

Subarachnoid, Subdural and Interdural Spaces at the Clival Region: An Anatomical Study

Klival Bölgede Subaraknoid, Subdural ve İnterdural Mesafeler: Anatomik Çalışma

Giyas AYBERK¹, Mehmet Faik OZVEREN², Sevil ASLAN¹, Mesut Emre YAMAN¹, Onur YAMAN³, Selim KAYACI⁴, Ibrahim TEKDEMİR⁵

¹M.H. Atatürk Training and Research Hospital, 2nd Department of Neurosurgery, Ankara, Turkey

²Rize University, Faculty of Medicine, Department of Neurosurgery, Rize, Turkey

³M.H. Rize Training and Research Hospital, Department of Neurosurgery, Rize, Turkey

⁴Sar Hospital, Department of Neurosurgery, Rize, Turkey

⁵Ankara University, Faculty of Medicine, Department of Anatomy, Ankara, Turkey

Correspondence address: Giyas AYBERK / E-mail: giyas67@hotmail.com

ABSTRACT

AIM: We aimed to show the significance of the anterior pontine membrane as a determining structure between the subdural and subarachnoid space in the clival region.

MATERIAL and METHODS: Five adult cadaver heads and five cerebral hemispheres were used. The skull vault and hemispheres were removed by sectioning through the pontomesencephalic junction. Five other heads hemispheres were removed but the arachnoid membrane was protected and the cerebral side of the clival dura mater was dissected. In another specimen, the dural porus of the abducens nerve was sectioned for histological evaluation. Three cases of hematoma at the clivus were presented to support our findings.

RESULTS: The anterior pontine membrane is the arachnoid membrane forming the anterior wall of the prepontine cistern with its lateral extension at the skull base. This membrane forms the subdural and subarachnoid spaces by forming a barrier between the clival dura mater and neurovascular structures of the brainstem. There were rigid fibrous trabeculations between both cerebral and periosteal dural layers forming the basilar plexus as the interdural space in the clivus.

CONCLUSION: The anterior pontine membrane separates the subdural and subarachnoid spaces at the clival region. The hematomas of the clival region require to be evaluated with consideration given to the existence of the subdural space.

KEYWORDS: Anterior pontine membrane, Arachnoid, Clivus, Interdural space

ÖZ

AMAÇ: Bu çalışmada, klival bölgedeki subdural ve subaraknoid mesafenin belirlenmesinde anterior pontin membranın önemini göstermek istedik.

YÖNTEM ve GEREÇ: Çalışmada beş yetişkin kadavranın kafatası ve beş serebral hemisfer kullanılmıştır. Kafatası ve hemisferler pontomezen-sefalik bileşke boyunca kesilerek çıkarılmıştır. Diğer beş hemisfer, araknoid membran korunarak çıkarılmış ve klival duramaterin serebral kısmı diske edilmiştir. Bir başka spesimende, abducens siniri dural porusu civarında histolojik kesit almak için kesilmiştir. Bulguları desteklemek için üç klival hematoma vakası sunulmuştur.

BULGULAR: Anterior pontin membran, prepontin sisternin anterior duvarını oluşturur ve kafa kaidesinin lateraline doğru uzanır. Bu membran, beyin sapının nörovasküler yapıları ve klival dura dura mater arasında bariyer oluşturarak, subdural ve subaraknoid mesafenin oluşmasını sağlar. Klivusta baziler pleksusu oluşturan serebral ve periosteal dural tabakalar arasında rijit fibröz trabekülasyonlar vardı.

SONUÇ: Anterior pontin membran, klival bölgede subdural ve subaraknoid mesafeleri ayırır. Klival bölgedeki hematomların, subdural mesafenin varlığı göz önüne alınarak değerlendirilmesi gerekir.

ANAHTAR SÖZCÜKLER: Anterior pontin membran, Araknoid, Klivus, İnterdural mesafe

INTRODUCTION

Although the subdural space (SDS) and subarachnoid space (SAS) terms are clearly defined as being in the calvarial region, there is little account concerning both of these anatomical spaces of the clival part of the brain (29). The inner layer of the dura mater and external layer of the arachnoid mater are adjacent to the calvarial region, and there is no space between them (11). However, the differences between these layers can be obtained radiologically, as a result of advances in magnetic resonance imaging (MRI) technology such as the availability of 3 Tesla devices and much more sophisticated software. In this study, we aimed to show the inadequately explained structure of the meningeal layers in the clival region and to emphasize the significance of the anterior pontine membrane (APM) as a determining structure between the subdural and subarachnoid space, through the use of cadaveric examination. Additionally, the radiological imaging showing epidural, subdural and subarachnoid hemorrhage obtained from some of our cases were included into the discussion to clarify both terms in clinical practice.

