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Original article

Microsurgical Neurovascular Anatomy of the Brain: The Posterior Circulation (Part II)

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Abstract. *Introduction:* Vascular complications of posterior fossa surgery are often deadly although widely preventable through in-depth knowledge of the microsurgical neurovascular anatomy of the infratentorial region and careful surgical planning. The target of this study is to provide a synoptic overview of the normal anatomy and anatomic variants of the infratentorial neurovascular system, critical to safely operate tumors and neurovascular pathologies of the posterior fossa. *Methods***:** Two fresh-frozen and five formalin-fixed cadaveric heads were used. Cervical arteries and internal jugular veins were injected with red and blue latex, respectively. The heads were dissected under a surgical microscope, with magnifications ranging between 3× to 40×, focusing on the infratentorial region. The infratentorial arteries, their collaterals and perforating branches, the brainstem and cerebellar veins, the tentorial venous sinuses, and the relative vascular territories were summarized according to a synoptic approach. *Results:* The vertebral artery, basilar artery (BA), and posterior cerebral artery (PCA) are the main sources of the arterial supply of the brainstem and cerebellum through the posterior inferior cerebellar artery (PICA), the anterior inferior cerebellar artery (AICA), the superior cerebellar artery (SCA), and the perforating arteries. The perforating arteries of the vertebrobasilar system derive from the PICA, BA, AICA, SCA, and PCA, and provide for a key contribution to the vascularization of the midbrain, pons, medulla oblongata, fourth ventricle, cerebellar and cerebral peduncles, thalamus, hypothalamus, subthalamus, posterior part of the internal capsule, and optic tract. The distal segments and branches of the PCA also add a significant arterial supply to the temporal, occipital, and parietal lobes. The venous outflow of the posterior fossa is a prerogative of the internal jugular veins via the tentorial venous sinuses. *Conclusion:* A perfect mastery of the arterial, venous, and cisternal anatomy of the infratentorial region is vital for the planning and execution of the whole range of posterior fossa approaches.

Key words: Anterior Inferior Cerebellar Artery, Basilar Artery, Posterior Cerebral Artery, Posterior Inferior Cerebellar Artery, Superior Cerebellar Artery, Vertebral Artery.

Introduction

The intracranial infratentorial compartment is frequently involved by tumors, cavernous malformations, aneurysms, arteriovenous malformations, and dural arteriovenous fistulas of the posterior cranial fossa or craniovertebral junction. The surgical and endovascular management of these lesions is entirely dependent on a thorough knowledge of the normal neurovascular anatomy of the posterior circulation as well as its variants. Additionally, the cisternal anatomy of the infratentorial region and the triangles delimited by the cranial nerves have great relevance from the surgical standpoint since they define corridors and landmarks to access specific segments of the vertebrobasilar system (1-9).

The present study strives at a synoptic outline of the microneurosurgical anatomy of the posterior circulation of the brain necessary to deal with the tumors and neurovascular pathologies involving the intracranial infratentorial region.

The occipital artery has been herein included because it frequently results be the main feeder of posterior fossa arteriovenous fistulas. It also frequently serves as the main donor vessel in those cerebral bypass procedures involving the posterior circulation.

Methods

Two fresh-frozen heads and five formalin-fixed latex-injected heads were employed for the study. The cuts were executed at the base of the neck to study the proximal segments of the vertebral and occipital arteries. Three of the injected heads were used for the study of the arterial system, whereas two for the venous one. The fresh-frozen specimens were utilized within 72 hours from the death, while the formalin-fixed ones were kept in a plastic bag for 48 hours to allows for the solidification of the latex. In all heads, the skeletonization of the extracranial part of the vertebral artery (VA), its venous plexus, and the occipital artery were performed under the naked eye. The intracranial vascular compartment was examined under a surgical microscope (OPMI pico, Carl Zeiss, Oberkochen, Germany), where the magnification varied between 3× and 40× depending on the size of the vessel and the topographic region. The vertebrobasilar arterial system and its collateral branches, dural sinuses, and veins of the brainstem and cerebellum were thoroughly investigated in their course within the posterior fossa arachnoid cisterns and synthesized in synoptic tables. A series of digital pictures were obtained for each step of the dissection.

Results

Vertebral Artery

The VA has four segments. The first three are extradural and the fourth is intradural. The V1 segment (pre-foraminal) arises from the subclavian artery within the triangle of the VA, which is delineated by the longus colli and anterior scalene muscles, and the first part of the subclavian artery (10). The V1 segment ascends up to the most caudal of the transverse foramina of the subaxial cervical vertebrae, generally C6. At this point, the V2 segment (foraminal) begins. It spans from the transverse foramen of C6 to that of C1. Noteworthy, after exiting the C2 transverse foramen the vertebral artery heads lateralward to reach the transverse foramen of the atlas (11). The V3 segment (atlantic) is comprised of the portion of the artery ranging from the C1 transverse foramen to the dural entry point. This segment runs above the posterior arch of the atlas, within the so-called "J-groove" lying behind the lateral mass of C1 and atlanto-occipital joint (12). The most lateral part of the V3 segment lies medial to the rectus capitals lateralis which acts as a landmark for the atlantic part of the VA (30). On an axial plane, the V3 segment forms a curve convex posteriorly. Not infrequently, the artery is contained within a complete or incomplete bony canal instead of a groove on the posterior arch of the atlas (13-17). The V3 segment, vertebral venous plexus, and C1 nerve root are located within the superior suboccipital triangle. The superior suboccipital triangle is bordered by the rectus capitis superior major superomedially, the obliquus capitis superior superolaterally, and the obliquus capitis inferior inferolaterally (Figure 1).

