Childs Nerv Syst (2013) 29:17–33
DOI 10.1007/s00381-012-1910-x

REVIEW PAPER

The intracranial arachnoid mater

A comprehensive review of its history, anatomy, imaging, and pathology

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Received: 27 July 2012 / Accepted: 27 August 2012 / Published online: 8 September 2012

Abstract
Introduction The arachnoid mater is a delicate and avascular layer that lies in direct contact with the dura and is separated from the pia mater by the cerebrospinal fluid-filled subarachnoid space. The subarachnoid space is divided into cisterns named according to surrounding brain structures.
Methods The medical literature on this meningeal layer was reviewed in regard to historical aspects, etymology, embryology, histology, and anatomy with special emphasis on the arachnoid cisterns. Cerebrospinal fluid dynamics are discussed along with a section devoted to arachnoid cysts.
Conclusion Knowledge on the arachnoid mater and cerebrospinal fluid dynamics has evolved over time and is of great significance to the neurosurgeon in clinical practice.

Keywords Meninges · Leptomeninges · Arachnoid mater · Intracranial · Anatomy · CSF · Arachnoid cysts · Arachnoid granulations · Villi

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Introduction

Ancient descriptions of the cranial meninges were limited to the dura mater and pia mater. At that time, the use of the word arachnoid was limited to web-shaped membranes found normally or pathologically in the body. The first description of an arachnoid membrane surrounding the brain can be traced back to Herophilus in the 3rd century B.C. Herophilus, the father of anatomy, was born in Chalcedon and moved to Alexandria early in his life, where, along with Erasistratus, he studied human anatomy for almost 40 years. For the first time in history, they performed systemic dissection and vivisection of the human body. These kind of examinations, although considered unethical, contributed to a huge amount of medical knowledge that has persisted until today. Regarding the nervous system, Herophilus studied and described the arachnoid mater and the ventricles (mainly the lateral and the fourth ventricles) and its linings, which he named "choroid meninx."

Although the presence of the arachnoid mater was outlined by Constantius Varolius [132] in 1573 and the atlas of Casserius [17] in 1627, its "discovery" is attributed to the efforts of Gerardus Blasius [14] in 1666 and Andreas Ottomar Goelicke [37] in 1697, who called it tertia cerebri meninge (third cerebral meninge) [89]. However, Frederick Ruysch [106], to whom the name of arachnoid mater can be attributed, was the first to describe the full covering of the brain by this layer in 1699. In addition, he described the exact spider-like morphology of this layer by blowing air under it. Furthermore, detailed descriptions of this layer were later made by many physicians, including von Haller [138], Bichat [11], who is the first to study the arachnoid mater in details, Cruveilhier [22], Virchow [136], Key and Retzius [59] (Figs. 1, 2 and 3), and many others [7, 108].

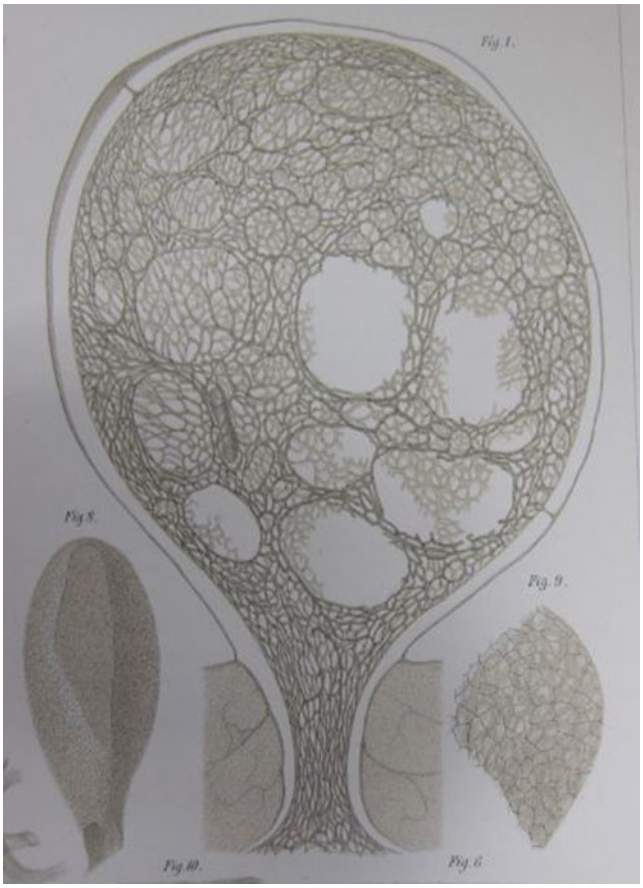

Fig. 1 Tafel XXVIII. Arachnoidalzotten beim Menschen "Arachnoid villi in Humans." Figure 2 from "Studien in der Anatomie des Nervensystems und des Bindegewebes" By Axel Key and Gustaf Retzius, 1875

Etymology

The Greek term arachnoid is derived from "arachne," which means spider, or spider's web, and "eidos," which means shape. This term, and its Latin translation (aranea), were used since the early years to describe components of the eye ball. However, from the eighteenth century, it was almost always used to refer to the arachnoid mater. Other names of the arachnoid mater were also proclaimed by many anatomists, but they were rarely, if ever, used. These include: Meninx media, Meninx mucosa, and Meninx serosa [89].

The use of the term "arachne" for spiders was derived from an old Greek myth about a young girl named "Arachne," who challenged the goddess Pallas Athena in a weaving contest. After she lost, and as reward for her boldness; she was transformed into a spider, so she could exercise her weaving skills [108].

Anatomy

Arachnoid mater

The arachnoid mater is a delicate and avascular layer that lies in direct contact with the dura, from which it can be easily separated along a potential space named "subdural space." It is separated from the pia mater by the CSF-filled subarachnoid space, which is traversed by fine filaments that connect both layers, named arachnoid trabeculae [39, 93, 118, 119]. The arachnoid villi and granulations protrude into the venous sinuses and will be discussed below (Figs. 4 and 5).

The arachnoid follows the pia mater and invests the entire brain (Fig. 6), covers the superior surface of the pituitary fossa, and becomes continuous with the spinal arachnoid at the level of the foramen magnum. In contrast to the pia, it bridges over the sulci and fissures, except the great longitudinal fissure separating both cranial hemispheres. It surrounds the blood vessels and nerves, which have to pass through the subarachnoid space, as they enter the cranial cavity, and becomes continuous with their epineurium and adventitia as they leave [118, 119]. In the special case of the

Fig. 2 Tafel XXIX. Arachnoidalzotten des Menschen "Arachnoid villi of Humans." Figure 4 from "Studien in der Anatomie des Nervensystems und des Bindegewebes" By Axel Key and Gustaf Retzius, 1875

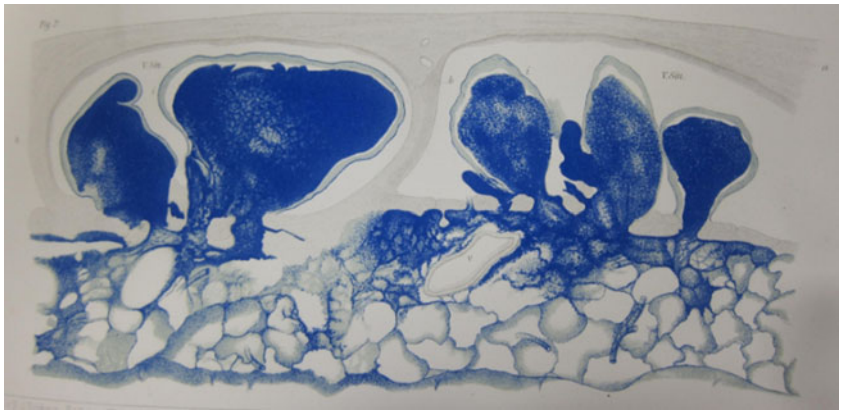

Fig. 3 Tafel XXXI. Der Feinere Bau der Arachnoidalzotten beim Menschen "The fine structure of the Arachnoid villi in Humans." Figure 1 from "Studien in der Anatomie des Nervensystems und des Bindegewebes" By Axel Key and Gustaf Retzius, 1875

optic nerve, the arachnoid mater and subarachnoid space surround the nerve through its course to the orbital cavity, where it fuses with the sclera of the eyeball [118]. The arachnoid is reflected onto the surface of the blood vessels in the subarachnoid space, and is mainly adherent to the internal carotid and vertebral arteries [119].