MATERIAL and METHODS

Cadaveric study

Five adult cadaver heads and 5 cerebral hemispheres obtained from the Department of Anatomy, School of Medicine, Ankara University were examined using 2.4x to 12x magnification. The skull vault and hemispheres were removed by sectioning through the pontomesencephalic junction in order to study the area between the pons and clivus in the five heads. These heads were embalmed in a 10% formalin solution. The cerebral side of the clival dura mater was dissected to observe internal membranous structure of the clivus dura mater. The hemispheres with cerebellum were removed from the cranium by protecting the arachnoid membrane coverage in the other 5 heads. In another specimen, the portion surrounding the dural entrance porus of the abducens nerve was sectioned and stained with hematoxylin and eosin to enable study under light microscopy, as in the examination of the arachnoid membrane in the dural porus.

RESULTS

Cadaver

It was detected that the arachnoid membrane thickened gradually and laterally towards both sides at the skull base in which the hemispheres were removed. This thickening is known as the APM, according to a previous report regarding this area (16) (Figure 1 A). The space between the clivus and the APM is the SDS with the arachnoid membrane coming in to the porus around the sixth cranial nerve penetrating the dura mater of the skull base. The SDS extended into the porus of the sixth cranial nerve between the dura and arachnoid mater. The space between the pons and the APM is the SAS, containing the basilar artery and its perforating branches together with the pontine veins. The SAS continued into the cranial nerve porus between the sixth cranial nerve and the arachnoid. The basilar plexus was exposed when the meningeal side

of clival dura mater was dissected and removed. There were very strong and firm fibrous trabeculations between both dural layers (Figure 1B), with the periosteal dura mater securely attached to the clival bone. It was not possible to detach the periosteal dura mater from the clival bone without rigorous dissection, with a scalpel, in some parts of the basilar plexus.

It was observed that the APM engulfed all related structures from the anterior side in the specimens, so the cerebral

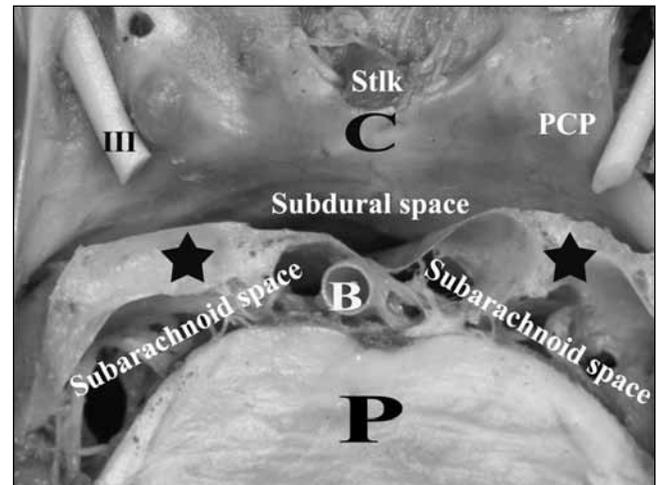


Figure 1A: Axial section at the pontomesencephalic region shows the relationship between the subarachnoid and subdural space in the brainstem. The lateral extension of the anterior prepontine arachnoid membrane is known as the anterior pontine membrane (stars). **Stlk:** Pituitary stalk, **C:** Clivus, **B:** Basilar artery, **P:** Pons, **PCP:** Posterior clinoid process.