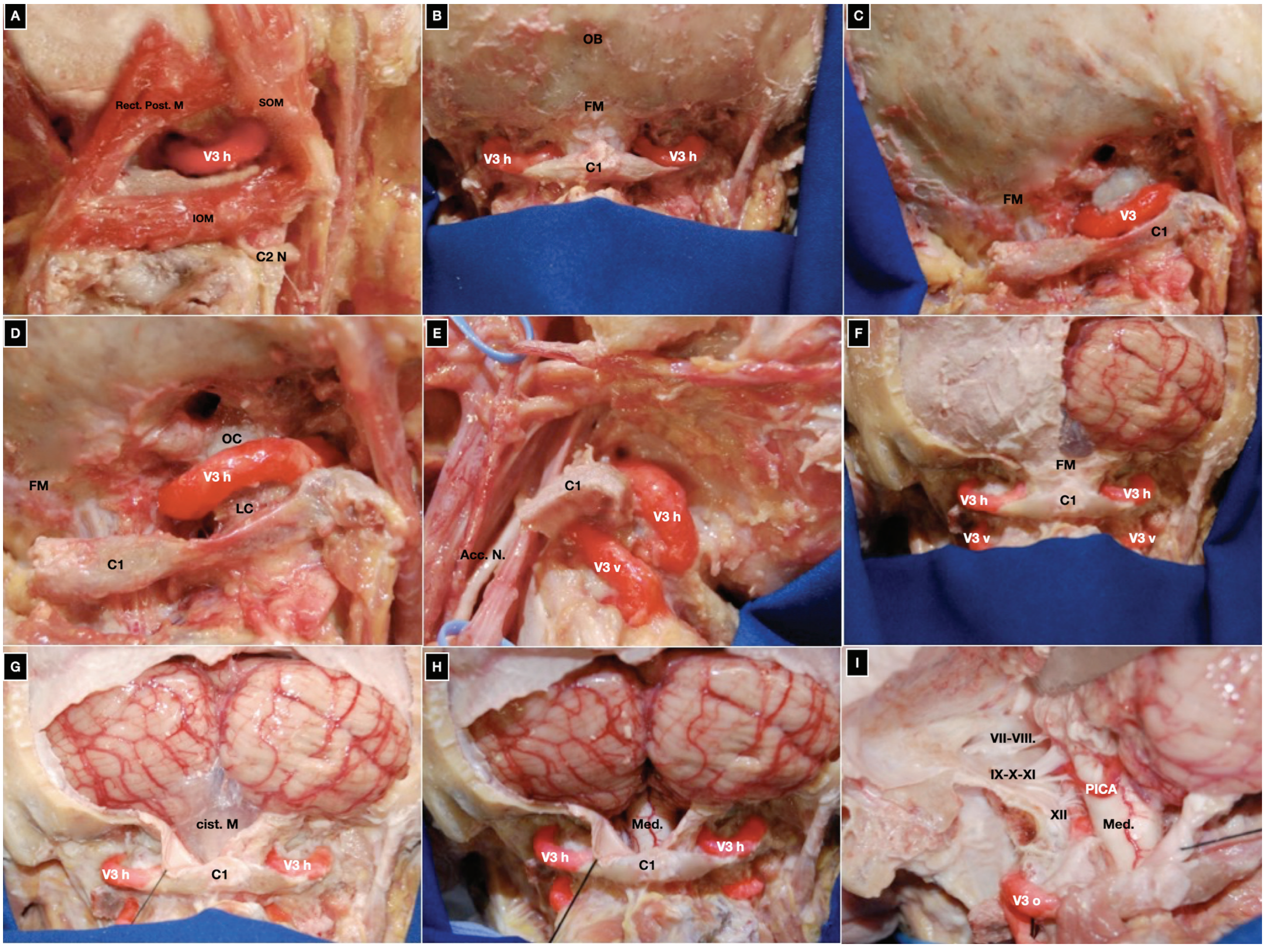

Figure 1. (A-I) Extradural segments of the vertebral artery.

The C1 nerve root passes beneath the artery and above the posterior arch of the atlas. During their course through the superior suboccipital triangle, all the neurovascular structures are located in between the posterior atlanto-occipital membrane, which forms the floor of the suboccipital triangle, and a thick fibrofatty layer that closes the triangle posteriorly forming its roof (13, 18, 19). The superior suboccipital triangle is covered by the semispinalis capitis. The posterior atlanto-occipital membrane may form a funnel-shaped dense ring around the vertebral artery just before its dural entry point. The V3 segment gives rise to the posterior meningeal artery, posterior spinal artery, and deep cervical branches. The posterior meningeal artery ascends through the foramen magnum and vascularizes the dura of the posterior and lateral portion of the posterior fossa and part of the tentorium and falx. It anastomoses with meningeal branches of the occipital and ascending pharyngeal arteries. The posterior spinal artery anastomoses with the lateral spinal artery and irrigates the restiform body, the gracile and cuneate tubercles, accessory nerve, choroid plexus, and the superficial portion of the dorsal half of the cervical spinal cord (20). The deep cervical branches are directed to the deep suboccipital muscles where they anastomose with deep cervical arteries from the costocervical trunk of the subclavian artery. The V4 segment (intradural or intracranial) is intradural. The preolivary sulcus marks the limit between the lateral medullary and anterior medullary segments. The lateral medullary segment passes above the rootlets of the C1 nerve and ascends forward anteriorly to the dentate ligament and spinal accessory nerve. The anterior medullary segment courses in front of or between the hypoglossal rootlets (Figure 2A), crosses the pyramid