The arachnoid is thicker at the basal part, between the temporal lobes, and at the anterior surface of the pons. With age, the arachnoid of the superior surface may become white and opaque, mainly near the midline [118].

Subarachnoid space and cerebrospinal fluid (CSF)

Although the presence of fluid in the ventricles and surrounding the brain was mentioned in early descriptions, the first discovery of the CSF is attributed to Contugno [21] in 1764. It was rediscovered later in 1825 by Magendie [77]. In 1844, Rokitansky [105] proclaimed that the arachnoid mater forms a serous sac containing serous fluid, with the visceral layer directly attached to the pia mater. However, Virchow [136], in 1856, although agreed that the arachnoid consists of two layers, he denied any fluid content in the sac under normal circumstances, and he denied any continuity of this space. Key and Retzius [59], through their experimental study on human cadavers and living animals, had a remarkable contribution in the discovery and description of the CSF-filled subarachnoid space and its communication with the ventricles. They declared that the subarachnoid space entirely surrounds the brain in a continuous fashion, contains CSF, and freely communicates with the ventricles [8, 59]. Bichat [10], in 1800, proclaimed that the arachnoid forms a closed sac and its fluid content communicates with the third ventricle by a small opening on its roof, named "canalis Bichati." Magendie [77] also described a similar opening on the roof of the fourth ventricle. In 1855, von Luschka [139] found that the fluid within the arachnoid sac is communicated with the fourth ventricle and with that surrounding the spinal cord [7].

The subarachnoid space

The subarachnoid space presents between the arachnoid and pia mater. It varies in thickness and is absent in certain places were the brain and pia are in direct contact with the arachnoid, and where nerves and blood vessels exit the brain. Otherwise, this space is continuous around the brain and with the subarachnoid space surrounding the spinal

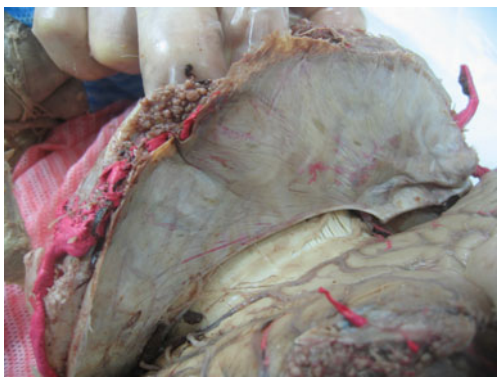

Fig. 4 Gross brain dissection noting the opened superior sagittal sinus at the superior aspect of the falx cerebri. Note the prominent arachnoid granulations that protrude into this sinus

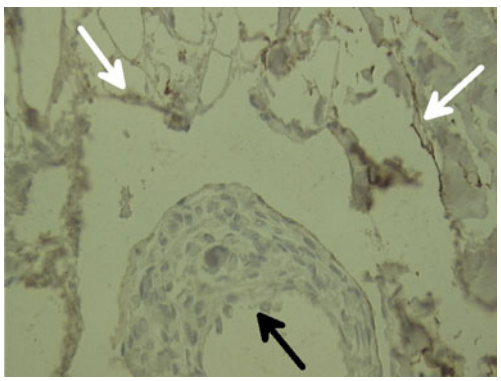

Fig. 5 Immunohistochemical slide illustrating the arachnoid vill (*black arrow*) protruding into a nearby vein (*white arrows*)

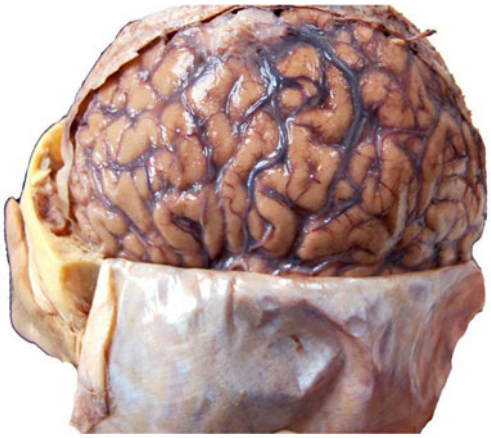

Fig. 6 Lateral view of the exposed cerebral hemisphere noting the glistening arachnoid overlying the superficial vessels of the brain

cord. It communicates with the fourth ventricle through the midline foramen of Magendie, and the paired foramina of Luschka [139]. According to Hodges [54], the subarachnoid space can be divided into the basilar cisterns and the channels passing over the dorsal peripheral surface of the cerebral and cerebellar hemispheres. They proclaimed that no sheet-like spaces exist over the hemispheres as the arachnoid is indirect contact with the gyri, but instead it is formed where the arachnoid bridges over the sulci. It creates a subarachnoid space within each sulcus of about 1–2 mm across and 5–10 mm deep [54].

In 1828, Magendie [78] presented his findings regarding the CSF at the Academy of Sciences in Paris, titled "Mémoire Physiologique sur le Cerveau." He described an opening in the midline of lower part of the roof of the fourth ventricle that is variable in size and wide enough to admit the point of the finger [103, 127]. The presence of this opening has been confirmed later by Luschka [139], Key and Retzius [59], and others. However, it has been also denied by many authors, including Todd [125] in 1847, Virchow [135] in 1854, Reichert [97] in 1861, and many others. In 1931, Rogers [103] documented this controversy and confirmed the presence of this aperture, but stated that it is not a normal foramen, but rather a deformity in the roof of the ventricle.

The foramina of Luschka were first described by the Dutch anatomist Hubert von Luschka in 1855 [139]. In his work, he confirmed the presence of the foramen of Magendie and described an open communication between the fourth ventricle and the subarachnoid space at the outer margins of the fourth ventricle. His findings were later confirmed by Key and Retzius [59] in 1875, but have been denied by some authors [116, 128]. At the foramina of Luschka, where the fourth ventricle empties into the cerebellomedullary and cerebellopontine cisterns, the tela choroidea and accompanying choroid plexus rotate, proceeding laterally so that what was superior becomes lateral. The rhomboid lip, which was initially caudal, becomes the medial lip of the foramen of Luschka. The origins of the glossopharyngeal and vagus nerves are immediately anterior to the foramina, whereas the acoustic striae, cochlear nerve, and flocculus are just anterosuperior [57].

The basilar cisterns underlie and partially surround the structures lying on the floor of the skull (Figs. 7, 8, 9, 10 and 11). They completely surround the midbrain and communicate with the surface by three routes: anteriorly, between the hemispheres and along the rostrum of the corpus callosum, accompanying the anterior cerebral and pericallosal vessels; anterolaterally, along the Sylvian fissure over the insula, accompanying the middle cerebral vessels laterally to the surface of the brain; posteriorly, from the quadrigeminal cistern up around the splenium of the corpus callosum between the hemispheres and posteriorly over the vermis and dorsal cerebellar surfaces [54]. The first description and naming of the major cisterns is ascribed to Key and Retzius [59]. They described the cerebellomedullaris, intercruralis, pontis, chiasmatic, corporis callosi, and ambiens, and these terms are still generally used [7]. Later on, Liliequist [69, 70] in 1956 and 1959, Yaşargil [153, 154] in 1976 and 1984, and others [66, 150] described these cisterns in more details.

The basilar cisterns are named according to the major anatomic structure they bathe [54], and they can be classified according to the series of contrast flow through them [54, 69] or according to their anatomic location [154]. In the following subsections, we will describe the major cisterns using Yaşargil's [154] anatomic classification.

Supratentorial Cisterns

Anterior (parasellar) The *chiasmatic cistern* (Figs. 9 and 10) surrounds the optic chiasm and the internal carotid arteries, and communicates posteriorly with the interpeduncular cistern, from which it is partially separated by Liliequist's membrane.

