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Review Article

The functional anatomy of the foramina of Luschka revisited

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ABSTRACT

Background: The German Anatomist Hubert Von Luschka first described the foramina of Luschka (FOL) in 1855 as lateral holes in the fourth ventricle. By his discovery, he refuted previous beliefs about the lateral recess as blind ends of the fourth ventricle, proving the continuity of the ventricular system with the central canal of the spinal cord. In this paper, we question the outline variations of the patent parts of FOL and their consistency, drawing attention to the apparent query of the valvular mechanism of FOL.

Methods: We conducted a literature review in PubMed and Google Scholar databases to review the existing literature describing the history, pertinent anatomy, and function of FOL. In addition, we reviewed the original German book written by Luschka.

Results: While reading the available articles and original works regarding FOL, we noticed the developmental phases through which FOL was discovered, tracking the process from Aristotle till Luschka's discovery. We also discussed controversies and opinions about FOL's existence and function.

Conclusion: FOL is halved into two compartments: choroidal and patent. The function of FOL resembles a one-way valve mechanism, and it depends on the patent slit-like part. Luschka had discovered over 20 anatomical structures, including several foramina, confusion in a debate may result from eponyms.

Keywords: Choroid plexus, Foramen of Luschka, Fourth ventricle, Lateral openings, Patency

INTRODUCTION

The foramina of Luschka (FOL) are counted as a considerable microsurgical corridor to the floor of the fourth ventricle. Understanding the patency of FOL can potentially improve tetraventricular microsurgical and neuroendoscopic approaches. It also contributes to the development of transforaminal electrode placement for auditory nerve stimulation and intraoperative neurophysiological monitoring (IONM), especially brainstem auditory evoked potentials.[11,15]

A variety of previous revisiting attempts to explore the FOL anatomy, pathology, and surgical significance are reported [Figure 1]. In this paper, we question the outline variations of the patent

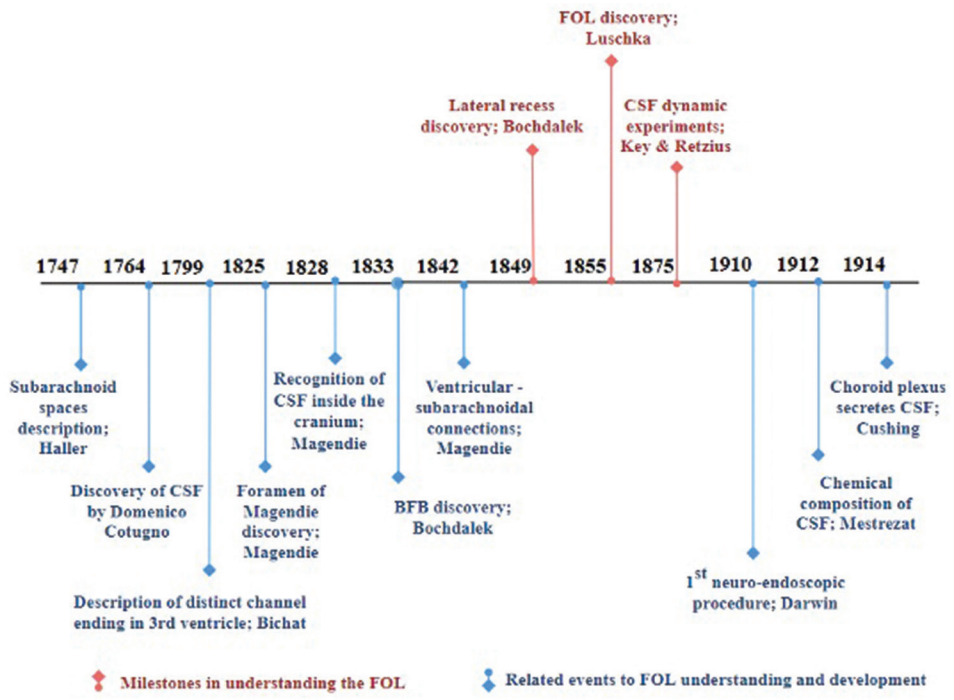


Figure 1: Timeline of foramen of Luschka discovery and development.

parts of FOL and their consistency, drawing attention to the apparent query of the valvular mechanism of FOL.

