Arachnoid membranes in the posterior half of the incisural space: an inverted Liliequist membrane–like arachnoid complex

Laboratory investigation

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Object. The aim of this study was to describe the similarity of configuration between the arachnoid complex in the posterior half of the incisural space and the Liliequist membrane.

Methods. Microsurgical dissection and anatomical observation were performed in 20 formalin-fixed adult ca-"'

The incisural space refers to an area between the upper brainstem and the tentorial edge, which can be divided into the anterior, lateral, and posterior incisural spaces.10 The neural, vascular, and cisternal relationships in the posterior tentorial space are extremely complex and have long been of interest to neurosurgeons. On the subject of the arachnoid membranes at the level of the tentorial incisura, only a limited number of studies have focused on the relevant arachnoid membranes in the posterior tentorial space and their relationships with the vascular structures in the posterior half of the incisural space were examined.

Results. The posterior perimesencephalic membrane and the cerebellar precentral membrane have a common origin at the tentorial edge and form an arachnoid complex strikingly resembling an inverted Liliequist membrane. Asymmetry between sides is not uncommon. If the cerebellar precentral membrane is hypoplastic on one side or both, the well-developed quadrigeminal membrane plays a prominent part in partitioning the subarachnoid space in the posterior half of the incisural space.

Conclusions. The arachnoid complex in the posterior half of the incisural space can be regarded as an inverted Liliequist membrane. This concept can help neurosurgeons to gain better understanding of the surgical anatomy at the level of the tentorial incisura.

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Key Words • arachnoid membrane • subarachnoid space • tentorial incisura • pineal region • Liliequist membrane • anatomy

Abbreviations used in this paper: AEPR = arachnoid envelope over the pineal region; APM = anterior perimesencephalic membrane; CPM = cerebellar precentral membrane; PCA = posterior cerebral artery; PPM = posterior perimesencephalic membrane; QM = quadrigeminal membrane; SCA = superior cerebellar artery.
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Methods

In 20 formalin-fixed adult cadaver heads used for anatomical dissection, the origin, distribution, and configuration of the arachnoid membranes and their relationships with the vascular structures in the posterior half of the incisural space were investigated. A surgical microscope (model M651; Leica Co.) was used for microsurgical dissection, with a digital video camera (model SCC-101BP, Samsung Co.) and a second camera (model EOS 600D, Canon Co.) attached for photographic documentation of the relevant structures.

Results

In the posterior half of the incisural space, the arachnoid envelope over the pineal region (AEPR),8 its secondary arachnoid envelope encasing the tributaries of the vein of Galen, and the tentorial edge serve as a framework to which the inner arachnoid membranes attach. There are the 2 main arachnoid membranes in the posterior half of the incisural space, forming an arachnoid complex that resembles the Liliequist membrane (Fig. 1). The upper membrane is the PPM, which corresponds to the APM. The lower one is the cerebellar precentral membrane (CPM), which is an analog to the diencephalic membrane of the Liliequist membrane.2,16 However, the posterior arachnoid complex is an inverted Liliequist membrane–like structure. The third membrane, the quadrigeminal membrane (QM), frequently takes a subsidiary role in subdividing the quadrigeminal cistern. However, when the CPM is hypoplastic on one side or both, the QM is always well developed and plays a prominent part in partitioning the subarachnoid cisterns in the posterior half of the incisural space.

The PPM

The PPM, a paired membrane in the shape of a crescent when viewed from above, has been described in our previous study in detail.7 In short, it can be divided into the horizontal and ascending parts (Figs. 1 and 2A). This membrane arises at the tentorial edge from the confluence of the outer arachnoid membranes above and below the tentorium. Anteriorly (ascending part) or medially (horizontal part), it attaches to the pulvinar and the dorsal and lateral midbrain (Fig. 2A). Posteromedially, it extends upward and ends at the lateral wall of the AEPR (Figs. 1 and 2). This membrane was constantly present in this study, but showed great variability between specimens and often between sides within specimens. Similar to the APM,16 the PPM typically comprises a posteriorly located dense nonporous part with variable size and an anteriorly located porous trabeculated part. When the anterior trabeculated part is poorly developed, the PPM has a concave free border facing the brainstem (11 [27.5%] of 40 sides, Fig. 2B).

The CPM

Posterolaterally, the CPM has a common origin with the ascending part of the PPM (Figs. 1 and 3A). Posteromedially, the CPM arises from the thickened inferior wall of the AEPR (Fig. 3A–C). The CPM was also present in all specimens. Typically, the well-developed CPM spreads anteroinferiorly to attach on the anterior surface of the cerebellar vermis medially and the cerebellar...