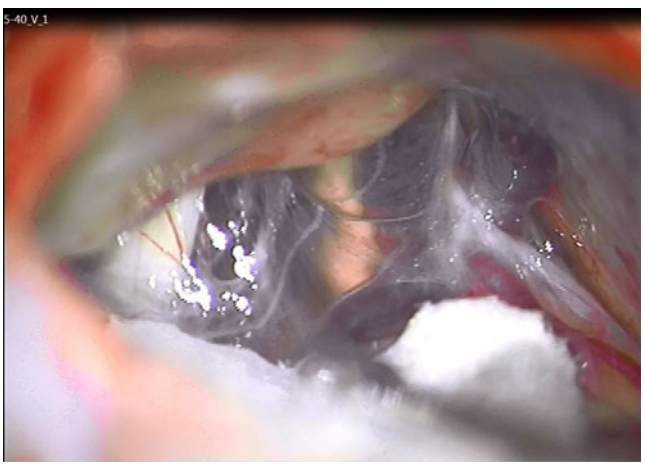

Fig. 7 Intraoperative view of the retromastoid approach to the CP angle. Note the distinct arachnoid mater overlying CP angle structures

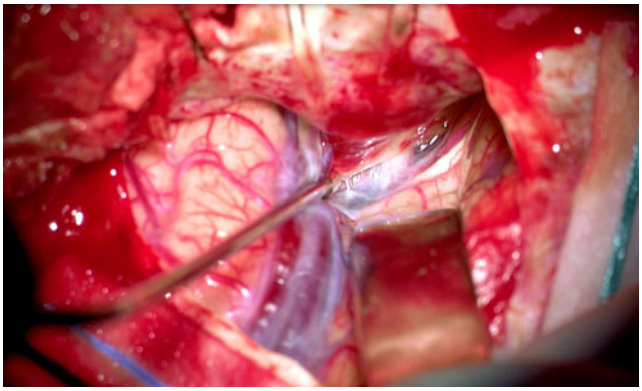

Fig. 8 Arachnoid over the optico-carotid region

Anteriorly, the chiasmatic cistern is related to the posterior edge of the gyrus rectus on the lower surface of the frontal lobe, except in the midline where the cistern communicates with the cistern of the lamina terminalis. Anterolaterally, it merges into the Sylvian fissure [69]. Sometimes the chiasmatic cistern is divided into *prechiasmatic* and *postchiasmatic cisterns* [119]. It contains the anterior aspect of the optic chiasm and optic nerves, the hypophyseal stalk, the origin of the anterior cerebral arteries, and the anterior communicating vein [153].

The chiasmatic cistern continues anterosuperiorly as the *cistern of the lamina terminalis*. It has a tent shape and is located at the midline of the deep cerebrum based on the lamina terminalis, and communicates with callosal the cistern. Its posterior and posteroinferior walls are formed by the lamina terminalis, and the inferior wall is formed by the optic chiasm. The lateral walls are formed by the septal area and the medial surface of the posterior gyrus rectus. The anterior boundary is formed by the union of the pia mater of the lateral walls in front of the anterior communicating arteries. The cistern of the lamina terminalis contains the anterior cerebral arteries, the A1 segment and the proximal part of the A2 segment, the anterior communicating artery,

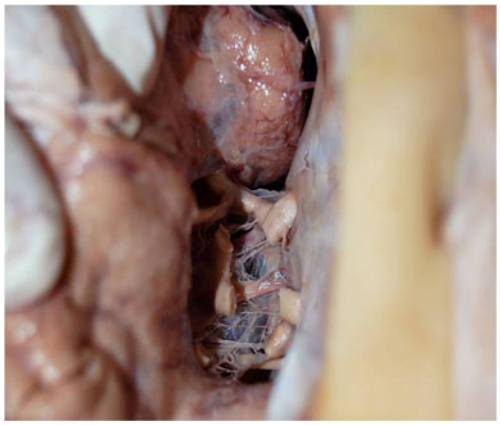

Fig. 10 Another view of Fig. 9 following transection of the optic nerves and noting the arachnoid mater around the pituitary stalk

Heubner's artery, the hypothalamic arteries, the origin of the fronto-orbital arteries, and the venous system of the lamina terminalis [143, 153].

The tem *carotid cistern* was introduced by Lewtas and Jefferson [68] in 1966, and was later subjected to criticism, representing no more than a part of the chiasmatic cistern [140]. According to some authors [140, 154], however, this term should be retained due to its large size and relative isolation from the chiasmatic cistern. Its roof is formed by the anterior perforated substance and the floor by the dura of the cavernous sinus. The anterior, medial, and posterior walls are formed by the optic chiasm and its lateral wall by the uncus and the anterior clinoid process. It contains the internal carotid artery, the origin of the anterior choroid artery, and the origin of the posterior communicating artery [140, 153].

The *olfactory cistern* covers the olfactory bulb and tract, and is situated in the most superficial part of the olfactory sulcus between the orbital gyrus laterally and the gyrus rectus. It is triangular in coronal section, and extends from the anterior olfactory tentorium anteriorly to the olfactory

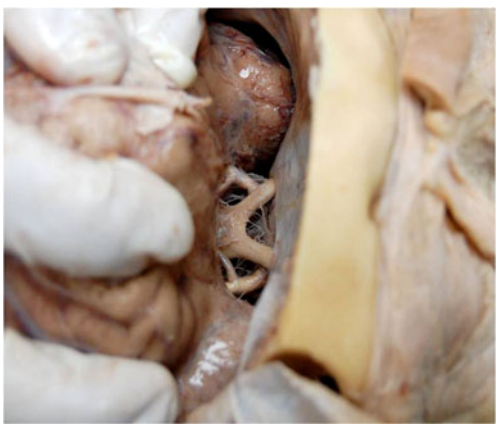

Fig. 9 Subfrontal approach in a cadaver noting the arachnoid of the optico-carotid region

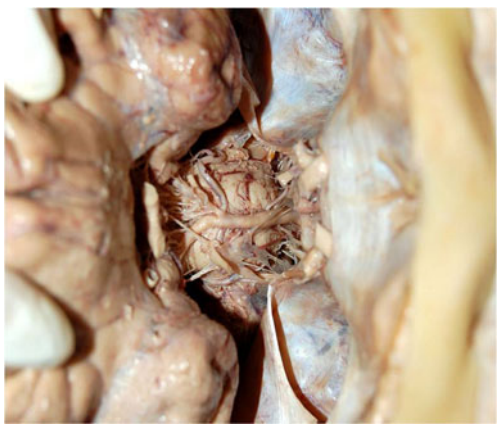

Fig. 11 Figure 10 with additional retraction noting the arachnid mater of the basilar cistern

trigone posteriorly. The floor is formed by the arachnoid mater bridging the orbital gyrus and gyrus rectus. The medial wall and medial part of the roof are formed by the pia mater covering the gyrus rectus, and the lateral wall and lateral part of the roof are formed by the pia covering the orbital gyrus [141]. The olfactory cistern contains the olfactory bulb and olfactory tract, part of the frontoorbital and olfactory arteries and their branches, and the frontobasal veins [153, 154].

The *Sylvian cistern* is considered transitional between the basal cisterns and the hemispheric subarachnoid spaces. It constitutes a potential space extending into the Sylvian fissure between the lower part of the frontal and parietal lobes, and the superior part of the temporal lobe. It has a T shape and is bounded by the insular cortex and the opercular cortex. It contains the middle cerebral artery and vein, the frontoorbital veins, and the collaterals to the vein of Rosenthal [12, 153, 154].

Lateral (parapeduncular) The paired *crural cisterns* continue forward from the interpeduncular cistern and follow along the inferior and lateral surface of the peduncles, between the peduncle and uncus. It contains the anterior choroidal artery, the medial posterior choroidal artery, and the basal vein of Rosenthal [54, 69, 153].

The *ambient cistern* is a twofold cistern surrounding the brainstem like a napkin ring. It issues posteriorly from the quadrigeminal cistern, turns round the brainstem, and communicates anteriorly with the pontine and crural cisterns. Each side has a lateral wing that extends from the anterosuperior part of the cistern over the thalamus and below the fornices, as far as the foramen of Monro. Laterally, it extends to the attachment of the choroid plexus. The two wings communicate with each other above the roof of the third ventricle. The ambient cistern is sometimes divided into a supratentorial and infratentorial compartment. The supratentorial compartment contains the basal vein and the posterior cerebral artery. The infratentorial compartment contains the superior cerebellar artery and the fourth cranial nerve [54, 69, 153].

Posterior (tentorial notch) The *quadrigeminal cistern* is located at the posterior part of the tentorial notch. It is bounded anteriorly by the dorsal mesencephalon, the quadrigeminal plate, and the pineal body, and posteriorly by the vermis. The roof is formed by the splenium and the floor by the colliculate bodies, the anterior medullary velum, and the lingual cerebelli. It is contiguous laterally with the ambient cistern and superiorly with the velum interpositum cistern. The quadrigeminal cistern contains the vein of Galen, the posterior pericallosal arteries, the third portion of the superior cerebellar arteries, perforating branches of the posterior cerebral and the superior cerebellar arteries, and the third portion of the posterior cerebral arteries [69, 153, 154].