WHO IS LUSCHKA?

The German anatomist Hubert Von Luschka (1820–1875) first studied pharmacology; thence, he was able to join medical college with the financial support of his brothers. However, he well deserved it being eponymous of more than 20 anatomical structures named after him.[15] Postgraduation, he worked in the anatomy department of the university of Tubingen until 1852, when he became a professor in anatomy and pathology and then director of the anatomical institute in 1855. Luschka made numerous contributions to neuroanatomy, including FOL, Luschka's sinus, the recurrent nerve of Luschka, and others. He was ennobled and received his honorary degree in 1865, a year before his death leaving his successor Wilhelm Henke (1834–1896).[6]

PERTINENT ANATOMY

The superior and inferior limbs of the cerebellopontine fissure form a deltoid space lateral to the pons called the cerebellopontine angle (CPA). CPA is occupied by the CPA's cistern, where blood vessels and cranial nerves are situated. It is the most frequent site for posterior fossa tumors due to the abundance of arteries which increases the risk of tumor growth in the CPA. Subsequently, the continuous blood supply to the tumors will result in more destructive damage to the surrounding structures.[12] The most lateral part of the fourth ventricle opens in the CPA by the FOL.

Ventricular side of FOL

The fourth ventricle is a cavity with a tent-shaped roof and rhomboid-shaped floor. It is located anterior to the cerebellum, extending from the Sylvian aqueduct to the obex, where it narrows and continues as the central canal of the spinal cord. The union of the floor and roof of the fourth ventricle on either side form the lateral recess, which opens at the CPA by the FOL.[6] Thus, the orifice of FOL views on two sides; a ventricular side caudally into the lateral recess and a cisternal side rostra-laterally into the cerebellomedullary cistern. FOL is commonly described as lateral apertures or openings of the fourth ventricle.[2,8,9] However, Jean *et al*. discerned the aperture to be halved into two partitions: choroidal and patent parts. This description was ratified by Sharifi *et al*. 6 years later.[7,14]

Choroidal compartment of FOL

The choroid plexus of the fourth ventricle has T-shaped distribution. Its lateral horizontal section sits laterally in the lateral recess and protrudes outside the FOL, the so-called Bochdalek's flower basket (BFB) [Figure 2].[1] Differentiation between subarachnoid hemorrhage in the FOL and BFB calcification in radiology is of critical clinical significance. The choroidal part stands for the lateral compartment of FOL, where BFB pouches out.[7] BFB does not obstruct the

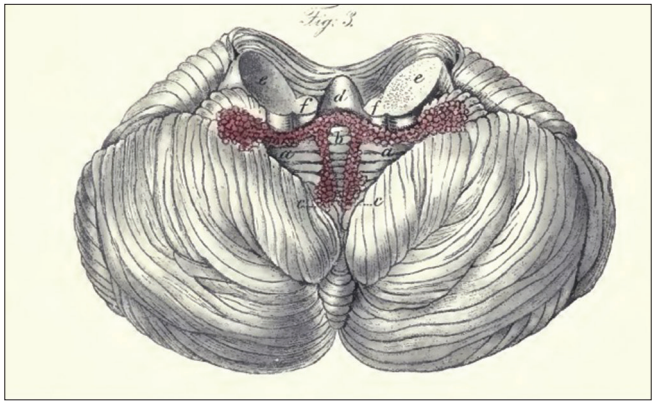


Figure 2: Original illustration by "The Choroid Plexuses of the Human Brain" book, inferior view of the cerebellum after removal of the medulla oblongata and the superior medullary velum to show the T-shape distribution of the BFB ending laterally by the choroidal compartment of FOL. (aa) Horizontal strands of the choroid plexus, (b) connector of the horizontal and longitudinal choroid plexus, (cc) longitudinal strands of the choroid plexus, (d) cerebellar nodule, (ee) middle cerebellar peduncles, and (ff) inferior cerebellar peduncles.

