Microsurgical anatomy of the mesencephalic veins

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Object. The mesencephalic veins drain crucial brainstem areas. Due to the narrowness of the tentorial notch, these veins can become obstructed as a result of herniation or surgery, leading to hemorrhage and severe consequences for the patient. There is little in the literature about the mesencephalic veins. The aim of this study was to perform an exact analysis of their microanatomy.

Methods. Fifty-two cadaveric hemispheres were examined under an operating microscope, and measurements were made with a digital caliper. The authors focused on the basal vein (BV), pontomesencephalic vein (PMV), peduncular vein (PV), lateral mesencephalic vein (LMV), and other smaller veins.

The PMV was identified in 84.6% of specimens (mean diameter 0.54 mm); the PV, in 86.5% (mean diameter 0.86 mm); and the LMV, in 100% (mean diameter 1.07 mm). Four types of LMV were identified on the basis of the vein’s course. Other smaller veins were also differentiated according to whether they drained mainly the cerebral peduncle, the lemniscal trigone, or the tectum. These veins and their junctions with other veins were depicted.

Conclusions. A thorough understanding of the microanatomy of the mesencephalic veins is crucial in brainstem surgery in order to avoid brain damage due to venous infarction and subsequent edema. Because knowledge of the course, variations, and outflow system of these veins could improve surgical outcome, they warrant special attention during surgery.

KEY WORDS • cerebral vein • lateral mesencephalic vein • mesencephalic vein • microsurgical anatomy • venous drainage • cadaver

The mesencephalon consists of the cerebral peduncles, the tegmentum, and the tectum. Its upper border is formed by the sulcus between the optic tracts and the cerebral peduncles; its inferior border is demarcated from the pons by the pontomesencephalic sulcus. The ventral aspect is represented by the cerebral peduncles, and the posterior aspect by the quadrigeminal plate. The lateral mesencephalic sulcus separates the cerebral peduncles from the tegmentum.

The course of the mesencephalic veins is often related to the sulci. Although this course is variable, these veins are intimately related to the surface of the brain and therefore may provide a more faithful representation of anatomic structures than the arteries. Thus they can also be helpful in the preoperative diagnosis of lesions of the midbrain and brainstem.11 Despite their importance, certain mesencephalic veins have received little attention in the literature, especially the veins of the cerebral peduncle, tegmentum, and tectum. In publications they are often simply referred to as “veins” without any further identification by individual names.9,13 Although excellent imaging studies have provided a better understanding of the anatomy of the mesencephalic veins,3,4,12,13,26,27,29–31 these studies lack the details needed during microsurgical operations in this area.

The mesencephalic veins drain such crucial brainstem areas as the cerebral peduncles, the tegmentum, and the quadrigeminal plate. Because of the narrowness of the tentorial incisura at the level of the cisterns, these veins are particularly susceptible to becoming obstructed as a result of herniation or surgical procedures, and their obstruction can lead to hemorrhage.20 The consequence is a typical midbrain syndrome encompassing shifting pyramidal signs, decerebrate rigidity, fluctuating states of consciousness, or pupil dilation. Therefore, attention to the anatomy and the variations of the mesencephalic veins and their tributaries is imperative, especially during surgery.

The aim of this study was to elucidate the topography of the mesencephalic veins by thorough anatomical dissections of these structures in order to exactly analyze the course and junctions of these veins. We focused on the BV, the LMV, the PMV, and the veins draining the cerebral peduncles, tegmentum, and quadrigeminal plate (Fig. 1A). Our findings should contribute to an improved understanding of the venous anatomy of the mesencephalon and thus be beneficial for surgery of the brainstem.

Abbreviations used in this paper: BV = basal vein; CT = computed tomography; LMV = lateral mesencephalic vein; MR = magnetic resonance; PMV = pontomesencephalic vein; PV = peduncular vein.
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Materials and Methods

Fifty-two formalin-fixed cadaveric hemispheres (26 brains) without any lesions provided the material for study of the venous structures around the midbrain. Structures were viewed using an operating microscope (OPMI 1 FC, Zeiss). The specimens were from 23 men and three women who died at a mean age of 34.3 years (range 20–55 years). A digital camera (Nikon D1, Nikon) was used to make microphotographs of relevant structures.