The *velum interpositum cistern* (Fig. 12) extends from the habenular commissure to the foramen of Monro. The roof is formed by the splenium of the corpus callosum and the floor is formed by the roof of the third ventricle. Anterior wall converges below the fornix to a point at the foramen of Monro, and the posterior wall has no clear distinction from the quadrigeminal cistern. The velum interpositum cistern contains the medial posterior choroidal artery, the splenothalamic branches of the pericallosal arteries, and the internal cerebral veins [154].

Superior (callosal) The *callosal cistern* lies between the inferior border of the falx cerebri, the cerebral hemispheres, and the corpus callosum. Sometimes, it is divided into anterior and posterior portions separated by arachnoid fibers at the branching of the callosomarginal and pericallosal arteries, but with no distinct division. The callosal cistern follows the falx anteriorly to the crista galli and joins the lamina terminalis cistern near the rostrum of the corpus callosum. Then, the cistern becomes narrow close to the corpus callosum, and continues posteroinferiorly until it ends in the quadrigeminal cistern and the velum interpositum cistern near the splenium of the corpus callosum. The anterior division contains the pericallosal artery, the origins of the frontopolar and callosomarginal arteries, and small

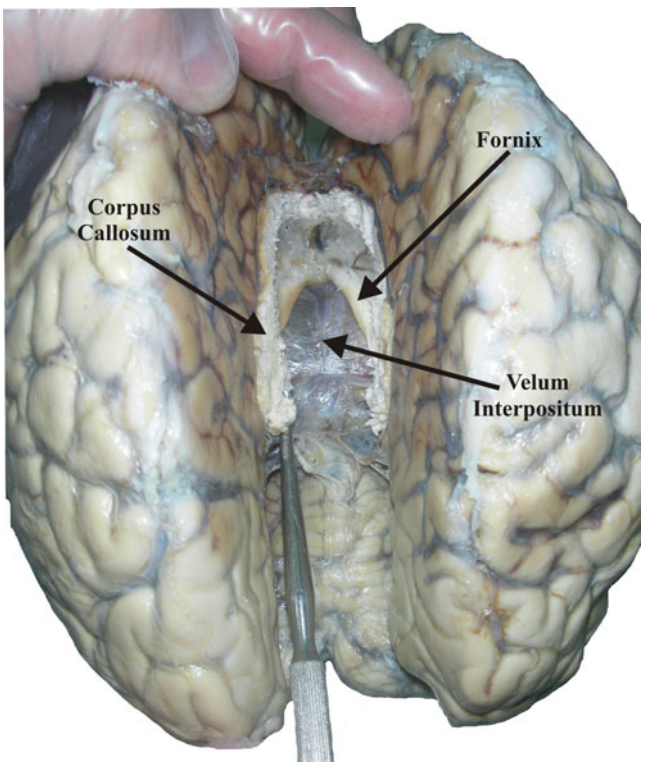

Fig. 12 Interhemispheric approach with transection of the corpus callosum illustrating the velum interpositum

anterior cerebral veins. The posterior division contains the pericallosal arteries and posterior pericallosal veins [154].

Infratentorial cistern

Anterior The *medullary cistern (or premedullary cistern)* is located in front of the medulla oblongata and is limited by the clivus anteriorly. It communicates with the cerebellomedullary cistern posteriorly, pontine cistern superiorly, and spinal subarachnoid space inferiorly. The medullary cistern contains the anterior spinal artery and the anterior medullary vein [69, 153, 154].

The *pontine cistern (or prepontine cistern)* lies between the anterior surface of the pons and the clivus, and is continued superiorly with the interpeduncular cistern, inferiorly with the medullary cistern and spinal subarachnoid space, and anteriorly with the chiasmatic cistern. On both sides of the pons, the pontine cistern communicates through a broad passage with the cerebellopontine cistern. It contains the basilar artery and origin of the anterior inferior cerebellar artery, the origin of the superior cerebellar arteries, the sixth cranial nerve, and the anterior and anteromedian pontine veins [69, 119, 153].

The *interpeduncular cistern* (or intercrural cistern) is a cone-shaped space that forms the confluence of the supratentorial and infratentorial subarachnoid space. It occupies the interpeduncular fossa and limited superiorly by the inferior surface of the diencephalon from the anterior edge of the mammillary bodies to the junction of the diencephalon and mesencephalon. The posterior wall is formed by the cerebral peduncles, the posterior perforated substance, and the ventral surface of the upper portion on the pons. The anterior and lateral walls are formed by the diencephalic and mesencephalic leaves of Liliequist's membrane separating the interpeduncular cistern from surrounding structures. The inferior surface is formed by the medial pontomesencephalic membrane and a pair of lateral pontomesencephalic membrane. Laterally, the cistern joins the ambient cistern inferiorly and is limited superiorly by the carotid and crural cisterns and the mesial temporal lobe. It contains the bifurcation of the basilar artery, peduncular segments of the posterior cerebral arteries, peduncular segments of the superior cerebellar arteries, perforating branches of the posterior cerebral arteries, one meningeal branch, artery to the third cranial nerve, posterior communicating arteries that connect with the midpoint of the peduncular segments of the posterior cerebral arteries, the basal vein of Rosenthal, the interpeduncular vein and posterior communicating vein, and the third cranial nerve [69, 73, 153, 154].

Lateral The *cerebellopontine cistern* is situated in the angle between the pons and the cerebellum. Anteriorly, it is limited by the posterior surface of the pyramid, posteriorly by the anterior surface of the cerebellum, and superiorly by the tentorium. It contains the fifth, seventh and eighth cranial nerves, the anterior inferior cerebellar artery, the lateral pontine veins, and the petrosal vein [69, 153].

The posterior infratentorial part of the ambient cistern is also considered in this group.

Posterior The *cerebellomedullary cistern* (cisterna magna) is the largest subarachnoid cistern that is located where the arachnoid bridges the interval between the medulla oblongata and the inferior surface of the cerebellum. It is limited laterally where the arachnoid becomes adherent to the surface of the cerebellum, and superiorly below the torcular Herophili where the arachnoid is adherent to the vermis. It merges above the vermis into the subarachnoid space. Anteriorly, it is bounded by the vermis above and the medulla below. The cistern continues forwards into the vallecula, situated between the tonsils, into which the foramen of Magendie also opens. Around the tonsils the cerebellomedullary cistern also communicates anterosuperiorly with the pontine cistern. It contains the vertebral artery and the origin of the posterior inferior cerebellar artery, the ninth, tenth, 11th, and 12th cranial nerves, the lateral medullary and postolivary veins, and the choroid plexus [54, 69, 153].

The *superior cerebellar cistern* covers the superior vermis and blends laterally with the subarachnoid space over the cerebellar hemispheres. Anteriorly, it meets the tentorium and the quadrigeminal and ambient cisterns. It contains the terminal branches of the superior cerebellar arteries and the superior cerebellar and vermian veins [154].

Superior This group includes the hemispheric and the vermian cisterns, but they received much less attention and descriptions in literature.

Lu and Zhu [74, 75] explored the microanatomical features of the cranial arachnoid membranes and, based on their study, described 27 arachnoid membranes and 21 subarachnoid cisterns. They classified these arachnoid membranes into three groups: convex, basal, and trabecular membranes. The convex and basal arachnoid membranes merge together to form an arachnoid sac that surrounds the brain. The trabecular arachnoid bridges the subarachnoid space between the arachnoid and pia mater. According to them, these membranes are crucial as limiting the entrance, extent, and termination of the cisterns. It is also important to the adequate and reasonable exposure of the lesion during operations, and also to the understanding of the growth of some lesions.

The convex arachnoid membranes include the*:* Dorsal cerebellomedullary membrane, Cerebral hemisphere membrane, Cerebellar hemisphere membrane. *The basal arachnoid membranes include the:* Olfactory membrane, Chiasmatic

membrane, Sylvian membrane, Ventral pontine membrane, Cerebellopontine membrane, Ventral cerebellomedullary membrane. *The trabecular arachnoid membranes include the:* medial carotid membrane, lateral carotid membrane, posterior communicating membrane, anterior choroidal membrane, anterior cerebral membrane, Liliequist's membrane, basilar artery bifurcation membrane, posterior perforated membrane, lateral oculomotor membrane, medial pontomesencephalic membrane, lateral pontomesencephalic membrane, basilar membrane, medial pontomedullary membrane, lateral pontomedullary membrane, superior cerebellar membrane, cerebellar precentral membrane, posterior–inferior cerebellar artery membrane, dorsal vermian membrane [74, 75].