whole orifice of FOL normally, but enlarged BFB causes functional obstruction. Cauterization of enlarged BFB is not recommended in diverticulum surgeries. Nevertheless, it can be an option if recurrence dictates reoperating.[9]

Patent compartment of FOL

The patent part is the crescent-shaped residual medial slit. The patency of FOL depends on the size of BFB and the probability of FOL obstruction, which is inversely proportional to the choroidal part's size. Membranous obstruction of FOL is caused by remnants of the rhomboid lip and is known as primary obstruction. Primary obstruction usually causes CPA cysts which may develop into diverticular lesions. Congenital syndromes such as Chiari malformation and Walker Dandy can lead to fourth ventricular outlets obstruction resulting in the closure of both the FOL and Magendie simultaneously. Secondary obstruction can be caused by CPA tumors or subarachnoid hemorrhage.[2]

Cisternal side of FOL

The FOL pours into the cerebellomedullary cistern or cisterna magna, from which ventricular CSF circulation communicates with subarachnoid spaces. Such a connection was not considered until (1747) when Von Haller (1708–1777) described a liquid superficially to the brain and a space between the arachnoid membrane and the pia mater. He assumed that this liquid must have its pathway outward the ventricles but did not describe the mechanism.[6] CSF then passes to cisterns, cerebral and spinal subarachnoid spaces, and sulci to be absorbed by arachnoid granulations.

Vessels in the vicinity of FOL

The brainstem receives its vascular supply chiefly from the vertebrobasilar system. The basilar artery gives rise to the superior cerebellar artery most rostrally; it, then, courses laterally and caudally to supply cerebellar hemispheres. A second branch of the basilar artery is the anterior inferior cerebellar artery (AICA).[14] It is highly changeable in size and course compared to the contralateral side, and this variety is dependent on the course of the posterior inferior cerebellar artery (PICA). PICA arises from the vertebral artery and has different levels of origin. It may arise near the foramen magnum at the immediate intracranial level or extradural, or even near the pons.

The choroid plexus of the fourth ventricle usually receives its blood supply through the AICA, supplying the choroidal part in the cisternal side and the adjacent portion of the lateral recess of the fourth ventricle through the FOL. At the same time, PICA supplies most of the choroidal part in the roof and the foramen of Magendie.[13]

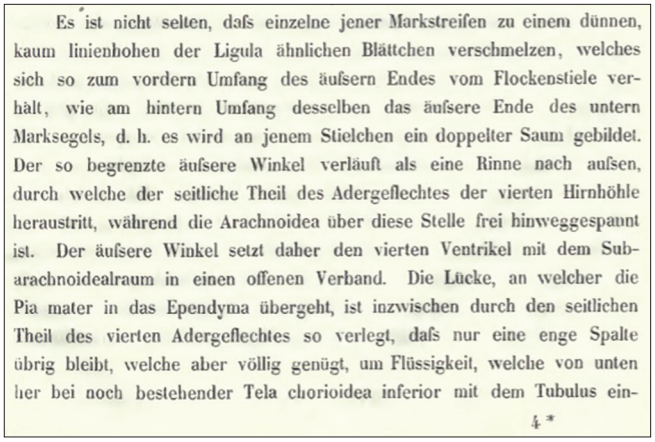
Cranial nerves in the vicinity of FOL

Cranial nerves from V to XI arise within the margins of the cerebellopontine fissure into the CPA cistern. The CN V exits the brainstem laterally to the pontomedullary sulcus. The entry zone of the vestibulocochlear nerve is 1–2 mm posterior to the trigeminal nerve emergence. The lower part of the CPA contains the CN IX, X, and XI. Perception of cranial nerves in the CPA is of considerable importance in mapping the ambiguous nucleus, facial nucleus, and hypoglossal nucleus during CPA tumors' surgeries and IONM.[10]

TRACKING DOWN THE ORIGINAL DESCRIPTION OF FOL

"*On either side, the outer angles of the fourth ventricle assume the form of a gutter leading outside, whereby the latter portion of the choroid plexus passes outside the fourth ventricle while the arachnoidea stretches freely over the place in question. The fourth ventricle, therefore by its exterior angles, has open communication with the subarachnoid space.***"**

That was a part of what Luschka stated in his book The Choroid Plexuses of the Human Brain *(Die Adergeflechte des menschlichen Gehirns*) (1855) [Figure 3].[15] With his discovery, Luschka rectified the misconception of the lateral recess as tetraventricular blind extensions described by Bochdalek (1849).[14] Since then, successive experiments have taken place to comprehend cerebrospinal fluid (CSF) circulation. CSF studies paved the way to understanding the anatomy of FOL, but its mechanism of function remained questioned.