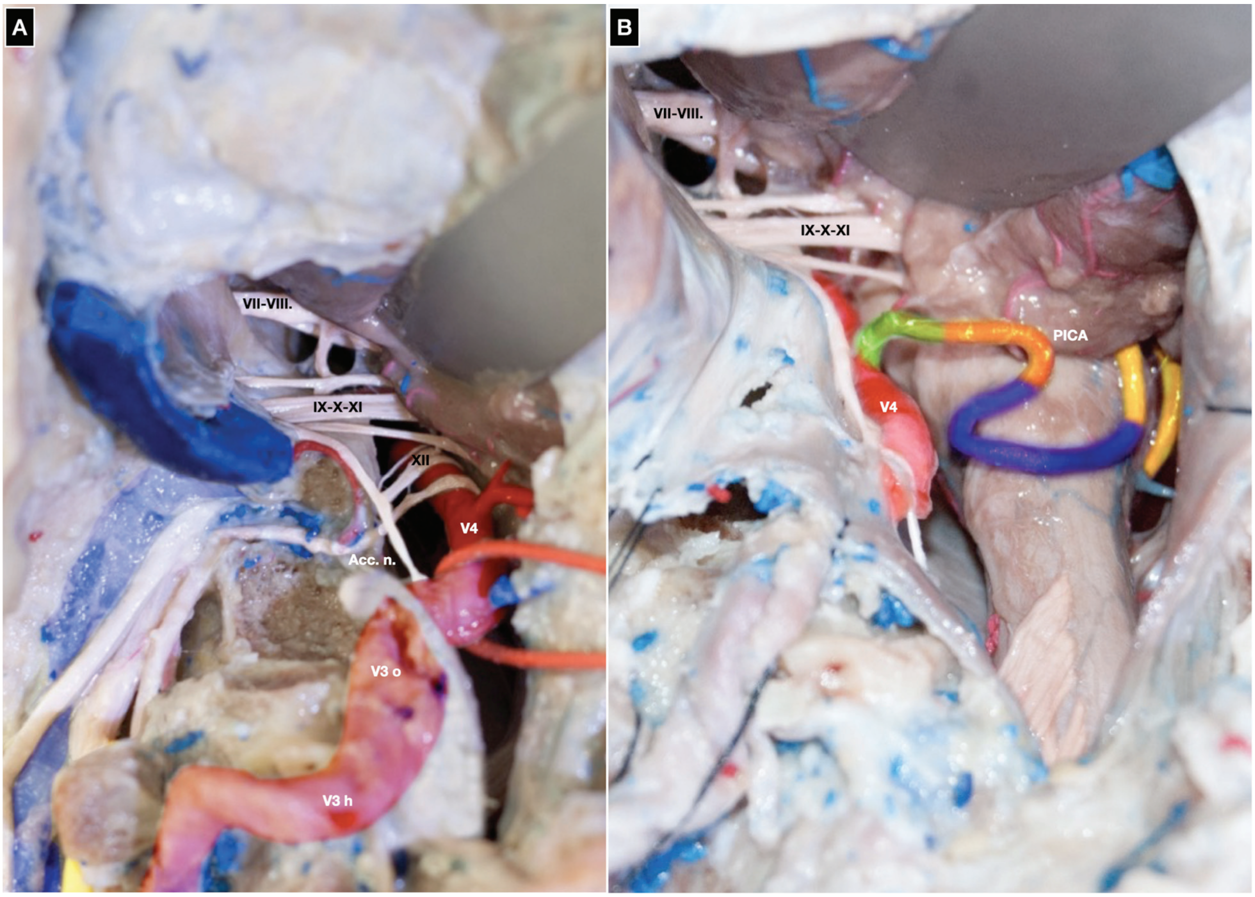

Figure 2. Intradural segment of the vertebral artery (A) and PICA (B): anterior medullary (green), lateral medullary (orange), tonsillomedullary (blue) and telovelotonsillar segments (yellow) of the PICA.

and joins the contralateral VA in the midline at the level of the pontomedullary sulcus to give rise to the basilar artery (BA). The anterior spinal artery emerges from the anterior medullary segment and provides for the main source of the arterial supply to the cervical spinal cord. The lateral medullary segment gives rise to the PICA in approximately 80% of cases (21, 22).

Table 1 reports the segments, collateral and terminal branches, and vascular territories of the VA (Table 1).

Posterior Inferior Cerebellar Artery

The PICA arises from the lateral medullary segment of the VA, although anatomic variations are possible. Lister and colleagues identified five segments of the PICA: anterior medullary, lateral medullary, tonsillomedullary, telovelotonsillar, and cortical (Table 2**)** (23). Perforating branches from the PICA are directed to the medulla oblongata and cerebellum. Along its tortuous backward course, the PICA crosses the rootlets of the hypoglossal, glossopharyngeal, vagus, and accessory nerves, before entering the cerebellomedullary fissure (Figure 2B).

Basilar Artery

The BA arises from the union of both VAs at the level of the pontomedullary sulcus. It ascends along the pons within the basilar sulcus to reach the pontomesencephalic sulcus where it bifurcates into the posterior cerebral arteries. The bifurcation point is also known as the basilar tip, which may be located at the same level, above, or below the superior border of the

Table 1. Segments, Collateral and Terminal Branches, and Vascular Supply of the Vertebral Artery

<table>
<tr><th colspan="2">VA segment</th><th>Distal Anatomic Border</th><th>Subsegment</th><th colspan="2">Collateral and Terminal Branches</th><th>Vascular Supply</th></tr>
<tr><td rowspan="7">Extradural</td><td>V1</td><td>C6 transverse process (121)</td><td></td><td colspan="2"></td><td></td></tr>
<tr><td rowspan="2">V2</td><td rowspan="2">Transverse foramen of the atlas</td><td rowspan="2"></td><td colspan="2">Lateral spinal branches (Lateral spinal artery (20))</td><td>Spinal cord</td></tr>
<tr><td colspan="2" rowspan="2">Muscular branches</td><td rowspan="2">Deep cervical musculature</td></tr>
<tr><td rowspan="4">V3</td><td rowspan="4">Dura of the foramen magnum (13, 15-17)</td><td>Vertical portion</td></tr>
<tr><td>Horizontal portion</td><td colspan="2">Posterior meningeal artery</td><td>Posterior fossa dura</td></tr>
<tr><td rowspan="2">Oblique portion</td><td colspan="2">Posterior spinal artery</td><td>Restiform body, gracile and cuneate tubercles, accessory nerve, choroid plexus, superficial part of the dorsal half of the cervical spinal cord</td></tr>
<tr><td rowspan="4">PICA (5-20% of cases extradural origin) (13, 21) (P1-P5 segments) (26)</td><td rowspan="2">Perforating arteries (23, 26)</td><td rowspan="2">Medulla</td></tr>
<tr><td rowspan="4">Intradural</td><td rowspan="4">V4</td><td rowspan="4">Ponto-medullary sulcus</td><td rowspan="3">Lateral medullary segment</td></tr>
<tr><td>Choroidal arteries (23, 26)</td><td>Choroid plexus of the fourth ventricle</td></tr>
<tr><td>Cortical arteries (23, 26)</td><td>Vermis, tonsils, hemisphere of the suboccipital surface</td></tr>
<tr><td>Anterior medullary segment</td><td colspan="2">Anterior spinal artery</td><td>Cervical spinal cord</td></tr>
</table>

PICA: Posterior Inferior Cerebellar Artery

dorsum sellae. Those cases where the basilar bifurcation lies above or below the dorsum sellae are referred to as high- or low-riding basilar tip, respectively. The BA gives rise to the anterior inferior cerebellar artery (AICA), pontine arteries, and superior cerebellar artery (SCA) (Figure 3-5). Table 3 summarizes the branches of the BA and their relative vascular territories (Table 3).