Arachnoid trabeculae

The subarachnoid space and basilar cisterns are traversed by networks of fine, continuous, sheet-like trabeculae that divide the space into compartments, facilitating a more directional CSF flow. They extend from the deep layers of the arachnoid mater to the pia mater. Moreover, it encloses the small blood vessels and adheres to the surface of larger blood vessels in the subarachnoid space. At the sites of attachment, the trabeculae cells become continuous with the cells on the surface of the pia or the blood vessels. These trabeculae have collagen core surrounded by leptomeninges joined by desmosomes and gap junctions [1]. According to Yaşargil [154], these trabeculae also adhere to the nerves within the space. Neural elements including nerve endings in the arachnoid and arachnoid trabeculae, mainly in the cisterna magna, have been described. These nerve endings may convey information about CSF pressure and might play a role in cerebral vasospasm. Moreover, fine capillaries have been found in the trabeculae of rats [154]. In an experimental study on rats, the core of the trabeculae has been found to be continuous with the subpial space [63].

Liliequist's membrane is the most important part the trabecular arachnoid and it presents an important anatomic landmark in the approach to the sellar and parasellar areas. It was first described by Key and Retzius [59], in 1875, and was named after Liliequist [69, 70], who described it in his pneumoencephalographic studies of the subarachnoid space and cisterns, beginning in 1956. Following his description, this membrane received more attention, and further descriptions full of controversy followed. Many authors, including Liliequist himself [69], Yaşargil [154], Brasil [15], and Vinas [134], described this membrane as a single-layered membrane. According to the findings of Froelich et al. [32], this membrane is a complex and variable arachnoidal structure that, when present, was either a single membrane or two-layered membrane. Matsuno [81] and Rhoton [99] mentioned two separate parts: the mesencephalic and diencephalic leaves. Lu and Zhu [72] described three leaves: mesencephalic, diencephalic, and a pair of diencephalic–mesencephalic leaves. Wang et al. [142] found that this membrane consists of three layers: mesencephalic, diencephalic, and a pair of hypothalamic membranes. Various descriptions about this membrane, regarding its morphology, orientation, attachment, classification, and relationship with surrounding structures, can be found in each of these studies.

Physiology of the cerebrospinal fluid

CSF production

In 1757 and 1825, von Haller [137] and Magendie [77], respectively, proposed that the CSF comes from the pia mater (and probably also the arachnoid). Faivre [27] in 1853 related the production and absorption to the arachnoid villi. Later on, in 1855, microscopic study of the choroid plexus by von Luschka [139] revealed its role in the production of the CSF. This finding was later supported by Pettit and Girard in 1902 and Meek in 1907. In 1914, Dandy and Blackfan [24], Frazier and Peet [31], and Cushing, and later, Dandy's experiment in 1919 [25], lead to a wide believes of the choroid plexus as the main source of the production of the CSF. Dandy's theory was supported by experiments of Welch [148] and Ames et al. [2–4]. Their findings indicated that most or all the CSF production is made by the choroid plexus. However, the techniques they used were questionable and raised controversy. Hassin et al. [50]e repeated Dandy's experiment, and they concluded that this production was mainly from the brain parenchyma and not from the choroid plexus. However, Hassin's theory was not accepted by some authors, including Weed [146]. Contribution of the brain parenchyma through the perivascular spaces into the subarachnoid space has been proposed and accepted in the literature [144]. More directed experiments estimated that 30 % of CSF production can be attributed to the ventricular ependyma, and 40 % is produced in the subarachnoid space. More evidence of a presence of extrachoroidal sites of CSF production comes from the fact the choroid plexectomy failed to treat non-communicating hydrocephalus. According to later experiments by Milhorat et al. [82, 83], the extrachoroidal production of CSF accounts for almost 60 % of the normal [84, 146].

This leaves a current idea about the mutual role of the choroid plexus (of the lateral, third, and fourth ventricles), ependyma, and brain parenchyma in the production of CSF, regardless of the exact proportion of each.

In 1934, using pig embryos as sources of blood and CSF, Flexner analyzed the chemical components of both, and found disparities in distribution, with the CSF containing higher concentrations of magnesium and chloride ions and lower concentrations of glucose, proteins, amino acids, uric

acid, calcium, phosphate, and potassium ions. His findings contradict earlier believes that the CSF resembles an ultrafiltrate of plasma. With later investigations, the CSF has been defined as a true secretion that needs energy in the form of ATP to be produced; this energy is used for active transportation, mainly by the ATPases and other transport enzymes in the cells of the choroid plexus, with the water passively equilibrates between both compartments [8, 84, 146].

CSF flow

Depending on the site of production, the CSF flows from the lateral ventricles through the interventricular foramina (of Monro) into the third ventricle, from which it passes to the fourth ventricle through the cerebral aqueduct (of Sylvius). From the fourth ventricle, the CSF enters the subarachnoid space and basal cisterns through the paired lateral foramina (of Luschka) to the cerebellopontine angle and prepontine cistern, and by the median aperture (of Magendie) to the cisterna magna. In the cisterna magna the CSF has three routes: superiorly to enter the hemispheric subarachnoid space, inferiorly to enter the spinal subarachnoid space, and anteriorly to enter the cerebellopontine, prepontine cisterns, and premedullary cisterns. To get into the hemispheric subarachnoid space, CSF leaves the basilar cistern through two routes: ventrally through the interpeduncular and chiasmatic cisterns to enter the subarachnoid space of the lateral and anterior aspect of the hemispheres, and dorsomedially through the ambient and quadrigeminal cisterns to enter the subarachnoid space of the medial and posterior aspects of the hemispheres [8, 84, 146].

The movement of the CSF along its circulatory route is facilitated by: the continuous production of CSF, ciliary action of the ventricular ependyma, the pulsatile CSF movement, and the pressure gradient across the arachnoid villi, where the pressure of cranial CSF is estimated 150 mm saline, and 80 mm saline in the sagittal sinus. This difference gives the suction pump characteristic of the dural sinuses [84]. The pulsatile motion of the CSF is related to the interaction of brain movement, arterial blood flow, and cardiac cycle. The pattern of flow is directly related to different phases of the cardiac cycle, although the cerebral circulation and CSF pressure change during the cardiac cycle is relatively small. During early and mid systole, blood flow within the brain tissue compresses the ventricles and leads to choroid plexus expansion and displacement. This, in turn, propels the CSF in a caudal direction, away from the site of production and towards the spinal subarachnoid space. This caudal flow occurs first in the spinal canal or at the base of the brain due to expansion of the larger arteries, and then, as the blood fills the arterioles and capillaries in the brain tissue and choroid plexus, the caudal flow occurs in the ventricles. During late systole and diastole, the pressure is higher caudally, which propels the CSF cranially within the ventricles and the subarachnoid space. This allows the CSF to be mixed in the ventricles and spread in all direction in the subarachnoid space [9, 55, 112, 122]. So, any changes in the blood flow, the blood pressure, the size of the choroid plexus, and the state of the vessel walls, in addition to breathing cycle, intracranial pressure and the resistance to outflow created by the arachnoid villi, will affect this pulsatile movement [8].