First a lateral view of the brainstem was obtained after soft retraction of the temporal lobe and the cerebellum in order to identify the lateral mesencephalic sulcus and the LMV. The LMV was then carefully dissected in both directions to show its connections to the BV and the superior petrosal vein. The junction of the LMV and the BV was inspected after further retraction. The tributaries to the LMV around the midbrain were also meticulously inspected and depicted. After total dissection, the course of the LMV, especially its relation and distance to the lateral mesencephalic sulcus, was recorded.

The BV was identified and dissected along its course adjacent to the optic tract. The vein’s junction with the PV was inspected from its ventral aspect.

The PMV was identified at the pontomesencephalic junction by means of the useful landmark of the pontomesencephalic sulcus. The junctions of the PMV with the LMV and the more ventral veins were also depicted.

After identification of these greater veins of the mesencephalon, the smaller veins draining the cerebral peduncles, the tegmentum, and the quadrigeminal plate were identified along with their junctions with other veins. Measurements of diameter and distance were performed with a digital caliper (Digimatic CD-15B, Mitutoyo).

Results

Pontomesencephalic Vein

The PMV (Fig. 1B) was found in 84.6% of the brains (44 hemispheres). Its mean diameter was 0.54 mm (range 0.12–1.00 mm) with a standard deviation of 0.20 mm. Generally, the PMV began at the ventral aspect of the cerebral peduncle and coursed through the pontomesencephalic sulcus; in most of the specimens in which the PMV was found, it connected with the LMV at its point of intersection with the pontomesencephalic sulci. The PMV ran below the oculomotor nerve and in some cases (14.1%) anastomosed with smaller veins draining the cerebral peduncle. It also received tributaries from the pons.

Peduncular Vein

The PV originates in the interpeduncular fossa and courses laterally around the cerebral peduncle. The PV ran under the optic tract and drained into the BV in almost all cases (Fig. 1C). This junction occurred primarily at the ventral aspect of the cerebral peduncle, but could also appear more dorsally. In two cases the PV anastomosed with the LMV. The medial end of the PV was near the origin of the oculomotor nerve. Along its course the PV received smaller tributaries that drained the cerebral peduncles. In the 45 specimens (86.5%) in which the PV was identified, its mean outer diameter was 0.86 ± 0.29 mm (range 0.42–1.71 mm).

Lateral Mesencephalic Vein

The LMV is the most important supratentorial–infratentorial venous anastomosis. It normally links the BV to the superior petrosal sinus and lies near or in the lateral mesencephalic sulcus (Fig. 1D). In the hemispheres used in our study, the LMV had a mean outer diameter of 1.07 ± 0.36 mm (range 0.37–2.15 mm). Its junction with the BV was ventral to the lateral mesencephalic sulcus in 25% of the specimens (mean distance 3.23 ± 2.20 mm, range 1.03–7.97 mm) and dorsal to it in 40.4% (mean distance 2.66 ± 1.86 mm, range 0.48–8.02 mm); in 34.6% of the specimens, the junction with the BV was within the sulcus itself. At the level of the pontomesencephalic sulcus, the LMV was ventral to the lateral mesencephalic sulcus (mean distance 1.83 ± 1.48 mm, range 0.54–6.96 mm) in 38.5% of the specimens and dorsal to it (1.44 ± 0.64 mm, range 0.46–2.54 mm) in 19.2%; in 42.3% of the specimens, the LMV was within the sulcus.

Four types of LMV could be classified on the basis of the vein’s relation to the lateral mesencephalic sulcus and its course. Type I, which was found in 28.8% of the cases, ran its whole course ventral to the sulcus. Type II (25%) lay in the sulcus. Type III (34.6%) was only found dorsal to the sulcus. In 11.5% of specimens, a fourth course (Type IV) was observed: the junction with the BV was dorsal and the lower parts of the LMV were ventral to the lateral mesencephalic sulcus, so that the vein crossed the sulcus. The theoretical possibility of a ventral connection to the BV and a dorsal position of the caudal parts of the vein relative to the sulcus was not observed.