Anterior Inferior Cerebellar Artery

The AICA arises from the BA at the level of the origin of the abducens nerve. It courses superiorly along the convex surface of the pons (anterior pontine segment) to reach the cerebellopontine angle (lateral pontine segment) where, at the level of the vestibulocochlear nerve and near the internal acoustic meatus, it bifurcates into the rostral and caudal trunks (Figure 4). The bifurcation can occur in the premeatal, meatal, or postmeatal area. During its course within the cerebellopontine angle, the AICA gives rise to the nerve-related arteries, for to the cranial nerves from the 7th through the 11th, and recurrent perforating branches to the brainstem (22, 24) (Table 3). The concept of the AICA-PICA dominance indicates the prevalence of each of these arteries in giving the arterial supply to the cerebellum.

Superior Cerebellar Artery

The SCA arises from the BA immediately below the oculomotor nerve. It courses posterolaterally below the

Table 2. PICA Segments according to Lister et al. (23), Collateral and Terminal Branches, and Vascular Supply

PICA segment (23)	**Distal Anatomic Border**	**Collateral and Terminal Branches**	**Vascular Supply**
Anterior medullary	Most prominent part of the olive	Perforating branches (n. 1 on average) (23)	Anterior medulla
Lateral medullary	Retro-olivary sulcus	Perforating branches (n. 2 on average) (23)	Lateral medulla
Tonsillomedullary (Caudal loop)	Caudal half of the tonsil	Perforating branches (n. 4 on average) (23)	Posterior medulla
Telovelotonsillar (Cranial loop)	Posterior end of the cerebellomedullary fissure	Choroidal arteries	Tela choroidea; choroid plexus of the fourth ventricle
Cortical	Terminal cortical branches	Median	Vermis
		Paramedian vermian	
		Tonsillar	Tonsil
		Medial hemispheric	Cerebellar hemisphere, dentate nucleus
		Intermediate Hemispheric	
		Lateral hemispheric	

PICA: Posterior Inferior Cerebellar Artery

Figure 3. Overview of the posterior circulation.

trochlear nerve and above the trigeminal nerve to reach the cerebellomesencephalic fissure. Its cortical segments are directed to a large part of the infratentorial surface of the cerebellum along with the vermis. The SCA has four segments: anterior and lateral pontomesencephalic, cerebellomesencephalic, and cortical (25) (Figure 4 A,B; 5 B; 6). The SCA gives off a series of direct and circumflex perforating arteries, mainly from its first two segments, which are directed to the interpeduncular fossa, the cerebral peduncle, superior and middle cerebellar peduncles, and the collicular region (Table 3).

Posterior Cerebral Artery

The posterior cerebral artery (PCA) arises from the BA below the posterior perforated substance. Classically, the junction with the posterior communicating artery (PComA) divides the PCA into proximal P1 (precommunicating) and distal P2 (postcommunicating) segments. The posterior edge of the midbrain marks the boundary between the P2 and P3 (quadrigeminal) segments; the P4 (calcarine) segment is directed to the parieto-occipital and visual cortices. A PComA diameter greater than that of the PCA indicates a fetal-type posterior circulation. The P1, P2, P3, and P4 segments course through the interpeduncular, crural, ambient, and quadrigeminal cistern, respectively (Figure 5B, 7). During its course, the PCA gives

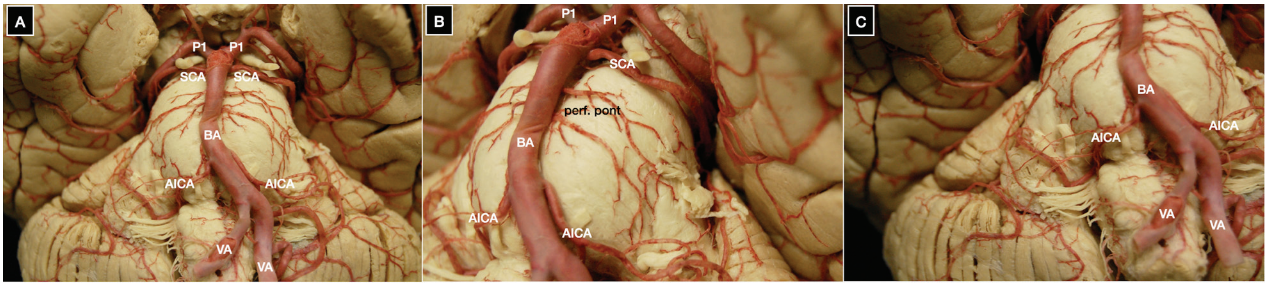

Figure 4. (A-C) Courses, collateral branches, and perforating arteries of the basilar artery.

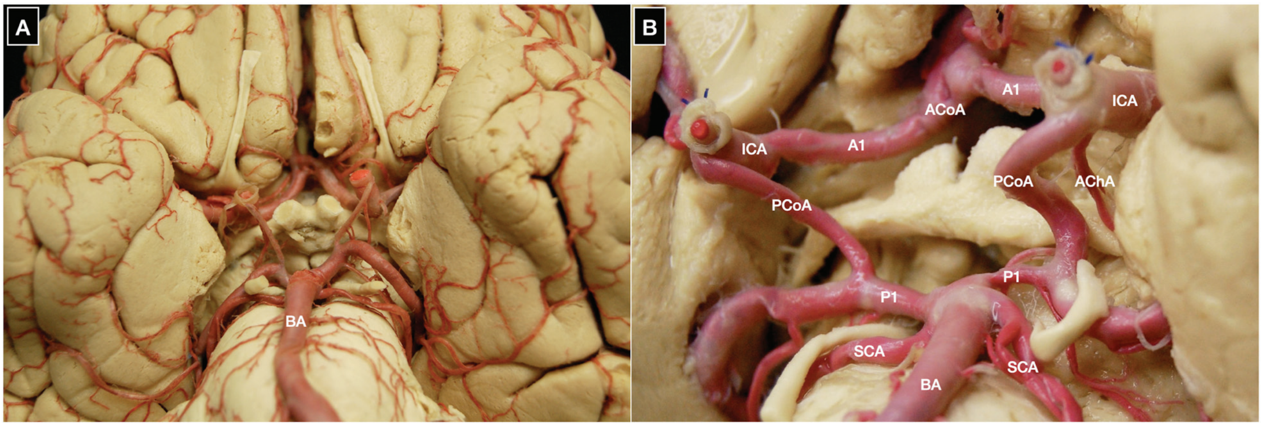

Figure 5. Circle of Willis at low (A) and high (B) magnification.

off three types of branches: perforating, choroidal, and cortical (Table 4).

