The superior wall of the cavernous sinus: a microanatomical study

Felix Umansky, M.D., Alberto Valarezo, M.D., and Josef Elidan, M.D.

Departments of Neurosurgery and Otolaryngology, Hadassah University Hospital and the Hebrew University Medical School, Jerusalem, Israel

✔ The superior wall of the cavernous sinus was studied in 30 specimens obtained from 15 cadaver heads fixed in formalin. Trapezoidal in shape, the superior wall of cavernous sinus is limited laterally by the anterior petroclinoid ligament, medially by the dura of the diaphragma sellae, anteriorly by the endosteal dura of the carotid canal, and posteriorly by the posterior petroclinoid ligament. An interclinoid ligament bisects the wall, dividing it into two triangles: the carotid trigone anteromedially and the oculomotor trigone posterolaterally. Similar to the lateral wall of the cavernous sinus, the superior wall is formed by two layers: a smooth superficial dural layer and a thin, less defined deep layer. In the area of the carotid trigone, both layers separate to wrap the anterior clinoid process. The removal of this process will reveal a "clinoid space" medial to which the internal carotid artery can be identified. This clinoid segment of the artery, still extracavernous, is surrounded by two fibrous rings: a distal ring formed by fibers of the superficial dural layer and a proximal ring related to the deep dural layer. Below the proximal ring, the internal carotid artery becomes intracavernous; above the distal ring, the artery is continuous with its supraclinoid segment. The complex dural anatomy of the superior wall, its fibrous rings, and the clinoid space in relation to a superior surgical approach to the cavernous sinus are discussed.

KEY WORDS • cavernous sinus • cranial nerve • internal carotid artery • anatomical study

THE continuous development of microsurgical techniques to treat lesions in and around the cavernous sinus emphasizes the need for an accurate understanding of the microanatomy of this complex region. Since the pioneering work of Parkinson[10] who demonstrated the feasibility of a direct operative approach to the cavernous sinus, there have been a number of papers published on the microsurgical anatomy of this area.[3,6,7,13,15]

Materials and Methods

Fifteen cadaver heads (30 specimens) fixed in formalin were dissected for this study. At the outset, the brains were carefully removed to fully expose the skull base. Each head was placed in a Sugita head holder, turned 45° from the side of dissection, and extended slightly to simulate the surgical position. The main anatomical landmarks were identified; namely, the optic nerve, supraclinoid internal carotid artery (ICA), anterior and posterior clinoid processes, petroclinoid folds, and the third and fourth cranial nerves. The optic canal was then unroofed and the anterior clinoid process was removed to completely expose the superior and lateral walls of the cavernous sinus.

Three incisions were made at the level of the posterior clinoid process: posterolateral along the posterior petroclinoid ligament toward the point of entry of the fourth cranial nerve into the cavernous sinus; anterolateral following the direction of the interclinoid ligament; and anteromedial close to the diaphragma sellae toward the medial aspect of the ICA. Another incision was made along the anterior petroclinoid ligament to clarify the dural relationship between the lateral and superior walls of the cavernous sinus. The dural leaves were carefully dissected under the operating microscope and the anatomical data were recorded.