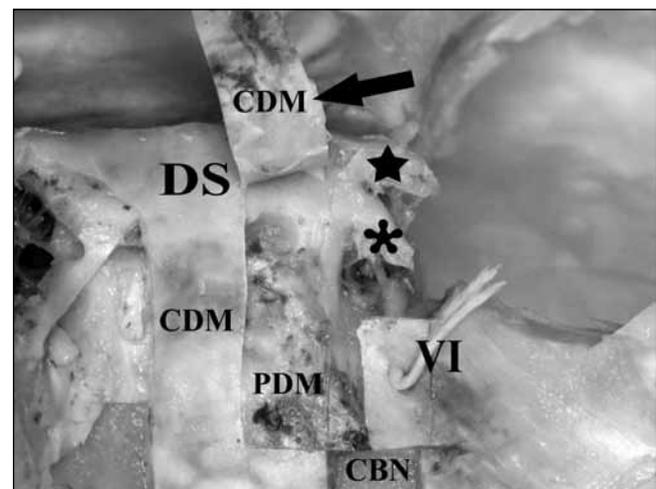


Figure 1B: Dissection of the cerebral dura mater in the petroclival region shows tight adhesion between the cerebral dura mater (CDM) and periosteal dura mater (PDM). The PDM is firmly attached to the clivus. The sixth nerve (VI) and arachnoid membrane are wrapped around the sleeve and enters into Dorello's channel under the petrosphenoidal ligament (asterix). **DS:** Dorsum sella, **Star:** Posterior clinoid process.

hemispheres and the cerebellum were cautiously dissected and disconnected (Figure 1C). Around the abducens nerve porus, the arachnoid membrane invaginated between the dural sleeve and the abducens nerve. The area between the dural sleeve and the arachnoid membrane corresponded to the SDS, with the area between the nerve and the arachnoid membrane corresponding to the SAS (Figure 1D, 2).

Illustrative Cases

Case 1: A 6-year-old female patient was admitted to the hospital following a fall. Her Glasgow coma scale (GCS) was 13 points. Computed tomography (CT) showed clival subdural hematoma (Figure 3). Hyperintensity denoting the blood has disappeared on the control CT posttraumatic 3rd day. The

patient was discharged on the fifteenth day of her admission with a GCS of 15 points.

Case 2: A 47-year-old female patient was admitted to the hospital after a fall of 3 meters. Her GCS was 13 points. There was otorrhea of the right ear. The CT showed right sided

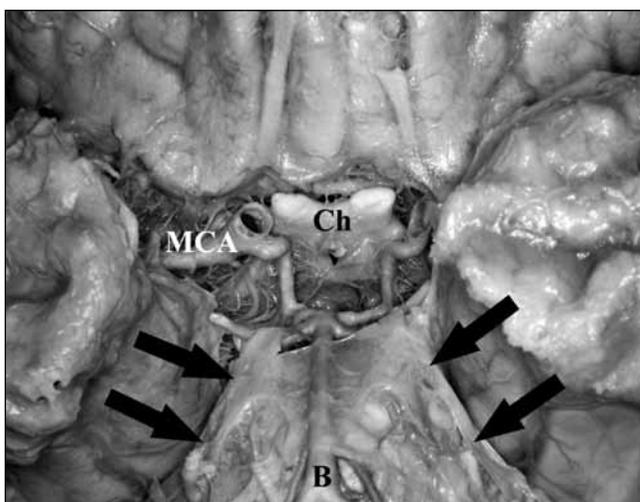


Figure 1C: The inferior view of the brain shows the relationship of the anterior pontine membrane with the brain stem and the basilar artery. Note how the membrane engulfs these structures (black double arrows). **Ch:** Optic chiasma, **MCA:** Middle cerebral artery, **B:** Basilar artery.

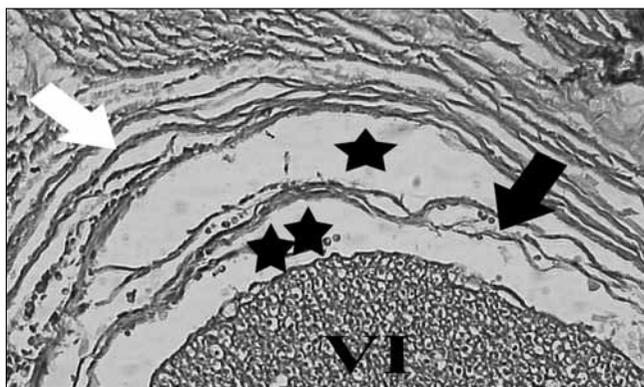


Figure 1D: A histological section taken from the abducens nerve entrance point shows engulfment of the sixth nerve (VI) by the dura (white arrow) and arachnoid mater (black arrow). The subdural space (star) and the subarachnoid space (double stars) were seen to be porus (HE 40x).