![Fig. 1. Schematic drawings showing the similarity between the posterior arachnoid complex in the posterior half of the incisural space (A) and the Liliequist membrane (B). aPPM = ascending part of the PPM; DM = diencephalic membrane; F = falx; hPPM = horizontal part of the PPM; IAPM = lateral part of the APM; mAPM = medial part of the APM; T = tentorium.](image-url)
hemisphere laterally (Fig. 3A–C); these attachments correspond to the diencephalic and temporal attachments of the diencephalic membrane of the Liliequist membrane, respectively (Fig. 1). In some specimens, the CPM appeared as a porous or trabeculated membrane. However, it was more often a sheetlike membrane with openings along its anteroinferior cerebellar attachments (Figs. 1A, 3A, and 3C). Not infrequently, the CPM was characterized by asymmetry between sides (6 [30\%] of 20 specimens). Under these circumstances, the CPM on the side that is not well developed extends inferiorly or even posteroinferiorly to attach on the superior surface of the cerebellar vermis (Fig. 4B). In another 2 specimens (10%), the CPM was hypoplastic bilaterally and presented as a small paramedian membrane on both sides (Figs. 3D and 4C).

The QM usually lies within the quadrigeminal cistern, which has not been described in the literature. The QM originates mainly from the CPM and attaches anteriorly on the quadrigeminal plate (Figs. 1A, 3A, 3B, and 4A–E). Typically, this membrane is relatively small and has 2 parts: sagittal and axial. When the sagittal part is present, part of this membrane can also arise from the inferior wall of the AEPR (Figs. 1A, 4D, and 4F). In this study, none of this membrane showed a complete cruciform appearance. Indeed, this membrane lay predominantly in either the axial (6 [30\%] of 20 specimens, Fig. 4D) or the sagittal (14 [70\%] of 20 specimens; Figs. 3A, 3B, 4E, and 4F) plane. It attaches anteriorly on the vertical ramus of the cruciform sulcus when it lies in the sagittal plane, or on the horizontal ramus of the cruciform sulcus when it lies in the axial plane. This membrane acts as a supplementary membrane and subdivides the quadrigeminal cistern into 2 parts: left and right, or superior and inferior. In some specimens the QM was a sheetlike membrane without an opening, so that the quadrigeminal cistern was completely subdivided (Fig. 4E).

In the 8 specimens in which the CPM was poorly developed on either one or both sides, the QM always lay predominantly in the sagittal plane and was significantly larger than normal. When the CPM is hypoplastic on one side, the QM extends posteriorly and paramedianly toward the opposite side. In this instance, the QM attaches on not only the relatively normal CPM but also on the anterior surface of the cerebellum (Fig. 4B). Provided the CPM is hypoplastic bilaterally, the QM directly attaches posteriorly on the anterior surface of the cerebellum and has no relationship with the CPM (Fig. 4C and F). Under these circumstances, the QM divides not only the quadrigeminal but also the superior cerebellar cistern, which makes this membrane important in partitioning the subarachnoid cisterns in the posterior half of the incisural space.

Cisternal Relationships

The superior cerebellar cistern is a tentlike cistern below the tentorial apex and is demarcated by the CPM anteriorly and the outer arachnoid membrane below the tentorium posteriorly. It communicates with the quadrigeminal cistern anteromedially and with the cerebellomesencephalic fissure cistern anterolaterally through the openings on the CPM or through openings along the anteroinferior attachments of the CPM (Figs. 3–5).

The quadrigeminal cistern is located anterior to the CPM and medial to the bilateral ascending part of the PPM. Superolaterally, it communicates with the ambient cistern through the openings along the anterior attachments of the ascending part of the PPM. Inferolaterally, it directly communicates with the cerebellomesencephalic fissure cistern without arachnoid separation.

Vascular Relationships

The posterior cerebral artery (PCA) encircles the midbrain and reaches the posterior limit of the ambient cistern—namely, the ascending part of the PPM—where branches of the PCA turn backward to the medial and inferior surfaces of the occipital lobe. Frequently, the PCA does not enter the quadrigeminal cistern (Figs. 1A and 2). However, when the anterior attachments of the ascending...
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Figure 3. Photographs showing the well-developed (A–C) and hypoplastic (D) CPMs viewed from different angles. A: Lateral view from right side with superior reflection of the ascending part of the PPM. Note that the CPM has a common origin (dotted line) with the ascending part of the PPM (grasped by forceps) and the vertical predominant QM attaches to the anterior surface of the CPM. B: Lateral view from right side with cutting of the right half of the CPM. This view shows that the CPM arises from the thickened inferior wall of the AEPR in the midline and constitutes the anterior wall of the superior cerebellar cistern. In this specimen, the ascending part of the PPM has a free border and the PCA protrudes into the quadrigeminal cistern. C: Posterolateral view of the cerebellar attachments of the CPM on the anterior surface of the cerebellum and the opening between the attachments from which the SCA emerges (same specimen as panel B). Note that the superior vermian vein courses within the CPM. D: Posterior view from the right side with opening of the right posterior wall of the superior cerebellar cistern. The black asterisks designate the CPM; the blue asterisks denote the QM. C = cerebellum; F = falx; p = pulvinar of the thalamus; QP = quadrigeminal plate; SVV = superior vermian vein; VG = vein of Galen.