Two groups of tributaries to the LMV were distinguished: veins ventral to the lateral mesencephalic sulcus and veins dorsal to the lateral mesencephalic sulcus. In 69.2% of the specimens (36 hemispheres) a vein draining the cerebral peduncle ran into the LMV. Veins dorsal to the sulcus were divided into veins draining mainly the lemniscal trigone or the quadrigeminal plate. Overall, there were 53 veins in the lemniscal trigone (1.0 per hemisphere) and 26 veins (0.5 per hemisphere) in the quadrigeminal plate, all draining into the LMV.

Additional Veins

Smaller veins drained into the main veins of the mesencephalon. They were differentiated according to their three drainage regions: the cerebral peduncle, the lemniscal trigone, and the quadrigeminal plate.

A total of 71 veins (labeled VP in Fig. 1A) were identified which drained the cerebral peduncle (average, 1.4 per hemisphere): 24 (33.8%) ran into the BV, 10 (14.1%) into the PMV, and the remaining 37 (52.1%) into the LMV.

An additional 53 veins drained the lemniscal trigone. All of them drained into the LMV (Fig. 1B).

A total of 37 veins draining the quadrigeminal plate were identified in 31 hemispheres (Fig. 1A): four (10.8%) lay on the superior colliculus, 21 (56.8%) on the inferior colliculus, six (16.2%) on both colliculi, and six (16.2%) between the colliculi. They were named according to their course: superior collicular vein, inferior collicular vein, and intercollicular vein (Fig. 1D). In 29.7% of the specimens, these veins drained into the BV, and in 70.3%, into the LMV.

Discussion

The veins of the brainstem and posterior fossa are among the most neglected of the intracranial vascular structures in the anatomical and neurosurgical literature. Although these veins are particularly susceptible to injury and
are important in surgery, they are often referred to simply as “veins” rather than being identified by their individual names.\textsuperscript{3,14} These veins have received considerable attention in neuroimaging\textsuperscript{3,4,12,13,27,29–31} and anatomical studies,\textsuperscript{6,7,17,18,21,23,28} but data on the course, diameter, relationship to neural structures, and frequency of the mesencephalic veins, especially of the smaller veins, are lacking in these studies.

**Morphometric Findings**

In our study, the PMV was found in 84.6\% of the specimens, and the mean outer diameter was 0.54 mm. Matsushima and colleagues\textsuperscript{18} found this vein in 90\% of 20 hemispheres and reported the mean outer diameter as 0.46 mm (range 0.2–0.9 mm). They found the PV in 100\% of the 20 hemispheres and reported a mean outer diameter of 0.88 mm (86.5\%); Lang and coauthors\textsuperscript{16} found the PV in 92\% of specimens. In contrast, we found the PV in 86.5\%, with a mean diameter of 0.86 mm (range 0.42–1.71 mm). While our findings regarding the course of the PMV and PV agree with those of the authors previously mentioned, those authors provided less information about the vein tributaries in their papers.

The LMV was initially described by Hochstetter\textsuperscript{11} and later by Padget.\textsuperscript{23} Further descriptions followed in anatomical\textsuperscript{7,16,17,18,21} as well as neuroimaging\textsuperscript{12,30,31} studies. From the neuroradiological point of view, Wolf et al.\textsuperscript{31} first described the LMV as a variation in the drainage of the BV, not an independent vessel. The vein was identified when the posterior part of the BV was absent and in some instances when both the LMV and the posterior part of the BV were seen. In a later work, Huang and Wolf\textsuperscript{12} referred to a constant vessel and not an anomaly. We were also able to show that the LMV is not an anomaly but a constant and independent vein. Duvernoy\textsuperscript{7} found the LMV in 75\% of specimens; Lang et al.,\textsuperscript{17} in 70\%. In contrast, we identified the LMV in 100\% (52 hemispheres). Matsushima et al. reported a mean diameter of 0.72 mm (range 0.3–1.8 mm) and Lang et al. a mean diameter of 0.81 mm (0.29–1.78 mm). In our study we found the diameter to be larger, with a mean value of 1.07 mm (range 0.72–1.71 mm).
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0.37–2.15 mm). We were able to show that the diameter of the LMV is not negligible, further supporting the possibility that it contributes significantly to venous drainage.