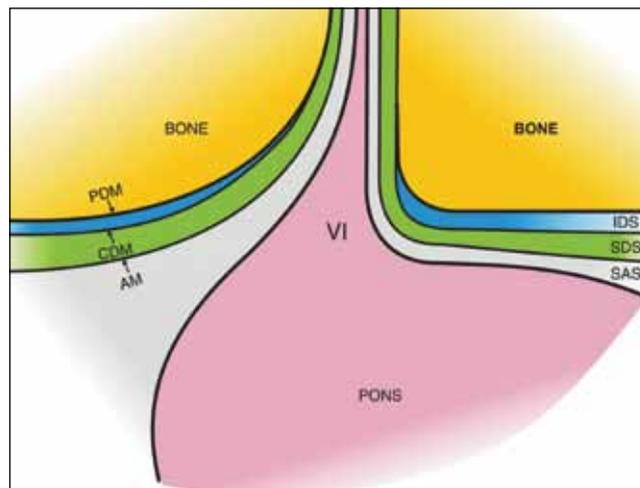


Figure 2: Schematic drawing of the dura and arachnoid mater around the abducens nerve (VI) entrance porus. Note the changing of the subdural space (SDS) and subarachnoid space (SAS) at clival, and the abducens nerve porus region. **IDS:** Interdural space, **PDM:** Periosteal dura mater, **CDM:** Cerebral dura mater, **AM:** Arachnoid membrane.

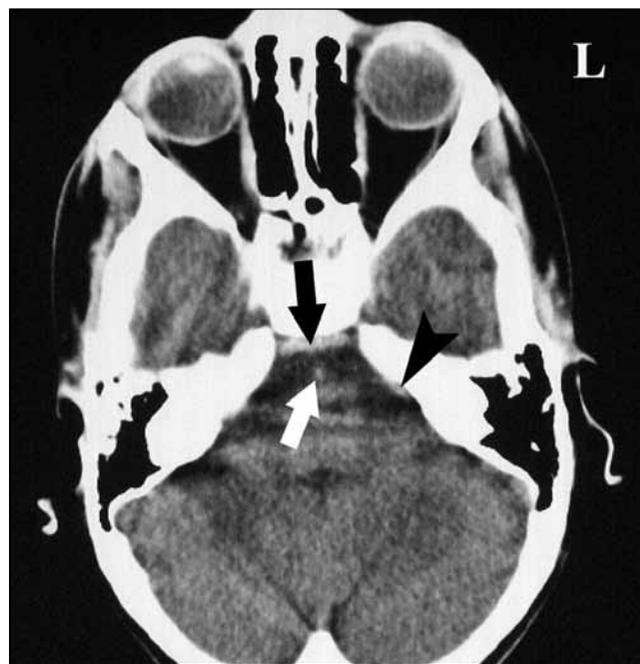


Figure 3: The computed tomography scan of case 1 shows subdural hemorrhage in the clival (black arrow) and the left petroclival region (black arrowhead). The subarachnoid space is free from blood. White arrow: basilar artery.

fronto-parietal epidural hematoma, right-sided clival biconvex hematoma near the petrous apex, and subdural hematoma at the left clival region (Figure 4). There was hemorrhage in the sphenoid sinus due to a skull base fracture. The calvarial epidural hematoma was evacuated surgically because of a decrease in consciousness. The otorrhea disappeared postoperatively. The patient was discharged with a GCS of 15 on the postoperative 15th day.

Case 3: A 50-year-old male patient was admitted to the hospital with a subarachnoid hemorrhage. His GCS was 15 points and the neurological examination was normal, except for neck stiffness. A CT confirmed a subarachnoid hemorrhage in the prepontine cistern, with a hypodense image of cerebrospinal fluid filling in the clival region (Figure 5).