Anatomical Observations

The superior wall of the cavernous sinus, trapezoidal in shape, is limited laterally by the anterior petroclinoid ligament, medially by the dura of the diaphragma sellae, anteriorly by the endosteal dura of the carotid canal, and posteriorly by the posterior petroclinoid ligament. A line parallel to the interclinoid ligament divides this wall into two triangles: the carotid trigone anteromedially and the oculomotor trigone posterolaterally (Fig. 1). Similar to the lateral wall of the sinus, its superior wall is formed by two layers: a smooth superficial dural layer and a thin, less defined deep layer. For didactic purposes, the superior wall of the cavernous sinus has been divided into three areas: the oculomotor trigone, the carotid trigone, and the clinoid space.
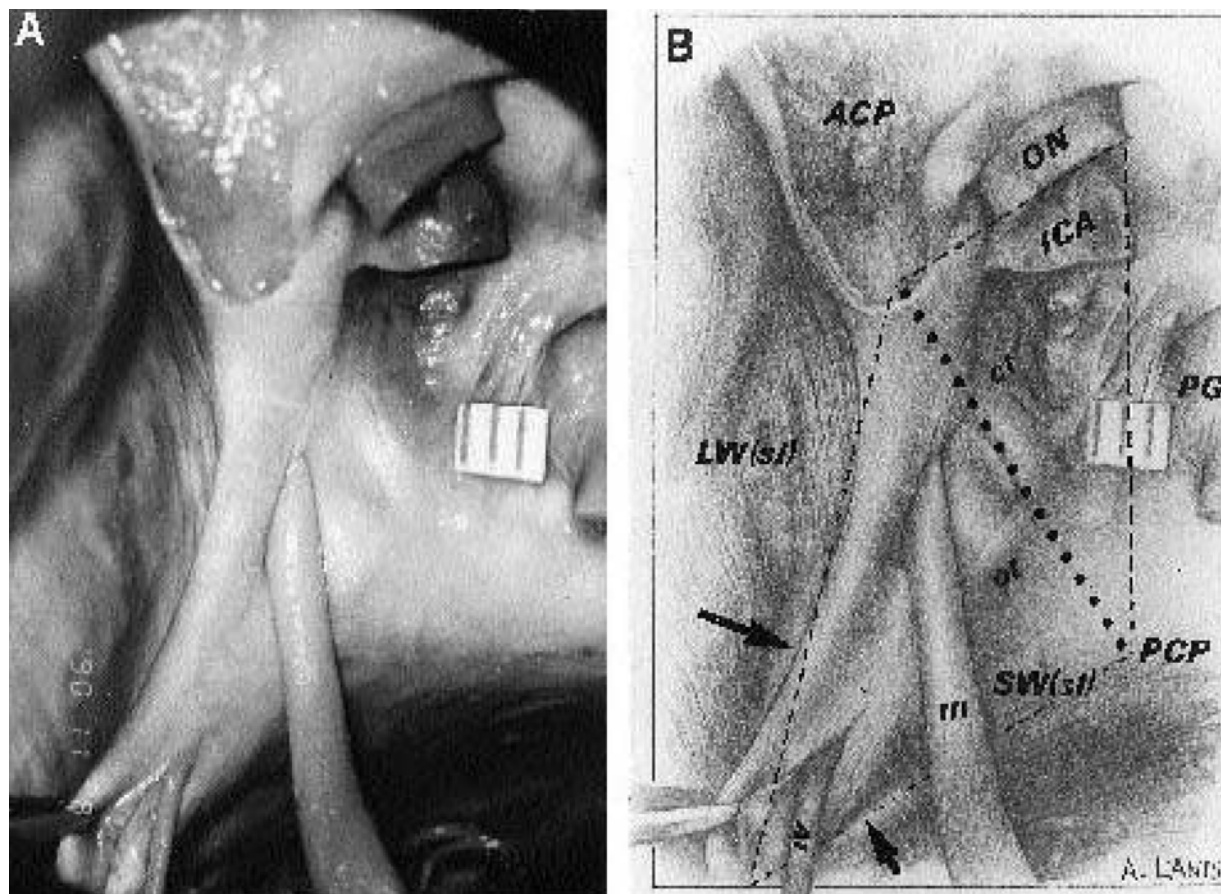
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FIG. 1. Photograph of cadaver specimen (A) and artist's drawing (B) depicting the superior view of the left cavernous sinus. The superior wall of the sinus *(broken line)* is divided into two triangles by a *dotted line* overlying the interclinoid ligament: the oculomotor trigone (ot) posterolaterally and the carotid trigone (ct) anteromedially. The third (III) and fourth (IV) cranial nerves enter the sinus through the oculomotor trigone while the internal carotid artery (ICA) exits the sinus in the area of the carotid trigone. The dura mater over the anterior clinoid process (ACP) has been removed. The superficial layer of the superior wall of the sinus SW(sl) continues laterally with the superficial layer of the lateral wall of the sinus LW(sl). The *long arrow* points to the anterior petroclinoid ligament and the *short arrow* to the posterior petroclinoid ligament. The scale is given in millimeters. ON = optic nerve; PCP = posterior clinoid process; PG = pituitary gland.

