp into the cranial cavity and supplying the endocranial blood vessels distally. This plexus also supplies the lower cranial nerves by the neural rami. We confirmed that the vertebral nerve is not located above the level of the C-3 vertebra.

Of interest is the discovery by Parke and Valsamis of an "amphuloglomerular organ" at the atlantooccipital interspace and within the suboccipital cavernous sinus, adjacent to the dural penetration of the VA. This formation was described as a group of venous aculations connected to a dural sinus, associated with a system of glomerular arteriovenous formations and numerous nerves, and capable of responding to changes in venous pressures. Structurally it resembled the carotid and aortic bodies. This finding, revealing yet another similarity between the petrous-cavernous ICA and the VP, helps support our hypothesis about the role and contribution of the suboccipital cavernous sinus in the regulation of "pressure."

Despite certain variations, the VP, maintains basic anatomical and functional properties. Although it adapts readily to movements at the craniospinal joint, if the rotations of the head and neck are pronounced and sudden, the artery can be subjected to shearing forces. The tight anatomical relations among the third muscular layer, the craniovertebral joint, the C-1 and C-2 nerves, and the VP, complex create the potential for neurovascular compression, with resulting clinical symptoms. The complete incorporation of the VP, by bone at the posterior arch of the atlas has been reported to occur in 7.8 to 28% of cases. In our study, it occurred in 20% of the cases, always unilaterally. The possibility of such complete bone bridging of the VP, complex from the atlas, in approximately every fifth patient, should be anticipated before the surgery. The asymmetry of VAs has been reported, with the larger artery occurring more often on the left side and called the dominant artery versus a contralateral minor artery. The size of the transverse foramen of the axis also has been found to be larger on the left side. In addition to confirming these findings, our study showed that almost all the mean values of the measurements obtained were greater for the left side (Tables 1–3), the reason for which remains unknown.

Anatomical Considerations

The four loops of the VP, have been described as first-through-fourth contours or curves. In neurosurgical

![Diagram of blood vessels and nerves](image-url)
Suboccipital cavernous sinus

Branches of \( V_1 \) and Their Functional Significance

The posterior meningeal artery (Fig. 6), which arises from the posterosuperior surface of the \( V_h \) at its superior medial loop, vascularizes the neighboring portion of the posterior fossa dura. It belongs to the "posterior meningeal vascularization system," with the branches from the OA, the ascending pharyngeal artery, and the segment of the VA (anterior meningeal artery). This meningeal branch of \( V_3 \) arising within the suboccipital cavernous sinus also communicates with the dorsal meningeal artery, which is a branch of the meningohypophyseal trunk arising within the cavernous sinus. It can participate in the vascularization of meningiomas, glomus jugulare tumors, hemangioblastomas, and dural arteriovenous malformations (AVMs) of the transverse sigmoid sinus.\(^{14,37}\)

After passing through the foramen of the atlantooccipital membrane, the muscular artery of \( V_h \) (Fig. 7 right) communicates with the branches of the OA (Fig. 2). These communications are seen in only 1% of angiographic studies, but they have been detected often in postmortem studies.\(^{40,56}\) We detected this physical presence in 80% of the specimens. This branch of \( V_h \), described also as "Salmon's suboccipital artery,"\(^{19,24}\) has rich communications contained in a suboccipital (cervical) arterial collateral network.\(^{19,39,46}\) Other arteries involved in this network are the muscular branches of the OA and the branches of the thyrocervical and costocervical trunks. An important aspect of the connections between the \( V_1 \) and the OA is their potential to develop and maintain adequate blood flow when occlusive vascular disorders of the ICA or the VA interrupt the normal pathways. Under such circumstances, these communications can enlarge and occur either indirectly via the suboccipital muscles or directly. However, the stenotic lesions of the VA are not as frequent as those of the ICA.\(^{10,19,22,40,46,33,36,70}\)

The radiculomuscular artery of \( V_h \) (Fig. 7), the largest branch of the \( V_h \), has two branches: 1) a medial branch that vascularizes the spinal nerve and its ganglion and penetrates the dura, contributing to the perimedullary arterial vasocorona of the spinal cord; and 2) a lateral branch that vascularizes the suboccipital muscles and also participates in the suboccipital collateral arterial network.\(^{19}\)

The muscular artery of the \( V_h \) (Fig. 7 left), which arises at the ventral portion of the inferolateral arterial loop, is rarely and only indirectly reported in the literature, probably because of its tiny size, hidden position, and difficulties encountered in its preservation during dissection. We frequently see this artery during surgery and must divide it during the caudomedial transposition of the \( V_h \). It communicates with the branches of the ascending pharyngeal artery, which contribute to the vascularization of a glomus jugulare tumor;\(^{39,46,68}\) thus, this \( V_h \) branch contributes also to the vascularization of the glomus tumor and, presumably, contributes to the suboccipital arterial collateral network.