DISCUSSION

Enlarged areas of the SAS consisting of the intracranial cisterns, and cerebrospinal fluid (CSF) circulates throughout all portions of the SAS. There is no naturally occurring biological space at the dura-arachnoid junction in the calvarial region (11). While the periosteal dura mater was attached tenaciously to the cranial base and includes more extracellular collagen, the meningeal dura mater has less extracellular collagen and the inner aspect, has a special cell layer known as the dural border cell (DBC) layer (8). The arachnoid membrane consists of two different cell layers; the arachnoid barrier cell (ABC) layer, and the arachnoid trabeculea (11). The ABC layer has tight junctions between the ABCs which is peculiar to this layer (11). There is no possibility for space between the DBCs and the ABCs (11). A pathology in this area, such as subdural hematoma, is the result of a separation of the DBCs (11). Therefore, the "subdural space" word, in clinical nomenclature, can be considered a debatable term in the calvarial region (11). However, our observation of the subdural space was found to be different at the skull base. A layer of arachnoid membrane extends from the dorsum sellae posteriorly over the clivus (33). This layer can be distinguished at the anterior of the pons and with a gradual thickening increasing towards the lateral side. Thus, there is some confusion in the nomenclature, concerning the prepontine cistern arachnoid membrane. Matsuno et al. (16) have described lateral part (itself the arachnoid membrane) of the prepontine cistern arachnoid membrane as the APM. This paired membrane is between the prepontine and the cerebellopontine cisterns (16). It is preferable to include the arachnoid membrane, forming the anterior wall of the prepontine cistern, into the "anterior pontine membrane" terminology. As the APM clearly extends as a separate free layer without adhering to the clival dura mater, in our study (Figure 1A). It may be speculated that direct contact between the APM and dura mater was displaced during opening of the cranial vault. However, the waving of the APM in the CSF is a common observation when the Liliquest membrane is opened during the surgery. This type of observation can be also seen in MRI examinations of patients. In case 3, we observed that a subarachnoid hemorrhage collected in the prepontine cistern of the SAS

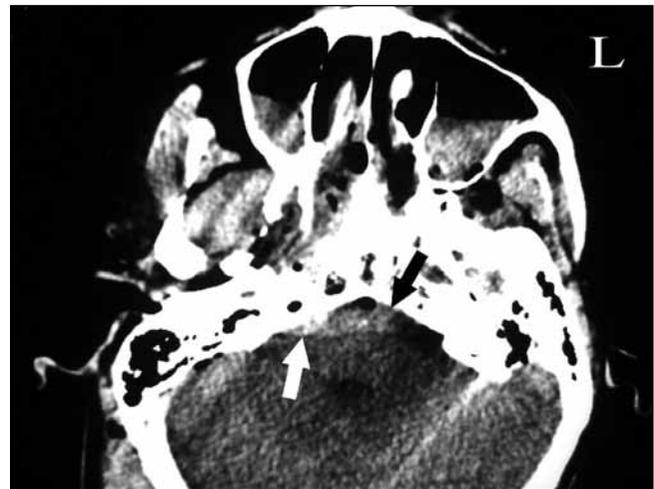


Figure 4: The computed tomography scan of the same patient shows a right-sided clival epidural hemorrhage (white arrow), and clival subdural hemorrhage (black arrow). Note the air bubble in the subdural space.



Figure 5: The computed tomography scan of case 3 shows the subarachnoid hemorrhage in the SAS (black arrow) and the SDS is protected from the blood (white arrow).

but the clival SDS did not show any hemorrhage (Figure 5). Our dissections verified the description of the DBC and the ABC layer, without any potential space, may be specific to the calvarial region and not to the skull base region.

The APM, along with cranial nerves, invaginates through the dural porus of the cranial nerves, as was illustrated in the dural entrance porus of the abducens nerve, in this study (Figure 1D). This alignment emphasizes that the SAS, which is a continuation of the prepontine cistern at the clival region, lies between the abducens nerve and the arachnoid membrane within the nerve sleeve. Yaşargil (31) has commented that the cranial nerves, along with their arteries and veins, advance

in the form of arachnoid packs in their own foramina. Direct contact of the CSF with cranial nerves extends inside their dural porus and sleeve presumably contributes to their nourishment (7, 21). A space between the clivus dura mater and arachnoid membrane is located inside the dural sleeve, as was confirmed by our dissections, and histological section. Arachnoid coverage of the cranial nerves inside their dural sleeve explains the avoidance of permanent injury after removal of tumors invading the cavernous sinus (12). Importance of the APM increased in as a result of using neuroendoscopic procedures recent years. Yaşargil (32) has been emphasized importance of the cisternal anatomy during surgery. The subarachnoid space and related anatomic structures are protected by the anterior pontine membrane in case of tumors located epidurally at the clival region, and facilitates creation of surgical dissection plane and protection of neural tissue.