Perforating Arteries

Perforating arteries of the posterior circulation vascularize the brainstem, cerebellum, fourth ventricle, cerebral peduncle, posterior perforated substance, optic tract, thalamus, hypothalamus, subthalamus, posterior portion of the internal capsule, substantia nigra, red nucleus, and reticular formation (23, 26). The perforating arteries arise from the PCA, BA, SCA, AICA, and PICA. Perforating pontine arteries are a series of tiny vessels emerging directly from the BA and are directed to the brainstem. In contrast to the recurrent perforating branches from the AICA, these arteries have an orientation that is perpendicular to the surface of the pons, which they pierce as medullary vessels (Figure 5B) (Table 5).

Occipital Artery

The OA arises from the back wall of the external carotid artery at the level of the angle of the jaw within the retrostyloid space of the maxillopharyngeal region. Its origin is located below the level of the posterior belly of the digastric, and just below before the point where the external carotid pierces the styloid diaphragm (27). The OA has three well-defined segments: ascending cervical, cervico-occipital (or horizontal), and ascending occipital (28).

The ascending cervical segment is located within the retrosyloid space and is covered by the posterior belly of the digastric muscle and stylohyoid muscle. It courses posteriorly and superiorly, remaining lateral with respect to the ICA, internal jugular vein, and lower cranial nerves. The cervico-occipital segment is located in the mastoid region between the transverse process of C1 and the mastoid tip. Here, the OA courses along a groove in the temporal bone that is

Table 3. Collateral and Terminal Branches and Vascular Supply of the Basilar Artery

Collateral and Terminal Branches of the BA				**Vascular Supply**
SCA Lateral pontomesencephalic segment Marginal branch Cerebellomesencephalic segment Cortical segment Hemispheric and vermian branches		Anterior pontomesencephalic segment	Direct and recurrent (circumflex) perforating arteries	Tegmentum, interpeduncular fossa, cerebral peduncle, superior and middle cerebellar peduncles, collicular region
		Petrosal surface of the cerebellum		
		Hemispheric surface of the cerebellum, dentate and deep cerebellar nuclei, vermis, inferior colliculi, superior medullary velum		
		Tentorial surface of the cerebellum; vermis; upper part of the petrosal surface; superior part of the suboccipital surface		
Perforating pontine arteries				Pons
AICA	Anterior pontine segment			Abducens nerve
	Lateral pontine segment (premeatal, meatal, and postmeatal) (22, 24)	Nerve-related arteries	Labyrinthine artery	Facial and vestibulocochlear nerves; labyrinth
			Recurrent perforating arteries	Brainstem; middle cerebellar peduncle; glossopharyngeal and vagus nerves, choroid plexus protruding from the foramen of Luschka
			Subarcuate artery	Subarcuate fossa
	Flocculopeduncular segment			Middle cerebellar peduncle
	Cortical segment			Petrosal surface of the cerebellum

BA: Basilar Artery; SCA: Superior Cerebellar Artery; AICA: Anterior Inferior Cerebellar Artery.

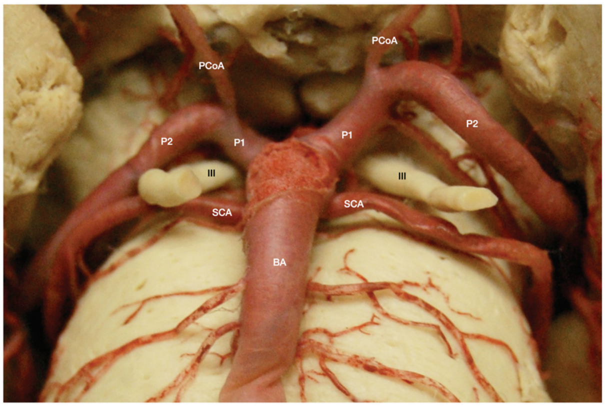

Figure 6. Basilar artery bifurcation.

medial to the digastric groove for the posterior belly of the digastric muscle. This segment courses medial to the rectus capitis lateralis and lateral to the digastric, splenius capitis, and sternocleidomastoid. Moving posteriorly, it passes above the obliquus capitis superior of the suboccipital triangle and beneath the longissimus capitis. Nevertheless, it may also run above the longissimus capitis. The ascending occipital segment courses posteriorly and superiorly toward the vertex of the skull becoming superficial at the level of the superior nuchal line of the occipital squama. Here, it pierces the semispinalis capitis and continues towards the scalp of the occipital region. During its course, the OA gives off four types of branches destined for the skin, facial nerve, posterior neck muscles, and posterior fossa dura. The stylomastoid artery, which arises from the cervico-occipital segment, supplies the facial nerve at its exit from the stylomastoid foramen. It also irrigates the dura adjacent to the stylomastoid foramen, tympanic cavity, and endolymphatic duct and sac. In case of hypoplasia or occlusion of the OA, branches of the ascending pharyngeal, posterior auricular, or vertebral artery may provide blood flow to the regions typically supplied by the OA (29).

Infratentorial Veins

Based on the area of drainage the veins of the posterior fossa have been classified by Rhoton into a superficial, deep, brainstem, and bridging group (26, 30-32). Each group is further classified according to the topography of the venous drainage. The posterior fossa venous outflow is a prerogative of the tentorial venous sinuses through the bridging veins. These last collect into three further groups: galenic, petrosal, and tentorial (33). The tentorial venous sinuses ultimately converge toward the internal jugular vein (Table 6).

Discussion

The present study acts as a synoptic overview of the microneurosurgical anatomy of the posterior circulation, the knowledge of which is mandatory to deal with every posterior fossa lesion. Three aspects are worthy of insights, namely the anatomic variants, the cisternal anatomy of the infratentorial region, and the key principles of the cisternal approach to the posterior fossa.