Oculomotor Trigone

This trigone was limited laterally by the anterior petroclinoid ligament (length 16.6 ± 2.4 mm), medially by a line overlying the interclinoid ligament (length 9.6 ± 2.0 mm), and posteriorly by the posterior petroclinoid ligament (length 13.8 ± 3.4 mm) (Fig. 1). The third and fourth cranial nerves entered the cavernous sinus in this area of the superior wall. The dural foramen of the oculomotor nerve, elliptical in shape (maximum diameter 4.9 ± 1.1 mm), was larger than the nerve crossing it in most of the cases. The distance from this foramen to the anterior clinoid process was 7.2 ± 1.8 mm and to the posterior clinoid process, 8.5 ± 1.9 mm.

The dural opening for the trochlear nerve was located in the angle between the anterior and posterior petroclinoid ligaments and in a large number of cases (63%) the diameter of the opening was equal to the diameter of the nerve. The distance between this fora-

men and the anterior clinoid process was 16.04 ± 2.52 mm; the distance to the posterior clinoid process was 12.74 ± 3.46 mm.

In the oculomotor trigone the dural layers (superficial and deep) could be easily separated (Figs. 2 and 3). The superficial layer continued laterally with the superficial layer of the lateral wall, medially with the superficial layer of the carotid trigone, and posteriorly with the superficial layer of the petroclival dura in the posterior wall of the cavernous sinus. The deep layer, thinner than the superficial layer, continued laterally, medially, and posteriorly with the deep dural layer of the lateral wall, carotid trigone, and posterior wall of the cavernous sinus, respectively. At the level of the trochlear and oculomotor foramina, the deep layer contributed to the dural sheaths surrounding the nerves through their course on the lateral wall of the cavernous sinus (Figs. 3, 5, and 6).

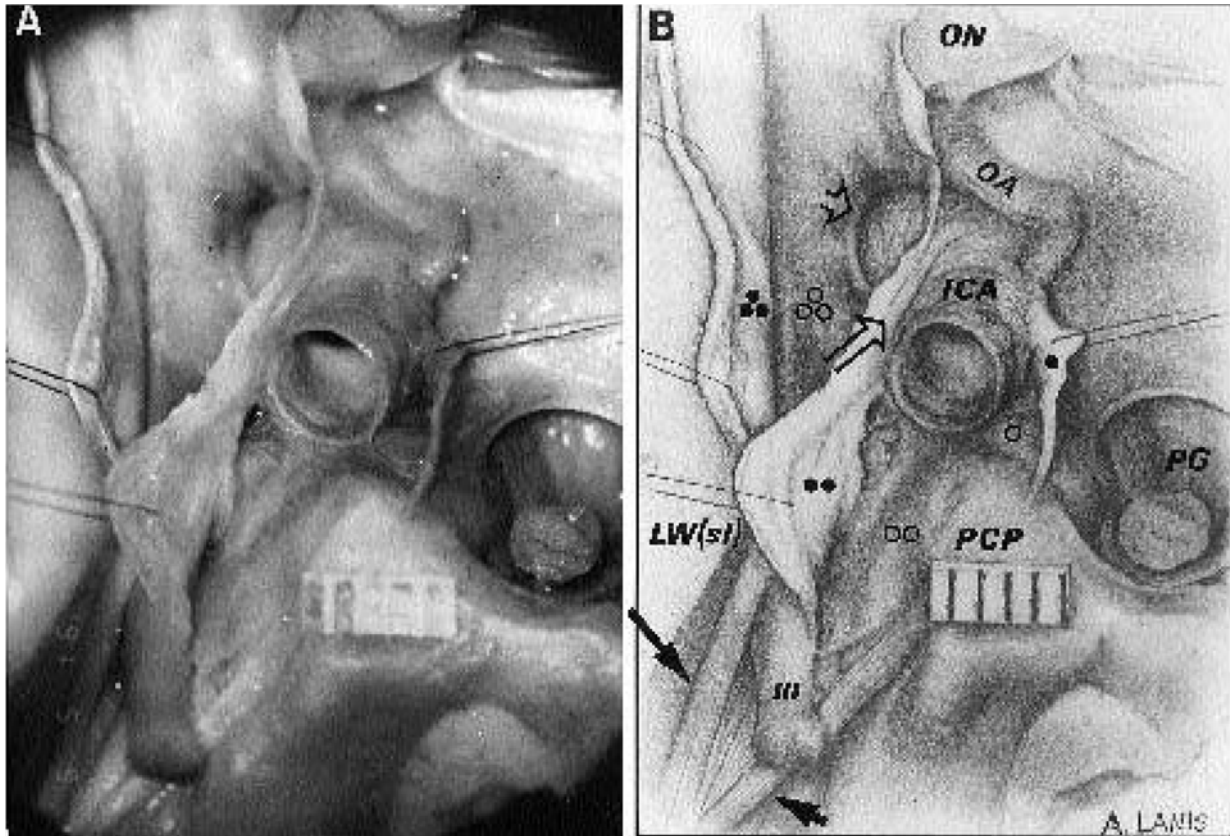The removal of both dural layers in the oculomotor

