
Microvascular anatomy of foramen caecum medullae oblongatae

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The foramen caecum (FC) is a triangular-shaped fossa situated in the midline on the base of the brain stem, at the pontomedullary junction. Although this area is known to have a very high concentration of brainstem perforating vessels, its microvascular anatomy has not been studied in detail. The purpose of this study was to detail the microvasculature of this territory. Twenty unfixed brains were injected with silicone rubber solution and dissected under a microscope equipped with a camera. The origin, course, outer diameter, and branching pattern of the perforators were examined.

The total number of perforators found in the 20 brains was 287, with an average (± standard deviation) of 14.35 ± 1.24 perforators per brain (range seven to 28). Their origin was as follows: right vertebral artery in 52 perforators (18.11%); left vertebral artery in 35 (12.19%); basilar artery below the anterior inferior cerebellar artery (AICA) in 139 (48.43%); basilar artery above the AICA in 46 (16.02%); AICA in 10 (3.48%); and anterior spinal artery in five (1.74%). Most of the perforators arose as sub-branches of larger trunks; their average outer diameter was 0.16 ± 0.006 mm while that of trunks was 0.35 ± 0.02 mm.

These anatomical data are important for those wishing 1) to study the pathophysiology of vascular insults to this area caused by atheromas, thrombi, and emboli; 2) to plan vertebrobasilar aneurysm surgery; 3) to plan surgery for vertebrobasilar insufficiency; and 4) to study foramen magnum neoplasms.

Key Words • basilar artery • foramen caecum • vertebral artery • vertebrobasilar junction

The foramen caecum, also known as the foramen caecum posterius, foramen of Vicq d'Azyr, or Schwab's foramen, is an important area in the brain stem because of the high concentration of perforating vessels entering it from the vertebrobasilar axis. However, the microanatomy of this area has not been described in detail. This study was designed to obtain data regarding the origin, course, and branching pattern of perforators penetrating the foramen caecum. This information is important in planning vascular procedures involving the foramen caecum. It also aids in understanding the vascular basis of some of the ischemic lesions in the brain stem as well as in studying the pathology of foramen magnum neoplasms.

Materials and Methods

Twenty unfixed human brains with no evidence of intracranial pathology were used for this study. The brains were removed at routine autopsy performed 4 to 8 hours postmortem and immersed in normal saline solution. The larger vertebral artery was cannulated with a No. 18 polyethylene catheter and the opposite vertebral and both posterior communicating arteries were ligated proximally. The basilar artery and its branches were flushed with 300 cc normal saline, then injected with colored silicone latex particles. A similar technique has been used in our laboratory in previous studies.

The brains were placed with the ventral surface uppermost so that the cerebellum and brain stem could be visualized. The dissections were performed under a surgical microscope with a camera attached and used for photographic documentation (Fig. 1). The perforating branches to the foramen caecum were examined in relation to their origin, course, outer diameter, and branching pattern. The vertebrobasilar axis was divided into four main segments for this purpose: right and left *Silicone latex particles manufactured by Cantor Biomedical Products, Boulder, Colorado.
† OPMI surgical microscope manufactured by Carl Zeiss, Inc., New York, New York; camera manufactured by Minolta Camera Co., Higashi-Ku, Osaka, Japan.
vertebral arteries, the basilar artery below the anterior inferior cerebellar artery (AICA), and the basilar artery above the AICA. Detailed drawings of the findings were made and photographs of different magnification were taken.

Results

Boundaries of the Foramen Caecum

The foramen caecum is a triangular-shaped expansion of the anterior median fissure of the medulla oblongata at its termination at the inferior border of the pons; its average transverse and vertical dimensions are 4.6 ± 0.16 mm and 4.16 ± 0.16 mm, respectively (Fig. 2). It is bounded laterally by the medullary pyramids and superiorly by the inferior border of the pons. The sixth cranial nerve exits just lateral to the foramen caecum, but does not form its lateral margins. Perforating branches to the foramen caecum come from the vertebrobasilar axis or its branches, such as the anterior spinal artery and the AICA. The vertebrobasilar junction (VBJ) was situated above the foramen caecum in nine brains (45%), opposite in six (30%), and below in five (25%). The left vertebral artery was larger in eight brains (40%) and the right vertebral artery was larger in four (20%); in eight brains, they were of equal size.