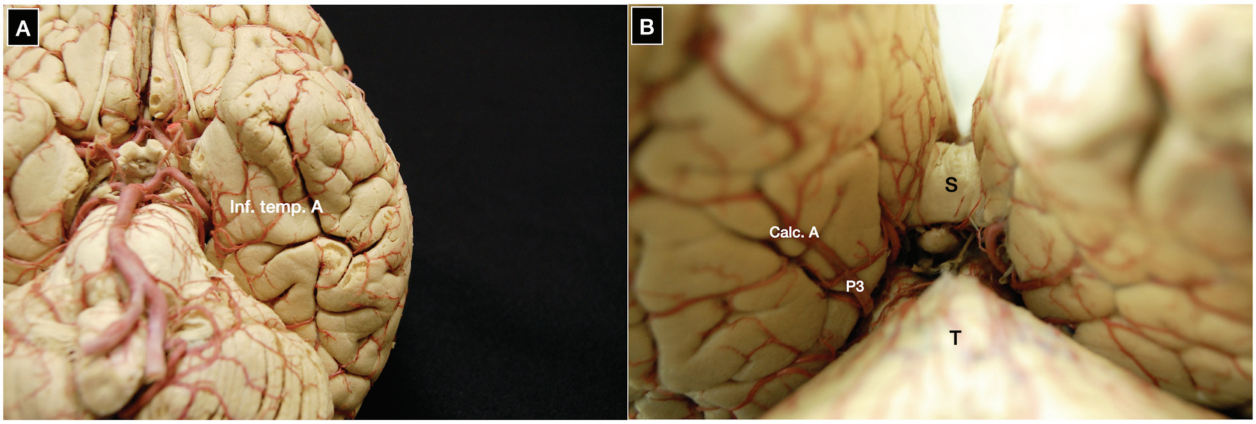

Figure 7. (A) Inferior temporal arteries and (B) calcarine artery from the P3 segment of the posterior cerebral artery.

Table 4. Segments, Collateral and Terminal Branches, and Vascular Supply of the Posterior Cerebral Artery

PCA segment	Distal Anatomic Border		Collateral and Terminal Branches	Vascular Supply
P1 (interpeduncular segment; 25 mm on average)	Junction with the PComA Branch to the quadrigeminal plate Branches to the cerebral peduncle and mesencephalic tegmentum Circumflex branches (short and long)		Thalamoperforating arteries (direct, short, and long circumflex; n. 4 on average (63); thalamoperforating artery is the major branch)	Posterior perforated substance; mamillary bodies; anterior and part of the posterior thalamus; hypothalamus; subthalamus; medial part of the upper midbrain; substantia nigra; red nucleus; oculomotor and trochlear nuclei; oculomotor nerve; mesencephalic reticular formation; pretectum; rostromedial floor of the fourth ventricle; posterior portion of the internal capsule (63)
			Superior and inferior colliculi	
			Cerebral peduncle; mesencephalic tegmentum	
P2	P2A (crural or peduncular segment; 25 mm on average) (62, 63, 99)	Posterior edge of the midbrain	Geniculate bodies, cerebral peduncle (short); quadrigeminal colliculi, tegmentum, pulvinar (long)	
			MPChAs (range 1-3 (63, 98))	Choroid plexus of the third ventricle; choroidal fissure; foramen of Monro; choroid plexus of the lateral ventricle; cerebral peduncle; tegmentum; geniculate bodies; quadrigeminal colliculi; pulvinar; pineal gland; medial thalamus.
			Peduncular Perforating Arteries	Corticospinal and corticobulbar tracts; substantia nigra; red nucleus
	P2P (ambient or lateral mesencephalic segment; 25 mm on average) (62, 63, 99)	Lateral part of the quadrigeminal cistern	Thalamogeniculate Arteries (n. 3 on average (63))	Geniculate bodies; posterior limb of the internal capsule; optic tract
			LPChAs (range 1-9 (98))	Choroid plexus of the temporal horn and atrium of the lateral ventricle; cerebral peduncle; posterior commissure; fornix; lateral geniculate body; pulvinar; dorsomedial thalamic nucleus; body of the caudate nucleus.
P3 (quadrigeminal segment, 20 mm on average) (62, 63, 99)	Anterior limit of the calcarine fissure Calcarine artery (terminal branch, courses within the calcarine fissure) Splenial branches Parieto-occipital artery (terminal branch, courses within the parieto-occipital fissure)		Inferior Temporal Arteries Anterior temporal arteries Middle temporal arteries Posterior temporal arteries Common temporal arteries	Hippocampal: Uncus; anterior parahippocampal gyrus; hippocampal formation; the dentate gyrus. Inferior surface of the temporal lobe
			Visual cortex	
			Splenium of the corpus callosum	
P4	Parieto-occipital cortical surface		Posterior parasagittal region; cuneus; precuneus; lateral occipital gyrus Parieto-occipital branches	

PCA: Posterior Cerebral Artery; PComA: Posterior Communicating Artery; MPChA: Medial Posterior Choroidal Artery; LPChA: Lateral Posterior Choroidal Artery.

Table 5. Perforating Arteries of the Posterior Circulation

Parent Vessel	Segment	Collateral Branch	Subsegment	Perforating Arteries	Vascular Supply
PCA P2A P2P	P1			Thalamoperforating (direct, short and long circumflex; n. 4 on average (63); thalamoperforating artery is the major branch)	Posterior perforated substance; mamillary bodies; anterior and part of the posterior thalamus; hypothalamus; subthalamus; medial part of the upper midbrain; substantia nigra; red nucleus; oculomotor and trochlear nuclei; oculomotor nerve; mesencephalic reticular formation; pretectum; rostromedial floor of the fourth ventricle; posterior portion of the internal capsule (63)
			Circumflex branches (short and long	Geniculate bodies, cerebral peduncle (short); quadrigeminal colliculi, tegmentum, pulvinar (long)	
			Thalamogeniculate arteries (n. 3 on average (63))	Geniculate bodies; posterior limb of the internal capsule; optic tract	
				Peduncular Perforating	Corticospinal and corticobulbar tracts; substantia nigra; red nucleus
BA – SCA	Anterior pontomesencephalic Lateral pontomesencephalic			Direct and recurrent (circumflex)	Tegmentum, interpeduncular fossa, cerebral peduncle, superior and middle cerebellar peduncles, collicular region
BA – Perforating pontine arteries				Direct	Pons
BA – AICA	Lateral pontine segment (premeatal, meatal, and postmeatal)			Recurrent perforating arteries	Brainstem; middle cerebellar peduncle; glossopharyngeal and vagus nerves, choroid plexus protruding from the foramen of Luschka
VA		PICA Lateral medullary Tonsillomedullary (caudal loop)	Anterior medullary	n. 4 (average) (23, 26)	Anterior medulla
			n. 2 (average) (23)	Lateral medulla	
			n. 4 (average) (23)	Posterior medulla	