FIG. 2. Photograph of cadaver specimen (A) and artist's drawing (B) depicting the superior view of the left cavernous sinus. The anterior clinoid process has been removed and the superficial layer of the superior wall of the sinus has been incised and separated from the deep layer. This separation between the superficial and deep layers of the dura mater can be clearly seen in the area of the carotid trigone: *one solid dot* and *one open dot*, respectively; in the area of the oculomotor trigone: *two solid dots* and *two open dots*, respectively; and in the area of the clinoid space: *three solid dots* and *three open dots*, respectively. The oculomotor nerve (III) enters the sinus below the anterior petroclinoid ligament *(long solid arrow)*, and the posterior petroclinoid ligament *(short solid arrow)* attaches to the posterior clinoid process (PCP). The *long open arrow* points to the distal carotid ring and the *short open arrow* to the proximal carotid ring. The scale is given in millimeters. ICA = internal carotid artery; LW(sl) = lateral wall (superficial layer); OA = ophthalmic artery; ON = optic nerve; PG = pituitary gland.

trigone allowed the identification of the following structures: the posterosuperior venous space of the cavernous sinus, the posterior bend of the intracavernous ICA with the origin of the meningohypophyseal trunk, the initial intracavernous course of the abducens nerve, and the interclinoid ligament.

Carotid Trigone

This area of the superior wall was limited laterally by a line overlying the interclinoid ligament, medially by the dura of the diaphragma sellae, and anteriorly by the endosteal dura of the carotid canal. The anterior portion of this trigone presented the opening for the ICA at the beginning of its supraclinoid segment (Fig. 1). The ICA foramen had a diameter of 6.86 ± 0.9 mm, and on its medial side, the dura mater could be easily separated from the artery, revealing a semilunar space known as the "carotid cave."[8]

In the area of the carotid trigone, dissection be-

tween the superficial and deep dural layers was more difficult than in the oculomotor trigone. The superficial dural layer continued laterally with the similar layer of the oculomotor trigone and with the dura that covered the superior aspect of the anterior clinoid process, medially with the dura of the diaphragma sellae, and anteriorly with the endosteal dura of the carotid canal. This superficial layer contributed to the formation of the distal ring of the ICA (Figs. 2 and 4). This ring is not complete and encircles only the dorsolateral aspect of the artery opposite the carotid cave. The plane of this ring is slightly oblique in an inferomedial direction.