The epidural space below the cranial bone, at the calvarial region, differs from its counterpart at the clivus. It is evident that the dura mater is a two-layered structure in the clivus, and the basilar plexus exists between these two layers (20, 23). As the epidural hematoma, involving the clival region, is located interdurally, not epidurally as in the calvarial region, it may be preferable to refer to these lesions as clival interdural hematomas. A hematoma on the right side of the petrous apex, in our second illustrative case, is therefore described as a biconvex hematoma within the text (Figure 4). The hematoma may be subdural or, because of the biconvex image, interdural; raising the cerebral layer of the clival dura mater in the region of the inferior petrosal sinus. A significant point requiring explanation is how such a fibrous tissue, having high adherence, could be separated from each other? The main clinical property of traumatic clival epidural, or interdural, is that hematomas are frequently associated with low GCS levels (14, 19). Severe injuries, such as, longitudinal clivus fracture, atlantoaxial dislocation, clival dural laceration and entrapment of the vertebrobasilar artery complex have been reported in these patients (5, 18, 19, 24). In trauma cases, it is possible to mechanically peel off the clival dura mater from below to above, by distraction of the dens towards the superior direction. Therefore, these types of the clival hemorrhage cases must be appraised for possible injury to the atlantoaxial structures (22).

Reports state, that the bleeding source usually causes disruption of the tectorial membrane, dura mater and fractured clival bone in the presented cases of the clival hematomas due to a trauma (14, 15,17). Casey et al. (3) have recently distinguished the clival hematomas as either epidural or subdural; and accomplished this classification by taking into account the tectorial membrane as the gauge. According to Casey's (3) classification, an epidural clival hematoma does not extend beyond the tectorial membrane, whereas a subdural clival hematoma may lead into the spinal subarachnoid space. However, the rigidity of the clival duramater prevents the slipping off, of the periosteal dura mater easily from the clival bone. Therefore, a classification

depending on sagittal level of the clival hematoma may be questionable descripton.

Another controversial issue regarding the clival hematoma term arises from the absorbtion of the hematoma, within a short period of time. We observed a disappearance of the hematoma on the third posttraumatic day in case 1 (Figure 3). The patient had a clival subdural hemorrhage, according to our findings. There is no report explaining the mechanism of blood removal within days. However, it may be speculated that the tear of the arachnoid membrane or migration of subdural blood into the spinal region may cause rapid spontaneous resolution of a posttraumatic intracranial acute subdural hematoma (1, 13, 27, 30). Wong et al. (30) presented a similar case, that an acute cranial subdural hematoma redistributed into the spinal subdural space and disappeared after 45 hours intracranially.

Another question concerning the clival epidural or interdural hematoma is related to the existence of venous blood flow at the hematoma location. Since this area was filled with the venous blood of the basilar plexus dynamically, why does the blood not continue to fill the space? An epidural hematoma at the lateral calvarial region could be resolved spontaneously, because there is no venous sinus below (6, 28). It is possible that initial trauma causes bleeding at the outset, from the basilar plexus, but when the hematoma creates a sufficient level of pressure, cessation of bleeding may result. This type of spontaneous hemostasis is seen supratentorial area (10). In our case 2 (Figure 4), a right-sided clival biconvex hematoma looks like a clival epidural hematoma and was smaller than the subdural hematoma on the opposite side. We defined this as a biconvex hematoma, located at the right side of the patient because of we were unsure whether the hematoma was located in epidural or subdural space.

However, clival hematomas are not only caused by trauma, but may also occur spontaneously (4, 9, 25, 26). Brock at al. (2) presented a case of interdural hemorrhage due to infraclinoidal carotid artery aneurysm rupture. They explained the mechanism of interdural hemorrhage as the detachment of the cerebral layer of the dura mater, at the oculomotor trigone, due to high pressure bleeding from the aneurysm. The MRI of Brock's case (2) disclosed that the bleeding was extended to the medial side of the internal acoustic meatus; in addition, to the clival side, as well as to the posterior side of the foramen magnum. The blood having been clearly distributed to the SDS of the posterior fossa, encircling the arachnoid membrane covering the brainstem and cerebellum, of the patient. Development of an interdural hematoma between both dural layers, extending to the very firm fibrous trabeculations is not easily performed through an aneurysm rupture, according to our findings. Moreover, the expectation was that, the development carotico-cavernous fistula after bleeding, of their presented example (2). Brock's report (2) has very illustrative images for clarification of our description on the differentiation of SAS and SDS in the clival region.

CONCLUSION

The anterior pontine membrane is the main structure which separates the subdural and subarachnoid spaces at the clival region. The hematomas of the clival region require to be evaluated with consideration given to the existence of the subdural and subarachnoid spaces. Additionally, the subarachnoid space and related anatomic structures are protected by the anterior pontine membrane in case of tumors located epidurally and subdurally at the clival region, and facilitates creation of surgical dissection plane and protection of neural tissue.

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