PCA: Posterior Cerebral Artery; BA: Basilar Artery; VA: Vertebral Artery; SCA: Superior Cerebellar Artery; AICA: Anterior Inferior Cerebellar Artery; PICA: Posterior Inferior Cerebellar Artery

Table 6. Venous Pathways of the Infratentorial Space

Main Group	Subgroup		
Superficial Veins	Tentorial surface	Superior vermian veins	
		Superior hemispheric veins	
	Suboccipital surface	Inferior vermian veins	
		Inferior hemispheric veins	
		Retrotonsillar veins	
		Medial and lateral tonsillar veins	
	Petrosal surface	Anterior hemispheric veins	
Deep Veins	Cerebellomesencephalic fissure	Vein of superior cerebellar peduncle	
		Vein of cerebellomesencephalic fissure	
		Pontotrigeminal vein	
		Tectal veins	
	Cerebellomedullary fissure	Vein of cerebellomedullary fissure	
		Vein of inferior cerebellar peduncle	
		Supratonsillar veins	
		Choroidal veins	
	Cerebellopontine fissure	Vein of cerebellopontine fissure	
		Vein of middle cerebellar peduncle	
Veins of the Brainstem	Longitudinal veins	Midline	Median anterior pontomesencephalic vein
			Median anterior medullary vein
		Anterolateral	Lateral anterior pontomesencephalic vein
			Lateral anterior medullary vein
		Lateral	Lateral mesencephalic vein
			Lateral medullary and retro-olivary veins
	Transverse Veins	Peduncular vein	
		Posterior communicating vein	
		Vein of pontomesencephalic sulcus	
		Transverse pontine veins	
		Vein of pontomedullary sulcus	
		Transverse medullary vein	
Bridging Veins (Major Draining Groups)	Galenic group (to vein of Galen)		
	Tentorial group (to torcula and tentorial sinuses)		
	Petrosal group (to petrosal sinuses)		
	Other bridging veins		

Anatomic Variations

Since the last few years, some revolutionary but convincing concepts are emerging about neurovascular communication during CNS development, where it would be especially the motor neurons to control the normal patterning of the blood vessels in the developing brain and spinal cord (34-39). The same pathways have been hypothesized to play a role in the vasculogenesis related to the anatomic variations of the intracranial vessels. This guiding role would be mainly attributable to the Vascular Endothelial Growth Factor (VEGF) and semaphorin 3A (Sema3A), largely the same which affect the neoangiogenesis related to brain tumors and traumatic brain and spinal cord injuries (40-47). Asymmetry secondary to hypoplasia or absence of the VA has an incidence of 45% and 30%, at the left and right side, respectively (48). Fenestration of the VA is a further possible finding. Variation of the V1 segment of the VA has been reported to have a higher incidence on the left side and comprehend an aberrant or dual origin. The aberrant origin is single or dual in 96% and 4% of cases respectively, while a bilateral dual origin is seen in 7.5% of the patients (49, 50). The aberrant origin may be from the subclavian artery, at a different position compared with the normal emergence of the VA (97.4%), or also from the external carotid, thyrocervical trunk, and common carotid (2.4%) (49). Dual origin concomitantly involves the subclavian artery and common carotid in most of the cases (83.3%), but other various configurations are possible (48, 49). The main variation of the V2 segment consists of an abnormal level of entrance compared to the C6 transverse foramen, which occurs in 7% of cases. It involves the entrance into the transverse foramen of C3 (0.2%), C4 (1%), C5 (5%), or C7 in 0.2%, 1%, 5%, and 0.8% of patients, respectively. A medial loop, making the VA medial to the uncovertebral joint, is also possible (2%) (51). These variations may be symptomatic and their identification is of utmost importance during the planning of surgery of the V2 segment (52, 53). Variation of the V3 segment entails loops (35%) and a high-riding horizontal segment (12%) with a consequently decreased distance between the artery and the occipital squama (54). The angiographic evidence of loops or aberrant course of the V3 may affect the choice of the corridor in treating lesions of the condyle or the jugular foramen area (55-58). Termination into PICA is occasional for the V4 segment but probably underestimated. Rarely, the posterior meningeal artery may arise intradural from the V4 segment. The PICA has the highest frequency of variation among the infratentorial arteries. Extradural origin of the PICA from the V3 segment has been reported in 5%–20% of cases (13, 21, 59). The origin of the PICA from the VA has been demonstrated to influence the relationships between the VA-PICA complex and the jugular tubercle. Accordingly, this aspect involves the need for specific maneuvers as the jugular tuberculectomy for clipping of proximal PICA aneurysms . The anterior spinal artery may show a duplication (22.2%) or a single origin from the VA (22.2%) (60). Basilar artery fenestration has an autoptic incidence of 5% (61). In 16% of cases, the BA has a widening at the level of the bifurcation which is responsible for a cobra-like appearance on angiograms (62, 63). An abnormal origin of the AICA from the lower or middle third of the BA, or even from the vertebrobasilar junction, has an incidence of 1% (64). The SCA is duplicated in approximately 7% of cases (25). A fetal origin of the PCA, consisting of a PCoA larger than the P1 segment of the PCA, has been estimated to be present in 10-30% of the patients (65, 66). Not infrequently, variations in the caliper or the origin of the PCoA are coupled with the persistence of embryonic intracranial and extracranial vessels, which are of mesodermal derivation contrarily to the ectodermal embryo remnants of the central nervous system (CNS) (67-69). PCA is seldom duplicated or fenestrated. Our group has stressed the advantages of a constant intraoperative check of the blood flow of the brain vessels during surgery of aneurysms and arteriovenous malformations, especially in the case of anatomic variations (70, 71).