Role of Venous Structures in Accessory Venous Drainage From the Intracranium

The suboccipital cavernous sinus and its inferior continuation below the transverse foramen of the atlas, the VAVP, should be clearly distinguished from the VVP, which Batson\(^{67}\) calls the vertebral venous system (VVS).

The VVP has two components; the internal, which lies within the spinal canal, and the external, which is found predominantly around the vertebral column.\(^{13,16,38}\) At every vertebral interspace, these components are connected by the intervertebral veins.\(^{48,7,13,25}\) The VVP has been described as either an accessory route of venous return from the intracranium during the flexion and extension, as well as during the rise in the intraabdominal or interbody
The suboccipital cavernous sinus is undoubtedly a functional part of the VVP. The role of the VVP in metastatic spread of diseases to the intracranial compartment, bypassing the lungs, was shown experimentally and explained by Batson, who also elucidated its multiple communications with the transverse sinus via the mastoid emissary and occipital veins, supporting the statement by Cooper that this plexus is a functional part of the VVP. This plexus may be the source of air embolisms when the patient is sitting in the operative position, which must be kept in mind during surgery.

Role of the VVS in Metastatic Spread of Diseases to Intracranium

Approximately 20 to 40% of cancer patients develop intracranial metastases. The role of the VVS (VVP) in the metastatic spread of diseases to the intracranial compartment is far more common in the pathogenesis of cerebral metastasis than the proposed mechanism of "paradoxical embolism" of the body tumor along the arterial tree, which is necessarily associated with persistent heart septal defects. Hence, because of its interrelations with the VVS, the suboccipital venous plexus is most likely also involved in the metastatic spread of diseases.

Surgical Considerations

The V3 can be approached via the lateral route between the sternocleidomastoid muscle and the lateral border of the IVJ. Care should be taken to preserve the accessory nerve. In addition to the V3 complex itself, the targeted pathological entities include AVMs, tumors, osteolytic, fibrous bands, infective processes, and traumatic lesions. One cautionary note is that rotating the head of the anesthetized patient during the surgical positioning can cause intermittent stenosis or even occlusion of the VA.
vascular lesions (AVMs or aneurysms), degenerative diseases (rheumatoid arthritis), congenital malformations, and traumatic lesions. After the V complex has been dissected from the transverse foramen of the axis to its dural entry, the posterior wall of the transverse foramen of the atlas is opened using a diamond drill. Careful subperiosteal dissection spares the lateral (periosteal) ring (Fig. 3 upper left and center), which may be used for surgical manipulation during the transposition. Cautious surgical dissection, opening of the posterior atlantooccipital membrane (Fig. 2), division of the retroretrigemoid ligament (Fig. 7 right), early coagulation and division of the condylar anastomotic veins (Fig. 3 upper), and preservation of the fibrous membrane surrounding the suboccipital cavernous sinus itself (Fig. 3 upper left, center, right, and lower left) should be implemented to minimize bleeding. If bleeding does occur, it usually can be easily controlled by packing because of the low intraluminal venous pressure. The V complex is transposed caudomedially to gain space for drilling the occipital condyle and the lateral mass of the atlas. Care should be taken while opening the dura at the distal (cortical) ring (Fig. 6) to preserve the C-1 nerve inferior to the artery and the origin of the posterior spinal artery behind the V (if it exists). The dura mater in this region is thicker than usual and contains venous channels of various sizes (the VVP). Maintaining an adequate dural cuff around the artery is important for a watertight dural closure that will prevent a cerebrospinal fluid leak.

The median inferior suboccipital approach through the vertical midline incision from the occipital protuberance down to C2-3 is used commonly to excise many lesions, including dorsal foramen magnum meningiomas, cerebellar hemangioblastomas and astrocytomas, vermian and fourth ventricular tumors, and medullary and cervico-medullary astrocytomas. If the incision is made in the strict midline position, the V complex is not encountered; nevertheless, the surgeon must appreciate the unseen course of the V.

The V may provide arterial blood supply to the upper dorsal cervical tumors or vascular lesions, either directly or indirectly by one of its branches. For glomus jugulare tumors, embolization and ligation of the feeding vessels suppresses the tumor vascularization and makes the definite tumor excision easier. Obtaining pre- and postoperative angiograms is essential.

Conclusions

The suboccipital cavernous sinus and the cavernous sinus are quite analogous anatomical complexes. The anatomical properties of their contents (the venous cushioning, the V, and the petrous–cavernous ICA, the arterial loops and the supporting fibrous rings, the arterial branches, the periarterial autonomic neural plexuses, the surrounding nerves, and transitional patterns of the arterial walls of the V, and of the petrous–cavernous ICA), their embryological development, their locations at the base of the skull, and their neurosurgical importance are all quite similar. Besides being morphological entities, they also play active and important functional roles.

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4. Anderson R: Dondrast studies of the vertebral and cranial venous systems. To show their probable role in cerebral metastases. J Neurosurg 8:411–422, 1951
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