Perforators to the Foramen Caecum

A total of 287 perforators were found in the 20 brains, with an average (± standard deviation) of 14.35 ± 1.24 per brain (range seven to 28). They originated as follows: right vertebral in 52 perforators (18.11%); left vertebral artery in 35 (12.19%); basilar artery below the AICA in 139 (48.43%); and basilar artery above the AICA in 46 (16.02%). In addition, five branches (1.74%) arose from the anterior spinal artery and 10 (3.48%) from the AICA. The largest number of branches by far originated from the basilar artery below the AICA, and branches from this segment were present in all but two brains. Branches from the basilar artery above the AICA were present in 11 brains. The right and left vertebral arteries sent perforators to this area in 12 and 10 brains, respectively. Branches from the anterior spinal artery were present in two brains and from the AICA in one.

Most of the perforators (247 or 86.06%) arose as subbranches of 62 trunks originating from the vertebral and basilar arteries. Only 40 (13.93%) arose as direct nondividing branches of the vertebrobasilar axis. Therefore, a total of 102 trunks arose from the vertebral and basilar arteries, of which 62 (60.78%) divided and 40 (39.21%) did not. The average outer diameter of the trunks that subsequently branched was 0.35 ± 0.02 mm, whereas the average outer diameter of their branches was 0.16 ± 0.006 mm. The outer diameter of the nondividing branches from the vertebral and basilar arteries was 0.18 ± 0.017 mm.

Configuration of Branches

The configurations of the branches were categorized as tortuous, curved, or straight, and their course as ascending, descending, or horizontal. All perforators arose from the posterior or posteroslateral surfaces of the vertebrobasilar axis, and none originated from the anterior surface. Their points of origin ranged from 14 mm below to 16 mm above the VBJ and from 9 mm below to 16 mm above the foramen caecum. However, the maximum number originated close to the VBJ and to the foramen caecum.†

†A detailed description of configuration and origin of perforators, including the relationship of their origin to vertebrobasilar junction and foramen caecum, is available in table form from the authors upon request.
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![Diagram showing branching patterns of perforators arising from the vertebral arteries (VA's).](image)

**Fig. 3.** Schematic representation of the branching pattern of perforators arising from the vertebral arteries (VA's). In Pattern A, a trunk arises with the anterior spinal artery (ASA). In Pattern B, a trunk arises separate from the anterior spinal artery. In Pattern C, trunks arise with and without anterior spinal artery. BA = basilar artery.

**Branching Patterns of Perforators**

Certain branching patterns were seen in perforators from all major segments of the vertebrobasilar axis.

**Branches From the Vertebral Arteries.** Branches arising from the vertebral arteries followed three main patterns (Fig. 3). In Pattern A, a single trunk arose with the anterior spinal artery then divided: 12 (44.44%) of 27 trunks from the vertebral arteries showed this pattern. In Pattern B, branches from the vertebral arteries arose separate from the anterior spinal artery; 11 trunks (40.74%) showed this pattern. In Pattern C, two trunks arose from the vertebral artery, one with the anterior spinal artery and one separate from it: four trunks (14.81%) followed this pattern.

**Branches From the Basilar Artery Below the AICA.** Branches from the basilar artery originating below the AICA followed four patterns (Fig. 4). Pattern A, a single trunk dividing into branches, was the most commonly seen (in eight or 44.44% of the 18 brains). In six of these the VBJ was above the foramen caecum and in two it was opposite to the foramen caecum. Patterns B, C, and D with two, three, and four trunks arising from the basilar artery, respectively, were seen in two (11.11%), three (16.66%), and five (27.77%) brains, respectively. The VBJ was either below or opposite the foramen caecum in the cases of brains showing Pattern B. The VBJ was situated above, below, or opposite the foramen caecum in the three brains showing Pattern C. In five brains showing Pattern D, the VBJ was below the foramen caecum in three and opposite in two. Therefore, when the VBJ was situated above the foramen caecum, the predominant pattern was A (85.71%). When the VBJ was below the foramen caecum, the pattern was either D (60%), B (20%), or C (20%), but never A. When the VBJ was opposite the foramen caecum, one of all four patterns (A in 33.33% of cases, B in 16.66%, C in 16.66%, and D in 33.33%) was seen.

**Branches From the Basilar Artery Above the AICA.** Branches from the basilar artery arising above the AICA showed two patterns (Fig. 5). In Pattern A, trunks descended on both sides. This was seen when the VBJ was either opposite (four brains) or below (two brains), but not when it was above the foramen caecum. Pattern B had only one trunk that arose and descended either posterior or lateral to the basilar artery. This was seen in five brains; in four of these, the VBJ was above the foramen caecum and in one it was below the foramen caecum. Therefore, the predominant pattern when the VBJ was above the foramen caecum was a single trunk descending and then branching.