Anatomical Variations

According to Duvernoy, three groups of supratentorial-infratentorial anastomoses can be differentiated: anteromedian, anterolateral, and lateral. The LMV belongs to the lateral anastomoses connecting the BV with the superior petrosal sinus. Like other authors, Duvernoy also described the LMV running along the lateral mesencephalic sulcus. Lang and associates were the only authors to mention that the LMV could run beside the lateral mesencephalic sulcus, but they provided no further description. Here we describe for the first time the exact course of the LMV and its relation to the lateral mesencephalic sulcus and also differentiate four types on the basis of the course of the vein (described in Results). Detailed information about the distance of the junction of the LMV from the BV and the distance of its inferior parts to the lateral mesencephalic sulcus are also given.

We also examined smaller veins draining the cerebral peduncle, tegmentum, and tectum as well as their junctions with greater veins. No comparable data existed before for veins that drain the cerebral peduncle and the tegmentum, although these draining areas of the brainstem are important. This is the first report to analyze and quantify these veins in detail, as well as to describe their connections with greater veins.

Some work has been done on the tectal veins. Duvernoy wrote of median superior or inferior collicular veins (running between the superior or inferior colliculi in the midline) and of right or left intercollicular veins (running between the colliculi on one side), but he did not give data on their frequency or diameter. Using only six brains for their examinations, Tamaki and colleagues divided these veins into superior and inferior quadrigeminal veins. In articles by Matsushima et al. and Rhoton, the veins are referred to as tectal veins without any further differentiation. Lang and colleagues found an intercollicular vein that matched Duvernoy’s definition of the intercollicular vein found in 57% of his cases (mean outer diameter 0.38 mm, range 0.19–0.91 mm). In our study we designated the tectal veins according to their course, depending on whether they lay on the superior or inferior colliculus or between the colliculi (like the intercollicular vein described by Duvernoy).

The PV, LMV, and PMV, as well as their tributaries, are connected to the BV. This connection is nearly always a direct one for the PV and LMV. In contrast, the PMV has an indirect connection with the BV via its outflow into the LMV. As is well known, the BV is part of the deep venous system and flows into the vein of Galen. The deep venous system drains the choroid plexuses via the straight sinus, the deep gray matter of the thalamus and striatum, and also the periventricular white matter, the hippocampus, the corpus callosum, the cortex of the limbic lobe and visual system, the diencephalon, and the rostral brainstem. These areas represent the drainage territory of the vein of Galen and the two BVs and their tributaries. Some of these tributaries are the veins described in this study. We can presume that these veins belong to the deep venous system. The LMV, in particular, plays a special role, because it connects the supratentorial venous system with the infratentorial system. It is important to note that the deep system shows greater constancy than the superficial system.

Clinical Relevance

Obstruction of the vein of Galen alone can be compensated for by anastomoses via the BV, but the simultaneous obstruction of the vein of Galen and the BV or their tributaries at the tentorial incisura can cause great damage, and the narrowness of the tentorial incisura in this area makes it a likely location for such obstruction. The effects of venous obstruction in this area have been described by Scheinker, who concluded that transtentorial herniation not only involves herniation of part of the temporal lobe, but also the displacement of the rostral brainstem in relation to the incisura. He found that the characteristics, severity, and distribution of midbrain lesions were influenced primarily by venous compression. Small veins and capillaries were greatly congested and surrounded by hemorrhages and edema.

In a review of 122 cases of vascular lesions, Cannon found that in cases involving supratentorial masses, hemorrhages were restricted to the pons and mesencephalon. Microscopic examinations of the pons and the midbrain revealed hemorrhages of various sizes, generalized engorgement of veins and capillaries, and edema of the surrounding brain tissue. These hemorrhages were associated with obstruction of venous outflow from the rostral brainstem into the galenic system.

Mayer emphasized that secondary brainstem lesions, which result from incarceration of the midbrain in the tentorial incisura, have often been mistaken for primary lesions. Incarceration of the mesencephalon after trauma is caused by intracranial hemorrhage or edema, which result from venous congestion and necrosis of the walls of veins in the drainage area of the galenic venous system, particularly the tributaries of the BV.

The authors of a 1990 report based on data from the National Institutes of Health’s Traumatic Coma Data Bank found that intracranial hypertension and death were strongly correlated with compression or obliteration of the mesencephalic cisterns. These findings corroborate the importance of midbrain swelling or displacement.