CSF absorption

Arachnoid villi and arachnoid granulations

The presence of the arachnoid villi and Pacchionian bodies (arachnoid granulations) (Figs. 1, 2, 3, 4 and 5) have been recognized and mentioned since ancient times, and were known as glandulae. However, it was illustrated for the first time by Vesalius [133] in 1543, as he found their imprints on the inner aspect of the skull, mainly at the junction of the sagittal and coronal sutures. In 1704, Pacchioni [91] described the large arachnoid granulation, later named after him, which he thought as having a lymphatic function and to irrigating the meninges. He is also considered the first to describe its relation to the sagittal sinus. Fantoni [28], in 1738, ascribed its function in the absorption of the intracranial humor, and the same function was also described by Faivre [27] in 1853. Rokitansky [105] thought that these structures originate as a fibrous thickening of the arachnoid, while Cruveilhier [22] believed that it arises from the subarachnoid tissue. The major contribution was made by Key and Retzius [59], who described arachnoid villi and Pacchionian granulations as an extension of the arachnoid membrane and subarachnoid tissue into the dural sinuses or lacunae, and related its function to the absorption of the CSF. They also described the role of osmotic pressure in the filtration process. Their findings were similar to later findings of Trolard [126] and von Luschka [139], and became widely accepted in literature. von Luschka also described the Pacchionian bodies as hypertrophied arachnoid granulations present in all brains. In 1914, Weed [144], sharing Rokitansky's idea, believed that Pacchionian bodies are pathological structures, as they do not present at young ages and in lower species. However, this finding was explained later on: the Pacchionian bodies occur when the subject obtains the upright position, which creates a negative pressure in the dural sinuses, and thus a suction force that cause the arachnoid granulation to enlarge and bulge into the lumen. Regarding the filtration, Cushing, in his 1901 Mutter lecture, mentioned that one-way valves, in the form of arachnoidal tubes, are present in the arachnoid villi to ensure the one way movement of CSF. His theory was later confirmed by experimental study of Welch and Friedman [147].

However, Weed convinced him that CSF absorption occurs by simple filtration controlled by the difference in hydrostatic and colloid osmotic pressure between the CSF in the subarachnoid space and villi and the surrounding blood in the sinuses. However, Davson et al. [26] ascribed it only to the difference of hydrostatic pressures [7, 36, 64, 95].

Arachnoid villi are microscopic finger-like projections from the outer layer of the arachnoid mater that depress but not completely penetrate the wall of the dural venous sinuses and lateral lacunae. These structures can be first observed during late fetal life, as immature and then more complex arachnoid protrusions. During that period they present with large numbers it the superior sagittal sinus, mainly in the middle third. These are also present in the transverse sinus, confluence of sinuses, and cavernous sinus. As the child grows, these structures not only increase in number, but also become larger and more complex until it can be seen grossly at 18 months old when they are termed arachnoid granulations or Pacchionian bodies. Large granulation may leave impression that can be seen on the inner aspect of the skull, and sometimes confused with certain pathologies. Total and partial agenesis of the arachnoid granulation has been reported in the literature [42]. These may also become calcified with age.

Le Gros Clark [64] examined the brains of 18-month to 4-year-old cadavers, and found that most of the arachnoid granulation were presented in the lateral lacunae along the superior sagittal sinus, and were frequently present in the middle third of the floor of the superior sagittal sinus. He believed that lateral lacunae are totally separated from the superior sagittal sinus. Also, he stated that any of these granulations, irrespective of their size, are attached to the undersurface of the dura mater, and if this attachment is removed, small aperture can be noticed at the site of the attachment. This indicates that with adequate pressure, blood can be squeezed through it. However, other authors did not agree with him, and they proclaimed wide range of variations in the arachnoid granulation distribution and characters. For instance, Wolpow and Schaumbur [152] showed that there are, in man, two types of granulations: one that is totally invested with dura mater and other that, in addition, is fused with the dura mater. Jayatilaka [56] also mentioned two major types: one protruding into the dural sinuses, and the other in the subdural space. Shanthaveerappa and Bourne [115] demonstrated almost eight types of the arachnoid granulations around the human optic nerve [152]. Grzybowski et al. [41] examined 35 brains ranging in age from 20 to 85 years (mean 53.1) and found that most of the granulations project into the lateral lacunae, and rarely into the superior sagittal sinus itself, a finding that contradict that of le Gros Clark. Moreover, he found that lateral lacunae have direct communication with the venous sinus, which is similar to the finding of Fox et al. [30].

According to le Gros Clark [64], the arachnoid granulations present, in decreasing frequency, in the superior sagittal sinus, transverse sinus, cavernous sinus, superior petrosal sinus, and straight sinus. It can also be found in the confluence of sinuses, sigmoid sinuses, sphenoparietal sinus, and vein of Galen [29, 40, 119].

In 1996, Roche and Warner [102], reviewed the radiological examination and follow-up of 32 patients (17 men and 15 women), 20 to 75 years old, with 41 arachnoid granulations. One patient had three granulations, seven patients had two, and the rest had one. 21 of these granulations were located in the middle third of the transverse sinus, 14 were located else were in the transverse sinus, two in the confluence of sinuses, two in the superior portion of the sigmoid sinus, and one in the middle of sigmoid sinus. They were oval or round, with a diameter ranging from 3 to 14 mm (average 7 mm).

In 2007, based on radiological study, Richard Farb [29] described the presence of intraluminal structures in the dural sinuses, these including the arachnoid granulation. These granulation were numerous and variable in size. Small arachnoid granulations (1–3 mm) were seen clustered in the middle third of the superior sagittal sinus, and sparsely scattered elsewhere in this sinus. Large granulations (4 mm or more) were found in 36 % of the patients. They were located, with decreasing frequency, in the transverse sinuses, vein of Galen, superior sagittal sinus, straight sinus, and the confluence of sinuses. In a study by Haybaeck et al. [51], in 2008, grossly visible giant arachnoid granulations, up to 2.5 cm, were found in 24 cases out of 651 study sample. These granulations occurred exclusively in the transverse sinuses and in patients older than 45 years old, and mainly older than 65 years.

Aberrant locations of the arachnoid granulations include the anterior and middle cranial fossae, and less frequently, the posterior temporal bone. Granulations of these locations possess high CSF pressure due to lack of proper communication with the venous sinuses. This pressure may cause bone erosion, and, depending on its site, result in otorrhea or rhinorrhea [113, 131].

In their experimental study on 33 cadavers and 40 patients in 2011, Chen et al. [18] focused on the arachnoid granulations of the middle cranial fossa. He classified these granulations into venous sinus protuberances and non-venous sinus protuberances. The venous sinus protuberances were found, in decreasing frequency, in the middle meningeal sinus, the sphenoparietal sinus, and the cavernous sinus. The non-venous protuberances were located in the venous lacunae adjacent to the middle meningeal sinus and at the dural venous plexus of the lateral foramen rotundum. These granulations were spherical or finger-like in shape, with diameters ranging from 0.6 to 9.5 mm. Some of these protuberances had smooth surfaces, while others were more irregular.

Microscopic examination of the arachnoid granulation, in vertical section, reveals that it consists of three main parts:

neck, core, and the apex. At the base of the arachnoid granulation, a thin neck is formed by an extension of the thin arachnoid mater through an aperture of the thick dura mater surrounding the venous sinuses. Then, the arachnoid granulation expands to form a bulbous core of collagenous trabeculae and interwoven channels, giving the core its honeycomb shape. At the apical region, these channels extend through the cap of the arachnoid mater and become continuous with the subendothelial space, whereas other parts of the core and its cap are separated from the endothelial layer by the fibrous dura. Horizontal sections, on the other hand, shows an opposition between the arachnoid cells and the endothelial layer in the apical region, with slit-shaped or rounded channels extending through them [119, 129].

The lymphatic pathway

Since the early description of the CSF pathways by Key and Retzius [59], they noticed that injected colored material into the CSF extends along the cranial nerves and gets into the lymphatic system. Later experiments by Weed [144] revealed the accumulation of CSF markers within the cranial nerve sheaths, nasal submucosa, paranasal sinuses, orbital sclera, lumen of lymphatic vessels, and cervical lymph nodes. In a study by Winkelman and Fay [151] in 1930, they found that three out of 14 cadavers with total absence of arachnoid villi had hydrocephalus and no cases of hydrocephalus in 28 cadavers with arachnoid villi hypoplasia. A similar study by Gutierrez et al. [42] revealed that no hydrocephalus was found in one child with total agenesis in the arachnoid granulation and villi. More recent experiments on rats and humans showed the accumulation of CSF tracers in the cervical lymph nodes (mainly deep cervical) and spleen [45, 149]. Others estimated that 14–47 % of CSF drains into the deep cervical lymph nodes [23]. However, these studies did not reveal the exact pathway, taking into consideration that no lymphatics are present in the brain parenchyma [60]. Presence of other sites for absorption of the CSF was also suggested by the fact that no or very few arachnoid granulations and villi present in the prenatal period [64], and failure of some attempts to produce hydrocephalus by occlusion of intracranial venous sinuses, with success of those by occlusion of extracranial veins [58].