**Anastomoses**

In 15 of the 20 brains studied, 18 anastomoses greater than 0.1 mm in diameter were found between the perforators entering the foramen caecum. These anastomoses could be further classified into major and minor: major when the main trunks from the vertebrobasilar axis joined to form an arch (outer diameter 0.2 to 0.3 mm) and perforators arose from this arch, and
minor when the anastomoses were between the perforators themselves (outer diameter 0.1 to 0.2 mm). Five such arches (major anastomoses) were found (Fig. 6): between two trunks from the same vertebral artery (Fig. 6A); between the right and left vertebral arteries (Fig. 6B); between the right and left anterior spinal arteries (Fig. 6C); between the vertebral arteries and the trunks from the basilar artery below the AICA (Fig. 6D); and between trunks from the basilar artery below the AICA and the basilar artery above the AICA (Fig. 6E). It is evident that such anastomoses were more frequent in the vertebral arteries than in the basilar artery.

Discussion

Classification of Perforators

Branches of the vertebrobasilar system have been classified as paramedian and short and long circumferential branches by Foix and Hillemand, and as median and lateral (transverse) branches by Stopford. The lateral or circumferential arteries course around the brain stem, whereas the median or paramedian arteries penetrate it along the anterior median fissure of the medulla and the basilar sulcus of thepons. A very high concentration of these median perforators is found at the foramen caecum. This fact has been described in the literature and can be seen in illustrations of works by different authors. However, the microvascular anatomy of this area has never been described in detail.

An average of 14.35 ± 1.24 perforators enter the foramen caecum, with the highest percentage being branches from the basilar artery below the AICA (48.43%) followed by branches from the right vertebral artery (18.11%), the basilar artery above the AICA (16.02%), and the left vertebral artery (12.19%). Smaller contributions were from the AICA (3.48%) and the anterior spinal artery (1.74%). It is obvious that the highest number of perforators to this area come from the basilar artery. This is in contrast to Hiller's statement that perforators to the foramen caecum come primarily from the vertebral arteries. We found that perforators from the right vertebral artery outnumbered those from the left vertebral artery, even though the latter was dominant in eight brains whereas the former was dominant in only four brains. The fact that a larger number of perforators arise from the right vertebral artery despite its being smaller has been described previously. Although the anterior spinal artery sends perforators to the anterior median fissure, they seldom reach the foramen caecum. Branches from the AICA were seen in only one brain; this limited contribution of the AICA to brain stem irrigation is also well known.

Parenchymal Distribution of Perforators

The midline perforators entering at the foramen caecum penetrated posteriorly to reach the tegmentum (Fig. 7), traversing the entire anteroposterior diameter of the brain stem. This agreed with the findings of Duvernoy. These vessels supply the corticospinal tracts, corticobulbar tracts, pontine nuclei, medial longitudinal fasciculus, medial lemniscus, abducens nucleus, and the cranial end of the hypoglossal nucleus. The most centrally located arteries of this group tend to be the longest, reaching the ventricular floor; the more laterally situated arteries of the median group are shorter, and they are basically distributed to fiber tracts. These median arterioles do not cross the midline and the majority are destined for nuclei; fiber tracts are only scantily supplied. Another interesting finding was the presence of anastomoses between the perforators as well as the trunks, especially those arising from the vertebral arteries. The anastomoses in the vertebrobasilar system have been described to be of significance only between the AICA and the posterior inferior cerebellar artery (PICA). Although more work is needed to define the exact frequency and significance of the anastomoses we found, they can be a source of collateral circulation in some if not all brains.

This anatomic information makes it possible to: 1) understand the pathophysiology of some vascular lesions in this area caused by atheromas, thrombi, or emboli; 2) plan vertebrobasilar aneurysm surgery; 3) plan surgery for vertebrobasilar insufficiency; and 4) study foramen magnum neoplasms.

Ischemic Lesions

The infarcts caused by occlusion of vessels entering the foramen caecum would involve the upper medial

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Fig. 6. Schematic representation of five anastomosis patterns between perforators entering the foramen caecum. VA = vertebral artery; ASA = anterior spinal artery; AICA = anterior inferior cerebellar artery; BbAICA = basilar artery below the AICA; BaAICA = basilar artery above the AICA.