The deep dural layer was very thin and friable and was usually incomplete in the posterior half of this area. Here the dark color of the venous blood of the sinus could be seen through this transparent layer. After covering, the undersurface of the anterior clinoid process continued anterolaterally with the deep
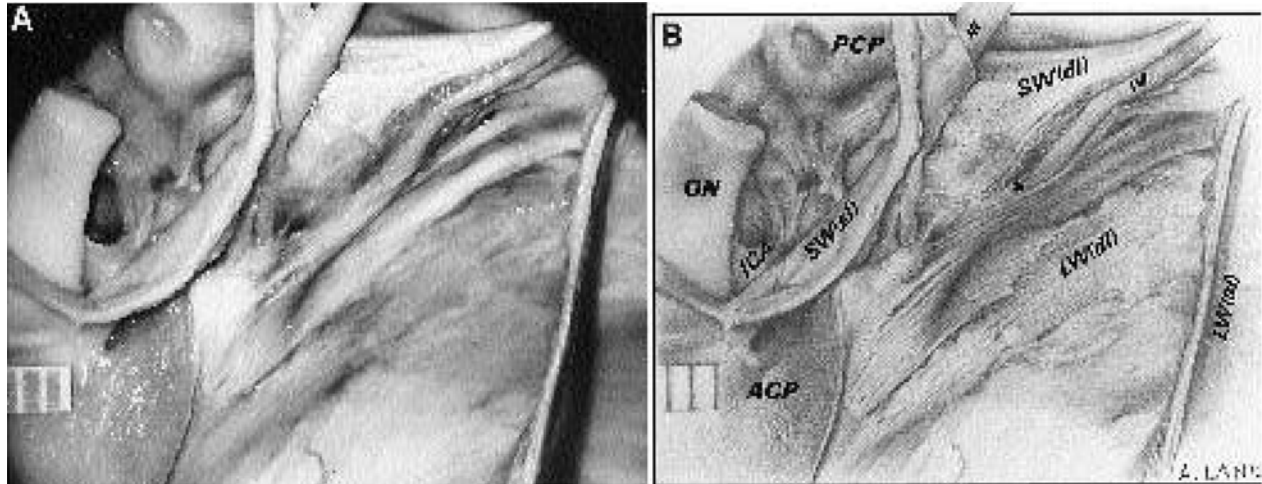
FIG. 3. Photograph of cadaver specimen (A) and artist's drawing (B) depicting the superolateral view of the left cavernous sinus after incision and separation of the superficial layer of the superior wall SW(sl) from its deep layer SW(dl) and of the superficial layer of the lateral wall LW(sl) from its deep layer LW(dl). The oculomotor nerve (III) has been lifted and the initial course of the trochlear nerve (IV) is located between the superior and lateral walls of the sinus. Note the continuity of the deep layer of the superior wall with the deep layer of the lateral wall in the oculomotor trigone area. Deep-layer fibers from the superior and lateral walls contribute to the dural sheath surrounding the fourth (IV) nerve *(asterisk).* The scale is given in millimeters. ACP = anterior clinoid process; ICA = internal carotid artery; ON = optic nerve; PCP = posterior clinoid process.