Es ist nicht selten, dafs einzelne jener Markstreifen zu einem dünnen, kaum linienhohen der Ligula ähnlichen Blättchen verschmelzen, welches sich so zum vordern Umfang des äufsern Endes vom Flockenstiele verhält, wie am hintern Umfang desselben das äufsere Ende des untern Marksegels, d. h. es wird an jenem Stielchen ein doppelter Saum gebildet. Der so begrenzte äufsere Winkel verläuft als eine Rinne nach aufsen, durch welche der seitliche Theil des Adergeflechtes der vierten Hirnhöhle heraustritt, während die Arachnoidea über diese Stelle frei hinweggespannt ist. Der äufsere Winkel setzt daher den vierten Ventrikel mit dem Subarachnoidealraum in einen offenen Verband. Die Lücke, an welcher die Pia mater in das Ependyma übergeht, ist inzwischen durch den seitlichen Theil des vierten Adergeflechtes so verlegt, dafs nur eine enge Spalte übrig bleibt, welche aber völlig genügt, um Flüssigkeit, welche von unten her bei noch bestehender Tela chorioidea inferior mit dem Tubulus ein-

4*

Figure 3: The original description of FOL in "The Choroid Plexuses of the Human Brain" book, the first section, page 27.

DEVELOPMENT

The first description of cerebral cavities was in the 3rd century BC by Aristotle (384-322 BC), as he noticed the central cavity in the brain while studying animals' cadavers. Then, he came the detailed identification of lateral, third, fourth, and mesencephalic aqueduct through dissections in human cavers by Herophilos of Chalcedon (335-280 BC).[5] Tracing the trail of the FOL developmental process revealed that it passed by several intimate and indirectly related events ending with the delicate anatomy known today.

Milestones of FOL anatomical and physiological development

The three main events intimately related to FOL development are represented first by the discovery of the lateral recess, which was described as blind end extensions (1849) by Vincent Alexander Bochdalek (1801–1883). Second, the correction of this description was achieved by the discovery of FOL in (1855) by Hubert Von Luschka (1820–1875). Finally, the ratification of Luschka's findings was crowned by the dynamic experiments (1875) of Axel Key (1832–1901) and Gustav Magnus Retzius (1842–1919), as they mentioned in their book "Studies in the Anatomy of the Nervous System and the Connective Tissue."[6]

Related events to FOL understanding

Ten subordinated events contributed to the milestones of FOL discovery. Albrecht Von Haller (1708–1777) gave the idea of brain liquid and the possibility of a default outlet of this liquid (1747).[6] Afterward, Domenico Cotugno (1736–1822) was credited with discovering CSF in (1764). Then, Bichat (1771–1802) described a distinct channel ending in the third ventricle (1799). The discovery of the foramen of Magendie (1825) and the recognition of CSF inside the cranium (1828) were both achieved by Francois Magendie (1783–1855), but the form of the choroid plexus of the fourth ventricle was understood in 1833 by Vincent Alexander Bochdalek (1801–1883) when he described BFB.[2,15]

Connections between the ventricles and subarachnoid spaces through the foramen of Magendie were also explained by Magendie (1842). Each discovery has played a key role in neurosurgery hitherto and assisted in improving neurosurgical procedures. Neuroendoscopic procedures emanated, and the first one to fulgurate the choroid plexus was done in 1910 by Vincent Darwin, a urologist. He used the cystoscope to make a third ventriculostomy in two children with hydrocephalus.[8] Another important event was the first accurate description of the chemical composition of CSF (1912) by Mestrezat. Two years later (1914), Cushing proved that the choroid plexus secrete CSF.