Cisternal Anatomy of the Posterior Circulation

Equally to the anterior circulation, each segment of the posterior circulation of the brain is related to specific infratentorial subarachnoid cisterns, and these last to defined natural corridors that allow achieving defined working pathways in the posterior fossa surgery (72-79). Infratentorial arteries and veins play also as landmarks for the identification of precise areas of the brainstem and cerebellum. Rhoton's group has classified the infratentorial cisterns in paired and unpaired. We discuss in this chapter the interpeduncular cistern, which is considered a "transitional" cistern between the supra- and infratentorial spaces. The paired cisterns are the cerebellopontine and the cerebellomedullary cisterns, whereas the unpaired ones comprehend the interpeduncular, prepontine, premedullary, quadrigeminal, superior cerebellar cistern, and the cisterna manga (72). The cisterns are separated by membranes. The Liliequist's membrane extends from the dorsum sellae of the sphenoid bone to the mamillary bodies of the diencephalon. The Liliequist's membrane has three sheets, namely the diencephalic leaf, the mesencephalic leaf, the diencephalic-mesencephalic leaf (83-89). The diencephalic-mesencephalic leaf and its diencephalic continuation (diencephalic leaf) divide the interpeduncular cistern from the chiasmatic cistern. The diencephalic-mesencephalic leaf attaches laterally to the medial surface of the cisternal segments of the oculomotor nerves (80-86). The lateral pontomesencephalic membrane, attaching to the lateral surface of the oculomotor nerve, is the boundary between the crural cistern and ambient cistern, lying above, and the cerebellopontine cistern located below them (87). The interpeduncular cistern communicates laterally with the crural and ambient cistern. The ambient cistern blends posteriorly into the quadrigeminal cistern (88-92). The mesencephalic leaf of the Liliequist's membrane separates cranially the interpeduncular cistern from the prepontine cistern (80-86). The anterior pontine membranes, attaching to the inferior surface of the third nerve, divide the prepontine cistern from the cerebellopontine cisterns. The medial pontomedullary membrane separates caudally the prepontine cistern from the premedullary cistern, whereas the lateral pontomedullary membrane divides the cerebellopontine cistern from the cerebellomedullary cistern. Posterolaterally to the medulla oblongata, the cerebellomedullary cistern merges with the cisterna magna which is related to the suboccipital surface of the cerebellum and the dorsal surface of the medulla oblongata (26).

The cerebellomedullary cistern receives the cerebrospinal fluid outflow from the fourth ventricle through the foramen of Luschka. The superior cerebellar cistern rests in between the straight sinus and the tentorial surface of the cerebellum. The superior cerebellar cistern interconnects with the quadrigeminal cistern anteriorly and the cisterna magna inferiorly. The cisterna magna contains the cortical branch of the PICA, while the cerebellomedullary cistern comprehends the remaining first four segments of the PICA, the lateral medullary segment of the VA, the 9th, 10th, and intracranial component of the 11th cranial nerve, and often also the choroid plexus of the fourth ventricle protruding from the Luschka. This relatively frequent finding is also known as the "Bochdalek's flower basket" from the Czech anatomist which described it (93, 94). The premedullary cistern includes the anterior medullary segment of the VA, the anterior spinal arteries, and the rootlets of the hypoglossal nerve. The prepontine cistern contains the BA and the AICA. The cerebellopontine cistern is the main cistern of the cerebellopontine angle. The trigeminal, abducens, facial, and vestibulocochlear nerves, the rostral and caudal trunks of bifurcation of the AICA, and the cerebellomesencephalic and cortical segments of the SCA are located within the cerebellopontine cistern. The interpeduncular cistern holds the apex and bifurcation of the BA, the proximal segment of the AICA, the cisternal segment of the oculomotor nerve, the P1 segment of the PCA, the thalamoperforating arteries directed to the posterior perforated substance, the medial posterior choroidal artery, the vein peduncular, posterior communicating, and median anterior pontomesencephalic, and the vein of the pontomesencephalic sulcus (31, 62, 63, 72, 95-99). The quadrigeminal cistern is the cistern of the pineal region. It contains the P4 segment of the PCA and the distal SCA, the medial posterior choroidal artery, the trochlear nerve, and the galenic venous system. The galenic venous system involves the vein of Galen, internal cerebral veins, basal veins of Rosenthal, internal occipital vein, occipitotemporal veins, precentral cerebellar vein, tectal veins, pineal veins, superior cerebellar vein, superior vermian veins, and posterior pericallosal veins (31, 88-92, 96, 100).

Cisternal Approach to the Infratentorial Region

The cisternal approach to the infratentorial lesions consists of a compartmental opening of one or more arachnoid cisterns of the posterior fossa along with their content. During the surgical planning to the infratentorial extra- and intra-axial lesions, a specific cistern, with the related neurovascular structures, ought to be identified as the target of the approach. Often, it is necessary to go through one or more cisterns to reach the target region, although this must be performed always in the context of a compartmental cisternal approach (6-9). The median and paramedian suboccipital approach expose the cisterna magna (101), whereas the supracerebellar infratentorial approach the superior cerebellar and quadrigeminal cisterns (102). The retrosigmoid approach has the cerebellopontine and prepontine cisterns as the main targets (103). The prepontine cistern may be exposed also through the lateral skull base approaches, namely the presigmoid posterior petrosal routes (retrolab, translab, and transcochlear), and with the anterior petrosal approach (104-107). The orbitozygomatic approach allows reaching the interpeduncular cistern, along with the crural cistern of the supratentorial region (108, 109). Transcranial posterolateral far lateral approach and endoscopic endonasal far medial approach expose the cerebellomedullary cistern and its content from the back and front, respectively (110-112). The endoscopic endonasal transsphenoidal intradural approach to the upper clivus is directed to the interpeduncular cistern (113). The endoscopic endonasal transclival intradural approach reveals the prepontine cistern superiorly and the premedullary cistern inferiorly (113, 114). The endoscopic endonasal transclival transodontoid approach is performed for lesions of the anterior spinal cistern (115). Endoscopic surgical treatment of posterior fossa aneurysms has been recently suggested similarly to other skull base and spine lesions (116-120), but its feasibility is still far to be proven.

Conclusion

The VA, BA, and PCA provide for the arterial vascular supply to the entire infratentorial region of the brain via the PICA, AICA, and SCA.

PICA, BA, AICA, SCA, and PCA provide for perforating arteries for the brainstem, fourth ventricle, cerebellar and cerebral peduncles, thalamus, hypothalamus, subthalamus, posterior part of the internal capsule, and optic tract.

PCA contributes to the vascularization of the temporal, occipital, and parietal lobes in the supratentorial region.

The venous outflow of the infratentorial region is given by the superficial and deep veins of the cerebellum, veins of the brainstem, and bridging veins. The infratentorial veins are primarily or secondarily tributaries of the internal jugular vein via the tentorial venous sinuses.

The different segments of the arterial ad venous posterior circulation of the brain are related to specific infratentorial subarachnoid cisterns, the in-depth knowledge of which is critical for surgery of the posterior fossa.

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