layer of the lateral wall of the cavernous sinus and posterolaterally with the similar layer of the oculomotor trigone. This layer ended medially at the level of the diaphragma sellae. The deep layer of the carotid trigone dura mater contributed to the formation of the proximal ring of the ICA. This ring is described in more detail in the area of the clinoid space. The deep layer continued posteriorly with the deep layer of the oculomotor trigone. The removal of both dural leaves in the carotid trigone allowed the visualization of the following structures: the anterior third of the horizontal segment of the intracavernous ICA, the anterior bend of this artery, the medial wall of the cavernous sinus, and the medial venous space of the sinus.
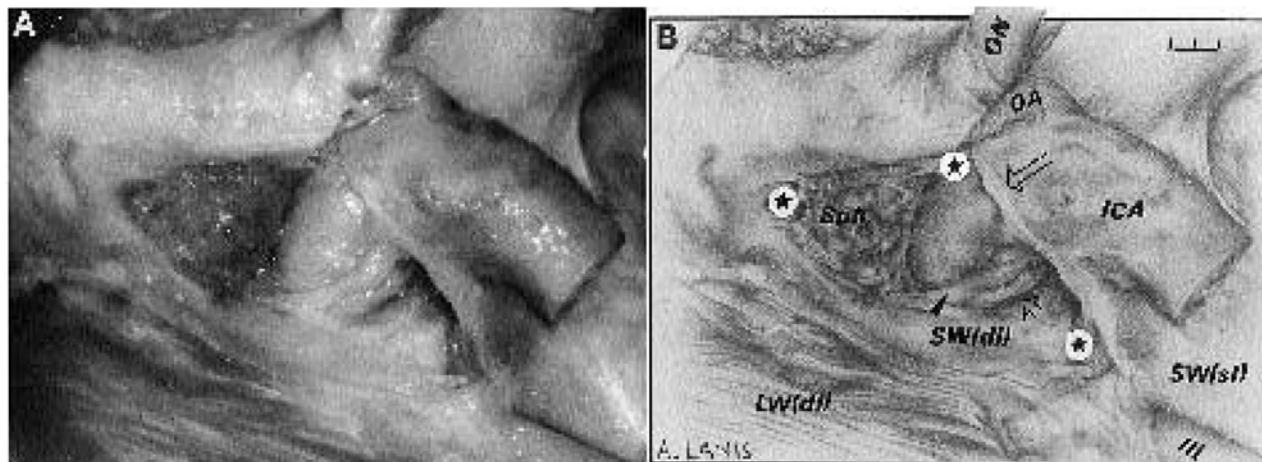

FIG. 4. Photograph of cadaver specimen (A) and artist's drawing (B) depicting the lateral view of the left cavernous sinus showing the boundaries of the "clinoid space" *(stars)* after the removal of the anterior clinoid process. The paraclinoid segment of the internal carotid artery (ICA) with its distal *(long open arrow)* and proximal *(short open arrow)* rings is adjacent to the middle third of this space. Posterior to the artery there is a small triangular space covered by the deep layer