Obstruction of the deep venous system can also lead to so-called “diffuse axonal degeneration.” This degeneration of the white matter is not diffuse, because it involves only the periventricular matter, which is drained by the deep venous system, and not the subcortical fibers. This phenomenon and the involvement of cortical areas drained especially by the deep venous system indicate that obstruction of veins of the deep system can cause white matter degeneration.

Surgical Planning

The drainage of the BV as part of the deep system is important in the preoperative planning of skull base and brainstem surgery. In comprehensive investigations of the development of the cranial venous system, Padget described how the BV is formed by anastomoses between the deep middle cerebral vein, the ventral diencephalic vein, the dorsal diencephalic vein, the mesencephalic vein, and a tributary of the primitive straight sinus. In view of the com-
complicated embryological and ontological development of the BV, it is not surprising that there are variations in its outflow. Using 3D CT angiography, Suzuki and colleagues investigated variations of the drainage of the BV. They observed that in 87.8% of the cases studied, the BV flowed into the vein of Galen; in 5.6%, into the LMV; in 1.6%, into the PV; and in 5.0% into the lateral or medial tentorial sinus. They pointed out that the vein of Galen is the most important outflow system for the BV, and the LMV is the most important of the BV outflow variations. Their observation agrees with that of Babin and Megret who noted that the LMV is a frequent outflow vein of the BV. Suzuki et al. emphasized that although the vein of Galen appears to be the only drainage pathway, it is necessary to consider the presence of narrow collateral vessels that are not detected by 3D CT angiography.

Concerning the visualization of these veins we recently started an interdisciplinary project with our neuroradiologist (J.L.) to achieve a better visualization of this deep venous system (Figs. 2 and 3). Using modern methods of CT and MR angiography, we were able to show the topographical relationship of these veins to the brainstem for improved surgical planning of approaches to this sensitive area. We hope that with the use of dynamic techniques, we will also be able to study the patency of collateralization.

Because these veins are visible, we believe that they can serve as useful landmarks during different surgical approaches in this area, such as the subtemporal approach to the brainstem, especially to the mesencephalon, and the lateral suboccipital approach for microvascular decompression, as well as for procedures involving the temporomesial region, such as the selective amygdalolimbicampectomy. The BV courses behind the parahippocampal gyrus and marks the upper border of the target area when we use the subtemporal approach to the midbrain. In a recent study we described the morphometrical analysis of the subtemporal approach with special regard to its applicability and the surgical corridor.

Because one or more tributaries or even the main trunk of the superior petrosal vein can be exposed to the risk of occlusion during microvascular decompression or tumor surgery, the possible outflows or variations thereof via the LMV to the BV should be considered. Although the patency of this kind of venous collateralization or the direction of drainage cannot yet be determined preoperatively with today’s imaging techniques, we are already able to visualize the vessels (Figs. 2 and 3). Knowing that during operations in this area (for example, microvascular decompression) the superior petrosal vein can in many cases be sacrificed without the severe consequence of venous infarction, we presume that the LMV is important for the drainage in the direction of the BV. In fact, we found that the system of the superior petrosal vein and the BV were directly connected in all our specimens via the LMV.

In our experience, only the severe complications following an occlusion of the superior petrosal vein are noticed. Typical clinical signs are vertigo, gait disturbances, hyponcusis, vomiting, and nausea. Minor consequences are often not registered. Therefore postoperative perfusion MR imaging studies are needed to determine if transient drainage deficits occur. Occlusion of the LMV can be important if the BV drains mainly through the LMV into the superior petrosal vein and not into the vein of Galen. Also, if there are tributaries from the tectum into the LMV, the occlusion of the PMV could lead to paresis of ocular movement. Occlusion of the PMV could cause an infarction in the midbrain and related signs. We hope that in the future improved MR angiography techniques will allow visualization of both the caliber and patency of the petrosal vein and the LMV.

In tumor surgery, for example in the resection of large acoustic neuromas or menigiomas of the cerebellopontine angle, drainage capacity may be removed along with the tumor. Therefore, both knowledge of the existence of and the preservation of this deep venous system are important.

Conclusions

The goal of the present study was to provide a detailed description of the mesencephalic veins and their smaller tributaries as part of the deep venous system with special emphasis on their course, their relation to neural structures,
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and their junctions with greater veins. The clinical application of this microanatomical knowledge should support the neurosurgeon during procedures in this challenging region of the brain.

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