Some suggestions stated that CSF may be transported through the adventitia of cerebral blood vessels with final absorption into the cervical lymphatics in the neck. However, the most accepted pattern of absorption is along the prolongations of the subarachnoid space associated with several nerves, mainly along the olfactory nerves through the cribriform plate. Once in the nasal submucosa, the CSF is taken by extracranial lymphatic vessels. Moreover, this pathway has importance in understanding the immune pathway to the central nervous system [58, 60, 92].

As a conclusion, evidence suggests that before birth the CSF absorption is mainly made by the extracranial lymphatics. After birth, the arachnoid villi and granulations develop and start to take over. During early adulthood, both contribute equally in the absorption, with the arachnoid granulations predominating with age. The degree of participation is not static, as any of these two routes can compensate with decreased function of the other.

Histology

In its adult form, the arachnoid mater consists of two main layers, and outer and inner layers. The outer mesothelial layer (or arachnoid barrier cell layer) consists of two to three [43] or five to six [1] layers of closely packed, flattened cells. These cells are separated by a rather narrow but regular gap (or extracellular space) that is periodically obliterated by tight junctions. At these junctions, the outer leaflets of the opposed cell membranes touched to form a dense intermediate lamina, giving this layer its barrier function. Some of these junctions, however, are not completely tight, and desmosomes and gap junctions are also present. The intercellular gap contains no extracellular collagen, elastic fibers or microfibril [87, 130]. The cytoplasm of these cells is more electron lucent than the overlying dural cells, and underlying layers of the arachnoid cells. It is also characterized by the presence of a full range of organelles, including a prominent Golgi apparatus and numerous mitochondria, vesicles, lysosomes, varying numbers of intermediate filaments oriented at random, and large round to oval-shaped euchromatic nuclei with peripherally distributed heterochromatin [43, 130]. On its inner surface, the outer layer is lined by a continuous or relatively continuous basement membrane. At this level, the cells are linked by hemidesmosomes [43, 87].

The inner arachnoid reticular cell layer is comprised of more loosely arranged and less flattened than those of the outer layer [87]. It contains denser cytoplasm, intermediate filaments, numerous small mitochondria with dense matrices and elongated nuclei [130]. These cells, and their interwoven processes, are linked by gap junctions and desmosomes, which also link cells of this layer with the cells of the outer arachnoid layer [87]. The extracellular space contains small cisterns or lacunae containing collagen fibers organized into randomly oriented bundles and intermingled with groups of microfibrils [87, 130]. The inner aspect of this layer is lined by elongated cells with dense nuclei, a few mitochondria, lysosomes and long pseudopod-like cytoplasmic extensions [130]. This inner layer is sometimes considered as a third layer of the arachnoid mater [39].

Embryology

Although Tiedemann [124] is considered the first to observe the development of the meninges in 1816, he only focused on the dura mater. His, and other early investigations, include Bischoff [13] in 1842, found that the dura and the leptomeninges originate from the neural tube ectoderm. Schwann [114], in 1839, proclaimed that the histological character of the dura indicates a different origin. His [53] in 1865, Kölliker [62] in 1884, Salvi [107] in 1898, Sterzi [121] in 1901, Claremont [20] in 1902, and others, pointed to a mesenchymal origin of the meninges. According to them, the meninges arise from a mesenchymal tissue surrounding the neural tube. This tissue was named "meninx primitiva" by Salvi [107]. The meninx primivita (or primitive meninx) can be subdivided into two layers: the endomeninx (or secondary meninx), which contributes to the formation of the leptomeninx, and the ectomeninx which contributes to the formation of the dura. This division is brought on by two cellular condensations proposed by His [53]. In birds and carnivores, the secondary meninx consists of three layers with distinct subdural space, the middle of which gives similar structure to the human arachnoid [6, 47, 88].

Lillie [71], in 1908, stated that in early embryonic stages, it is hard to define a pure mesenchymal tissue. Instead, it has been found that the meninx primivita actually consists of cells of different origins, including mesodermal and ectodermal cells (the latter being mainly of neural crest cells). According to Remak, the dura mater arises from the mesenchymal cells surrounding the neural tube, while the leptomeninx arises from the neural tube itself. A similar theory was proposed by Reichert, but instead, he stated that the arachnoid arises partly from the neural tube and partly from the mesenchymal tissue. Based on experimental study on Amblystoma, Harvey and Burr [46, 47] stated that the leptomeninges are derived from neural crest cells. They confirmed these results by observations on chick and pig embryos [48, 49]. A neuroectodermal origin of the leptomeninges was also proposed by Sayad and Harvey [109] in 1923, Lear and Harvey [65] in 1924, Pease and Schultz [94] in 1958, Millen and Woollam [85] in 1961, and other. LeLièvre's [67] experiment on the origin of the meninges in quail and chick embryos, revealed that in these birds, the leptomeninges (and perhaps also the pacchymeninx) of the forebrain and midbrain receive contribution from the neural crest, while those of the hindbrain and spinal cord are derived from mesoderm. In amphibians, however, the neural crest contributes to the development of all the meninges, with more contribution of the mesoderm to the leptomeninges [6, 46, 88].

In 1986, O'Rahilly and Muller [88] followed the development of the meninges in 61 human embryos. He found that except in the area of direct contact of the future spinal cord with the notochord and the roof of future brain, the neural tube gets surrounded by mesenchymal tissue. This tissue contains different types of cells including mesodermal and neural crest cells. This perimedullary tissue (formerly termed meninx primivita) contains two layers: an inner layer contributes to the leptomeninges and the outer layer contributes to the dura. Two condensations appear in the outer layer: one on the outer surface and the other on its inner surface. The outer condensation is thicker and contributes to the skeletogenous layer of the skull. The inner condensation contributes to the development of the dural limiting layer. On the other hand, the inner layer of the mesenchyme contains blood vessels, which play a role in the later development of the leptomeningeal meshwork or spaces that form the origin of the future subarachnoid space. However, according to Andres [5], the dural limiting layer forms the precursor for the development of the arachnoid mater, while the findings of Schachenmayr and Friede [110, 111] indicated that it contributes to the formation of both, the dura and arachnoid.

Regarding the subarachnoid space, Osaka et al. [90] observed a "primitive subarachnoid space" ventral to the midbrain and hind brain. This develops and expands as a meshwork of the intercellular space in the meninx primivita. This expansion is brought on partly by diffusion from the thin-walled blood vessel in this area, and, according to Weed [144, 145], by CSF outpouring from two areas in the roof of the fourth ventricle. These areas are: area membranacea superior and area membranacea inferior. However, the latter is not widely accepted in literature [88].

Arachnoid cysts

Pathology of the arachnoid includes such well known entities as arachnoid scarring and subarachnoid hemorrhage (Fig. 13). In addition, arachnoid cysts are frequently encountered on imaging (Figs. 14 and 15). These constitute 1 % of non-traumatic intracranial space-occupying lesions [38, 104]. First described by Bright [16] in 1831, arachnoid cysts may be developmental (majority) or familial. They appear mainly in the first two decades of life with a majority occurring in the neonatal period, and affect males in more than two thirds of the cases [38, 96]. They mostly occur as unilateral lesions, but bilateral symmetrical lesions have also been reported in the literature [44]. Neuroimaging studies of arachnoid cysts reveal well circumscribed, hypodense, non-enhancing mass lesions associated with the subarachnoid cisterns [52]. They contain clear, colorless fluid that resembles normal CSF [98]. In 1981, Rengachary and Watanabe [98] reported 208 cases of arachnoid cysts. They found that 103 (49 %) of the cysts were located in the Sylvian fissure, 22 (11 %) in the cerebellopontine angle, 21 (10 %) in the

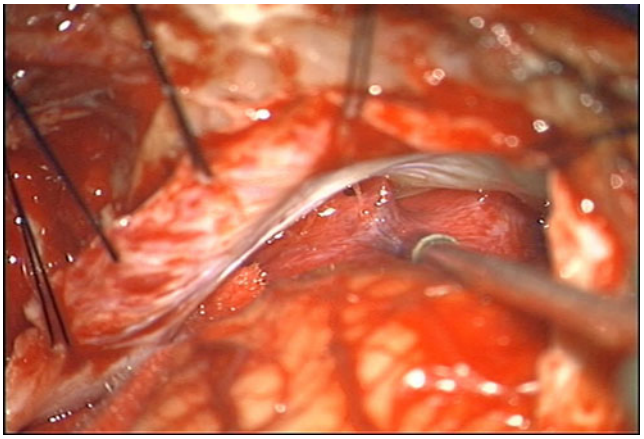

Fig. 13 Subarachnoid blood seen at operation

supracollicular area, 19 (9 %) in the vermian area, 18 (9 %) in the sellar and suprasellar area, ten (5 %) in the interhemispheric fissure, nine (4 %) over the cerebral convexity, and six (3 %) in the clival region. Seven of these eight sites are related to the subarachnoid spaces. Many of the described cases of the cerebral convexity actually arise from the Sylvian fissure or interhemispheric fissure and extend into the cerebral convexity. Heier et al. [52] reported 29 cases of arachnoid cysts. Their findings, regarding the distribution were similar to Rengachary and Watanabe with only one cyst (3.5 %) being found in the choroidal fissure.