of the superior wall SW(dl). Opening this membrane will lead to the interior of the cavernous sinus. The anterior third of the clinoid space is frequently lateral to an extension of the ethmoid or sphenoid (Sph.) sinus. The *arrowhead* indicates the sympathetic nerve. The scale is given in millimeters. LW(dl) = lateral wall (deep layer); OA = ophthalmic artery; ON = optic nerve; SW(sl) = superior wall (superficial layer); III = oculomotor nerve.
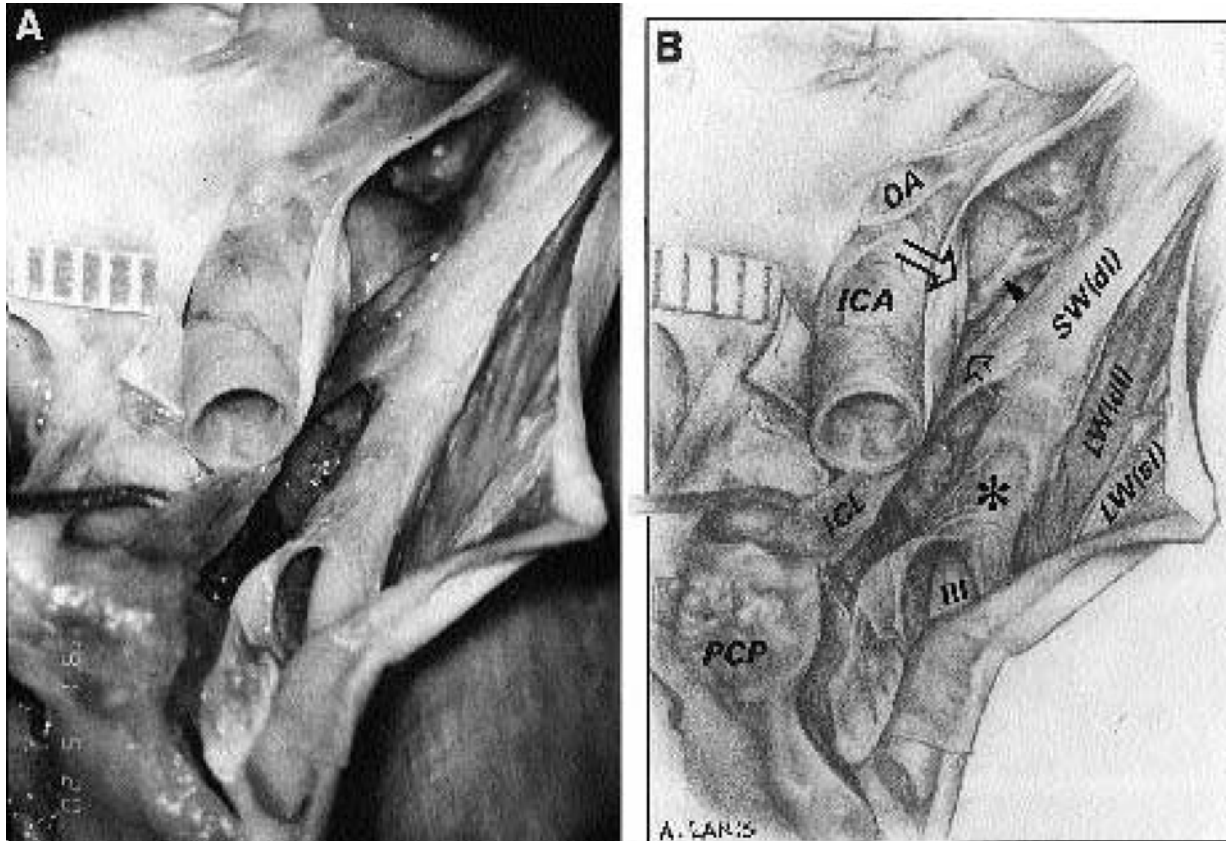
FIG. 5. Photograph of cadaver specimen (A) and artist's drawing (B) of the superolateral view of the right cavernous sinus after removal of the anterior clinoid process. The continuity of the deep layer of the superior wall SW(dl) with the deep layer of the lateral wall LW(dl) in the clinoid space area is clearly seen. The internal carotid artery (ICA) and its distal *(long arrow)* and proximal *(short arrow)* dural rings can be identified. The posterior attachment of the interclinoid ligament is shown (ICL) in the posterior clinoid process (PCP). The oculomotor nerve (III) is surrounded by a dural sheath *(asterisk)* of deep-layer origin. The *arrowhead* indicates the sympathetic nerve. The scale is given in millimeters. LW(sl) = lateral wall (superficial layer); OA = ophthalmic artery.