CONTROVERSIES AND OPINIONS REGARDING FOL

Although Monro's descriptions of the interventricular foramen and ventricular system's continuity fitted expectations, he denied the continuity between the fourth ventricle and the central canal of the spinal cord. However, the continuous ventricular system was already drawn with wax cast by Leonardo di Vinci at that time.[3]

The terms "holes" and "foramina" of Luschka are used synonymously in the literature for describing the fourth ventricular lateral apertures. In contrast, the same terms are used to name postglenoid foramen and jugular spurium foramen, discovered by Luschka as well. This may confuse the debate between all the foramina Luschka discovered unless an explanation is mentioned.[14]

Another contradiction in the literature is the determination of the roof and floor of the lateral recess, a pyramidal extension connecting the fourth ventricle's cavity with the cerebellomedullary cistern through the FOL.[4,7] We picture the reason for the contradiction as being related to the lateral recess axes. The tela choroidea, a thin film between the cerebellum and the inferior zone of the fourth ventricle's floor, represents the roof of both parts of the lateral recess. In contrast, the rhomboid lip is a sheet-like layer of neural tissue that forms the floor of the lateral recess. As the lateral recess proceeds rostrally, the rhomboid lip and the tela choroidea rotate to form the medial and lateral walls of the FOL, respectively.[7]

FUNCTION OF FOL

The central canal of the neural tube develops into the cerebral ventricular system. During the first trimester of pregnancy, the central canal expands into the ventricles, connected by

thinner canals. The fourth ventricle particularly originates from the rhombencephalic portion of the neural tube. FOL appears between the 14th and 26th weeks of gestation without exact known timing. Since the median aperture appears earlier, on the 9–10th week, a bilateral failure in the opening of the lateral recesses should not result in hydrocephalus.[2]

The anatomy around the FOL is delicate due to the rich vascularity and cranial nerve emergence (CN IX and X) near its opening. The microsurgical anatomy of FOL around the CPA is well described in the literature, but the interior compartment and mechanism of function have poor descriptions.[11] The clinical significance of FOL is to connect the fourth ventricle with subarachnoid cisterns and equalize extraintracranial pressure by participating in CSF circulation, thus preventing hydrocephalus. Closing one or both FOL may cause noncommunicating hydrocephalus, enlarging the cerebral ventricles. Congenital etiologies of FOL obstruction are anatomical abnormalities grouped into dysgenesis, agenesis, and arachnoiditis.[14]

The mechanism of the function of the FOL resembles a one-way valve by principle and directionality.[13] Unlike the foramen of Magendie, when CSF passes through FOL inside-out, it will not flow back to the ventricle again. This valvular mechanism was investigated by Magendie and Luschka[6] and supported by anatomical studies and experiments by Key and Retzius.

Magendie carried out human cadaveric experiments to prove CSF bidirectionality by injecting liquids through the subarachnoid space and observing the backflow of the fluid through the median aperture to the fourth ventricle, then to the third ventricle through the Sylvian aqueduct and ending in the lateral ventricles. He also studied the postural outflow drainage by emptying the injection in the lumbar sac.

Luschka conducted seven experiments to prove the continuity of the ventricular system with the subarachnoid spaces and the bidirectionality of the median and lateral foramina. He applied a liquid colored with black ink and injected it at several subarachnoid space levels; by doing so, he proved the CSF continuity, but the directionality of the foramina remained uncertain.[15]

Key and Retzius used dyed adhesive solutions mixed with paraffin and olive oil. The injected cadavers' brains were studied only after they were cooled till solidification. They found an uninterrupted stream of CSF in the ventricles, holes, and subarachnoid spaces, but they could not infer the direction as they studied frozen liquid.[6,8]

CONCLUSION

FOL is halved into two compartments: choroidal and patent. The function of FOL resembles a one-way valve mechanism dependent on the patent slit-like part. Although the directionality of FOL is believed to be inside-out, it lacks explanation. Hypothesized explanations suggest outer pressure of the choroid plexus.

Declaration of patient consent

Patient's consent not required as there are no patients in this study.

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Conflicts of interest

There are no conflicts of interest.

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