Bilateral temporal arachnoid cysts have been reported in association with certain diseases, including glutaric aciduria type 1 [76, 80], tuberous sclerosis [123], and neurofibromatosis [79].

Clinical manifestations of arachnoid cysts depend on their location, and are caused by neural compression due to expansion. Expansion of arachnoid cysts has been described in many theories, including: The ball valve hypothesis, which states that

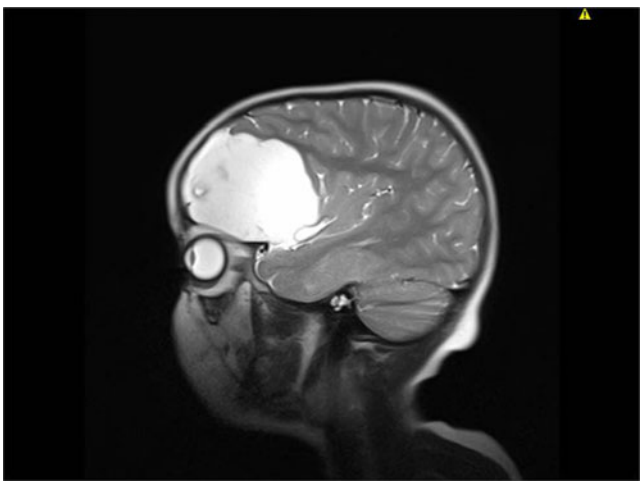

Fig. 14 Sagittal T2-weighted MRI illustrating a moderate sized arachnoid cyst

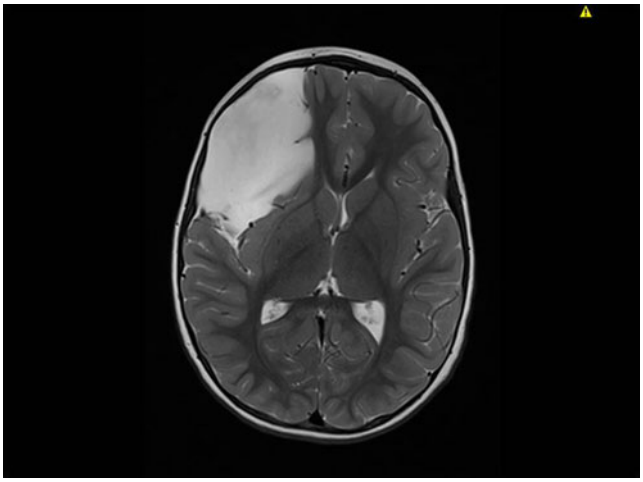

Fig. 15 Axial image of the patient seen in Fig. 14

a one-way valve between the arachnoid cysts and subarachnoid space leads to its expansion; an osmotic gradient between cystic content and CSF, which is opposed by the similarity in composition between the cysts contents and the CSF; and fluid production by the cells lining the walls of the cysts. The first and last theories are opposed by the fact the some arachnoid cysts remain static in size, regress, or totally disappear [38].

In their experiment, Rengachary and Watanabe [98] described the microscopic features of the arachnoid cysts. The subarachnoid space becomes narrower and eventually obliterates when traced from normal area towards the arachnoid cyst. At the margin of the cyst, the arachnoid membrane splits and encloses the cyst. The outer wall of the cysts along with the superficial layers of the dome contains dense connective tissue with compacted collagen fibers. The deep layers with the inner wall contain more loosely arranged collagen fibers. Moreover, the dense connective tissue of the dome is covered by subdural arachnoid membrane. The outer layer is formed by dark, flattened cells that resemble the arachnoid membrane. The inner layer is formed by lighter cells with round nuclei and abundant cytoplasm that are frequently seen lining the subarachnoid space as well. It also contains some hematogenous cells and rarely, blood vessels. Irregularly branching hyperplastic arachnoid cells can be found within the wall and surrounding the lumen of the cyst. The cyst cavity is clear and contains no proteinaceous or other material, and is devoid of arachnoid trabeculae [98]. These findings are similar to later descriptions of Miyagami and Tsubokawa [86] and Schachenmayr and Friede [110], which all support the idea that arachnoid cysts are intraarachnoid in location and appear to be formed by splitting or duplication of the arachnoid membrane [38].

In Bright's [16] early descriptions, he attributed the pathogenesis of the arachnoid cysts to anomalous splitting of the arachnoid membrane, a theory that resembles the later conclusions of Starkman et al. [120] in 1958. The latter

concluded that during the development of subarachnoid space and cisterns, small aberrations in the CSF pulsation and flow may result in sequestration of an enclosed chamber of diverticulum in the arachnoid membrane. Rengachary and Watanabe [98] noticed that the arachnoid cysts are almost exclusively associated with the subarachnoid cistern. The most involved cisterns are: the cistern of the Sylvian fissure, the quadrigeminal cistern, the cerebellopontine cistern, the cerebellomedullary cistern, the prepontine and interpeduncular cisterns, and the chiasmatic cistern. According to these authors, these cysts are a result of anomalous development of the subarachnoid cisterns secondary to errors in splitting of the arachnoid membrane. They also agree that at early stages, the arachnoid cysts communicate, indicating that they freely communicate with the subarachnoid space. At this stage, they are called arachnoid diverticulum or arachnoid hernia. At later stages, the cysts become separated and non-communicating with the subarachnoid space, at which stage they are called arachnoid cysts [98]. Robinson [101] in 1964 proposed the "temporal lobe agenesis" theory, which suggested that deference in hemispheric volumes secondary to agenesis leads to CSF collection and arachnoid cysts development. His theory was later rejected by Shaw [117]. However, Robinson withdrew this hypothesis later in 1971 [100] and agreed on the earlier theory of Starkman et al. [19, 104, 120]. Choi and Kim [19], in 1998, reported that in some cases, head trauma in infancy may be the pathogenesis of arachnoid cysts. Some traumatic arachnoid cysts had a latent period from head trauma to initial clinical manifestation ranging from 10 months to 6.2 years (mean was 2.2 years). Other similar cases were reported by the same authors in 2010 [61].

Based on their findings on CT scan and CT cisternography examinations of cases with arachnoid cysts, Galassi et al. [33–35] have classified the arachnoid cysts of the middle cranial fossa into three types, namely type I, type II, and type III. The first type, the mildest type, comprises a small, spindle-shaped lesion. It is limited to the anterior temporal fossa, and compresses the anterior temporal pole posteriorly, but with no effect on the ventricles or the midline structures. This type shows free communication with the subarachnoid space and basal cisterns. The second type, classical type, comprises a medium-sized, roughly triangular or quadrangular lesion. It occupies the anterior and middle parts of the temporal fossa, which renders a shortened temporal lobe. The lesion extends into the sylvian fissure, which is thus widely opened with the insula exposed. Communication with the subarachnoid space and cisterns is present but appears to be less than the first type. The third type, the most severe type, is large, round or oval-shaped lesion. It occupies almost all the temporal fossa and a large area of the cerebral hemisphere. Therefore, the temporal lobe is atrophied, with severe compression of the frontal and parietal lobes. The ventricle and midline structures are also affected. In contrast to the first two types, the third type has no communication with the subarachnoid space and cisterns.

These different types results in different clinical pictures, depending on the degree of compression of the brain tissue. Although important in determining the management plan, these different types might be a result of different developmental stages of the arachnoid cysts, as mentioned earlier by Rengachary and Watanabe [33–35, 98].

Conclusions

Knowledge on the arachnoid mater and CSF dynamics has evolved over time and is of great significance to the neurosurgeon. The subarachnoid space and subarachnoid cisterns comprises a natural plane during brain dissection. Arachnoid cysts are encountered frequently in clinical practice and the generally benign nature of this entity is emphasized.

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