Discussion

Vinas et al.13 first described 2 arachnoid membranes definitely related to the posterior half of the incisural space—namely, the CPM and the superior cerebellar membrane. We do not agree with their definitions for the following reasons. First, the CPM described by these authors probably corresponds to the ascending part of the PPM and the CPM in our definition, and the superior cerebellar membrane in their description probably corresponds to the horizontal part of the PPM and the lateral part of the APM in our definition. Although they have a common origin at the tentorial edge, the PPM and the CPM have different attachments on the brainstem and cerebellum, respectively. Their relationship is just like the one between the APM and the diencephalic membrane.
of the Liliequist membrane. Second, the PPM is not continuous with the lateral part of the APM. Therefore, we abandoned the name “superior cerebellar membrane” and redefined the CPM in this study. The CPM is confined within the posterior half of the incisural space and has no relationship with either the oculomotor nerve or the lateral part of the APM.

Similarities and Differences Between the Posterior Arachnoid Complex and the Liliequist Membrane

In our previous study we classified the Liliequist membrane into 2 major types according to the presence (Type I) or absence (Type II) of the diencephalic membrane, and Type I was further divided into 2 subtypes depending on whether the diencephalic membrane and the medial part of the APM form an oblique Y-shaped (Type IA) or inverted oblique L-shaped (Type IB) structure. The posterior arachnoid complex has a close affinity to the Liliequist membrane. The former one also has a medial part and 2 lateral parts. Frequently, the medial part of the posterior arachnoid complex is composed of the ascending part of the PPM and the CPM, which have common origins and form a Y-shaped structure in the sagittal plane resembling the medial part of the Type IA Liliequist membrane. When the CPM is hypoplastic bilaterally, the posterior arachnoid complex resembles the Type II Liliequist membrane. The 2 lateral parts of the posterior arachnoid complex are composed of the bilateral horizontal parts of the PPM, which are identical to the lateral parts of the Liliequist membrane.

The main differences are as follows. First, the CPM and the diencephalic membrane travel in opposite directions, which makes the posterior arachnoid complex an inverted Liliequist membrane–like structure. Second, the analog of the QM is rarely seen in the Liliequist membrane. Third, asymmetry between sides is more frequently seen in the posterior arachnoid complex and is more prominent when present. Finally, the PPM is a paired membrane and the bilateral PPMs are separated by the AEPR in the midline, whereas its counterpart, the APM, is an unpaired membrane.

Clinical and Surgical Significance

Tumors arising from the pineal region, the pulvinar, the anterosuperior portion of the cerebellar vermis, or the falcotentorial junction represent complex entities for surgical treatment due to their deep location and intimate relationships with the important and complex neurovascular structures (especially the deep veins) in the posterior incisural space. During surgery, certain subarachnoid cisterns are opened before the tumor can be well exposed. Exact knowledge of the construction and contents of the subarachnoid cisterns is of great significance for safe and effective dissection during surgery.

Because the vein of Galen and its tributaries are all fixed in their own arachnoid envelopes and then on cer-
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tain inner arachnoid membranes attaching to the AEPR, stepwise opening of these arachnoid membranes may reduce tension on these veins during surgical manipulation and enlarge the surgical corridor, while preservation of other arachnoid membranes may help to avoid injury to the underlying neurovascular structures. As for the PPM, it is routinely opened to expose the quadrigeminal and posterior ambient cisterns in the occipital transtentorial approach because the spaces above and below the basal vein are both important corridors in this approach. However, in the infratentorial supracerebellar approach, preserving this membrane when appropriate may reduce the chance of basal vein injury because the basal vein courses above the PPM.

Tumors arising from the pineal parenchyma frequently push the inferior wall of the AEPR and the QM backward on the CPM, forming an apparently thickened arachnoid layer, which can be clearly observed in both the infratentorial and supratentorial approaches.\textsuperscript{1,9,14} Incision of this thickened arachnoid layer will allow inferior displacement of the cerebellar vermis and exposure of the deep venous system. It should be borne in mind that the pineal vein and superior vermian vein course within this thickened arachnoid layer. The superior vermian vein can be divided easily. However, the pineal vein is relatively short, and part of its terminal segment frequently hides within its own arachnoid envelope before emptying into the vein of Galen. Stretching this vein may directly lead to tearing of the vein of Galen. Therefore, it is safer to coagulate and cut the pineal vein closer to the tumor surface.

Conclusions

Our results show that there are 3 distinct arachnoid membranes in the posterior half of the incisural space. The PPM and the CPM form an arachnoid complex that resembles an inverted Liliequist membrane, but that nevertheless has its own characteristics. If the CPM is hypoplastic on one or both sides, the well-developed QM plays a prominent part in partitioning the subarachnoid cisterns in the posterior half of the incisural space.

Disclosure

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author contributions to the study and manuscript preparation include the following. Conception and design: Zhang, Qi. Acquisition of data: Zhang, Fan, Huang, Peng. Analysis and interpretation of data: Zhang, Fan, Huang, Peng. Drafting the article: Zhang. Critically revising the article: all authors. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Zhang. Study supervision: Qi.

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