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Fig. 7. Brain stem and cerebellum, sagittal section, showing the midline perforators traversing the interpeduncular thickness of the brain stem.

medulla and lower medial pons; that is, a medial medullary syndrome and medial inferior pontine syndrome. Infarcts in this area are more likely to be caused by atheromas and thrombi rather than by emboli. In fact, atheromatous lesions are common at the VBJ. Embolic occlusion, on the other hand, is seen most at the basilar bifurcation. Ischemic lesions in the pons occur most frequently in the paramedian inferior and middle pontine segments. Infarction in the inferior medullary pons would involve the corticospinal and corticobulbar tracts, medial lemniscus, medial longitudinal fasciculus, and abducens nucleus, giving rise to contralateral paralysis of the face, arm, and leg, contralateral impaired tactile and proprioceptive sensations, and ipsilateral lateral rectus palsy (medial inferior pontine syndrome, Fig. 8). Infarction in the upper medulla would involve the pyramidal tracts, medial lemniscus, medial longitudinal fasciculus, and cranial end of the 12th nerve nucleus, giving rise to contralateral paralysis of the arm and leg but sparing the face, contralateral impaired proprioceptive and tactile sensations, and paralysis of the tongue on the same side (medial medullary syndrome, Fig. 8). The above-mentioned vascular syndromes may be unilateral or bilateral and may be complete or incomplete.

Vertebralbasilar Aneurysms

Vertebralbasilar aneurysms comprise about 15% of intracranial aneurysms, with 10% and 5% occurring on the basilar and vertebral arteries, respectively. Aneurysms involving the VBJ as well as the distal vertebral and proximal basilar arteries (the vascular segment adjacent to the foramen caecum) constitute about 0.5% of intracranial aneurysms. These are among the most difficult aneurysms to treat, and surgery is associated with a high mortality rate. Extreme care is necessary while approaching these aneurysms because of the high concentration of brain-stem perforators in this area. The recent consensus has been to approach these aneurysms either by subtemporal transtentorial or suboccipital craniotomy. The only role for a transclival approach, if any, is for lower vertebral artery aneurysms or those located below the jugular tubercle. Since all of the perforators in our study originated from the posterior surface of the vertebralbasilar axis, subtemporal and suboccipital approaches are adequate to obtain an acceptable view of the foramen caecum perforators with little brain-stem retraction. Surgery with the patient in the three-quarters prone position, with the operated side down as described by Ausman, et al., is best suited for visualization of these perforators and can be used for aneurysms of the distal vertebral junction or VBJ. For aneurysms that cannot be treated by clipping, ligation of the vertebral and basilar arteries has been tried. In a series of 21 cases reported by Drake, the results of intracranial vertebral artery occlusion were encouraging, whereas the outcome of basilar artery occlusion were poor. This can be explained partly because of better collateral circulation of vertebral compared to

Fig. 8. Schematic representation of infarctions showing a medial medullary syndrome (left) and medial inferior pontine syndrome (right), which would occur from occlusion of vessels entering foramen caecum.

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basilar arteries; four of five “major” anastomoses we found involved the vertebral arteries. Intracranial vertebral artery ligation thus can be used for those aneurysms that are difficult to clip.

Revascularization Procedures

With regard to microsurgical revascularization procedures in the vertebrobasilar area, our findings support the conclusions drawn by Shontz et al.,21 that the vertebral artery below the PICA is the area of choice for anastomoses and arteriotomies because most perforators arose above the PICA and close to the VBJ.

Tumors

The perforators at the foramen caecum can also be involved by extramedullary tumors in the region of the foramen magnum. Extramedullary tumors of the foramen magnum can include meningiomas, neurinomas, dermoid tumors, teratomas, lipomas, and cavernous hemangiomas.13 Meningiomas are by far the most common, representing about 65% of all the extramedullary foramen magnum tumors; however, they represent only 3% of neuroaxial meningiomas. Even though these tumors occur infrequently, they are an interesting pathological entity because 1) anatomical diagnosis can be erroneous (they can cause symptoms that do not correspond to the exact anatomical location of the neoplasm), and 2) the neurological deficits can have a remitting course. Diagnosis of multiple sclerosis has been made in many of these cases. The clinical symptoms usually are manifested in the form of suboccipital or neck pain, weakness, and dysesthesias of the extremities and cranial nerve involvement. Although these symptoms are caused primarily by direct compression of the neuraxis, they are partly caused by involvement of the vertebral and basilar arteries. Tumors in this area can compress, stretch, or completely incorporate the vertebral and basilar arteries. This has been found surgically and on angiography.11 Vascular compromise can also explain the remitting course of the symptoms as well as the location of deficits remote from the exact anatomical site of the tumor.

References


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