Clinoid Area or Space

The removal of the anterior clinoid process revealed an interdural space between both dural layers, which separated at this level to wrap the bone process. Beyond this interdural space, the paraclinoid or clinoid segment of the ICA could be clearly seen (Fig. 4). There was a small area anterior to the artery frequently occupied by an extension of the ethmoid or sphenoid air cells. Inadvertent opening of these cells during surgery may cause rhinorrhea. There was another small triangular area posterior to the ICA covered by the deep layer of the dura mater. Opening this thin membrane would lead to the interior of the cavernous sinus (Fig. 6). In five of our specimens, this membrane was incomplete. At the level of the ICA, the deep layer of the dura mater became thicker to form the proximal ring of the artery (Figs. 4 to 6). This ring fused medially with the endosteal dura of the carotid canal and posteriorly gave attachment to the interclinoid ligament.

This deep layer continued laterally with the deep layer of the lateral wall of the cavernous sinus and with the dura mater of the superior orbital fissure (Figs. 5 and 6). The removal of the deep dural layer in the clinoid area would expose the anterior bend of the ICA and the anteroinferior venous space of the cavernous sinus.

Discussion

A surgical approach through the superior wall of the cavernous sinus, medial or lateral to the C_3 segment of the ICA may allow a good view of the area that surrounds the anterior bend of the artery. To obtain a clear exposure of the superior wall of the cavernous sinus, the surgeon should remove the anterior clinoid process that may cover a large portion of this wall, unroof the optic canal, and open the dural sheath of the optic nerve, thus facilitating the mobilization of the nerve.
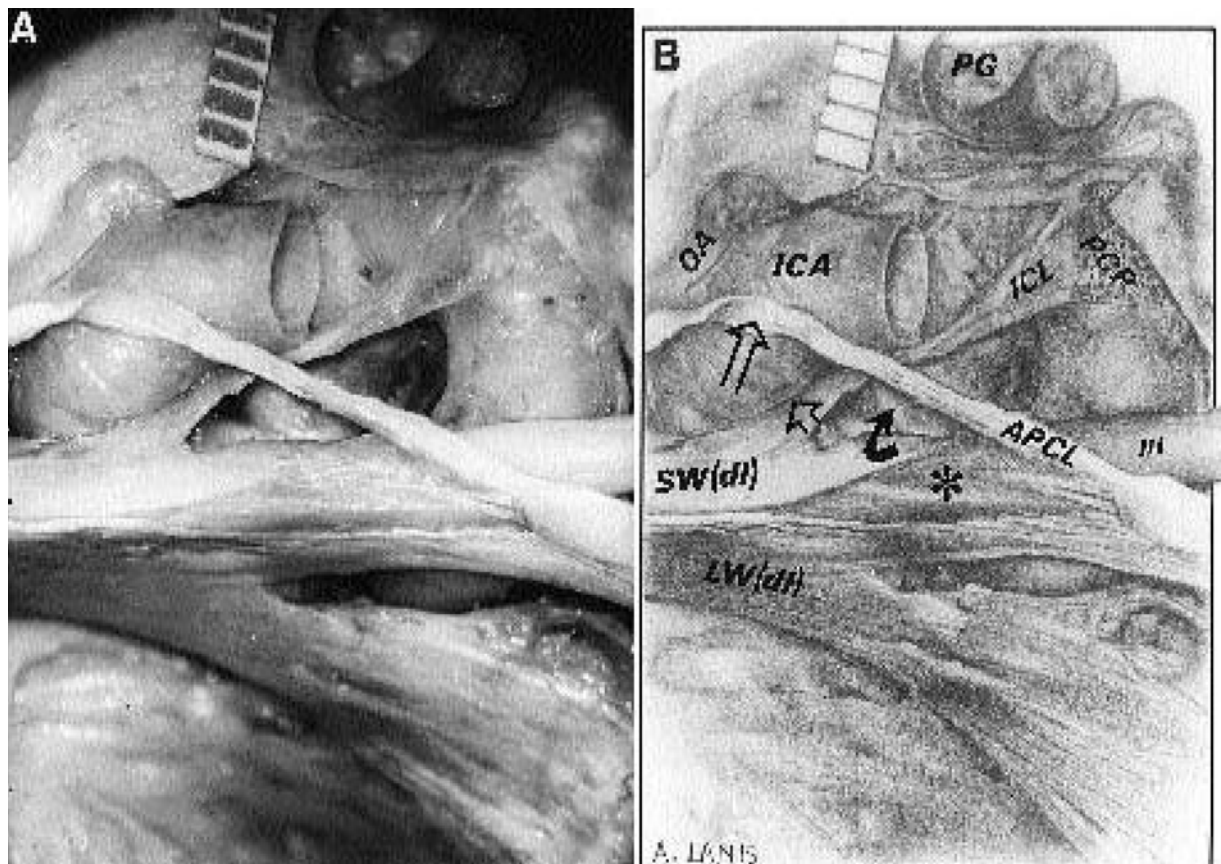
FIG. 6. Photograph of cadaver specimen (A) and drawing (B) depicting the superolateral view of the left cavernous sinus after removal of the anterior clinoid process, the superficial dural layer of the superior and lateral walls, and most of the deep layer of the superior wall SW(dl). The three areas of the superior wall of the sinus can be seen without the dura mater cover. The opening of the posterior third of the clinoid space into the cavernous sinus is now apparent *(curved arrow)*. The interclinoid ligament (ICL) has been dissected free, showing its anterior attachment to the proximal carotid ring *(short arrow)* and its posterior attachment to the posterior clinoid process (PCP). Note the relationship between the anterior petroclinoid ligament (APCL) and the distal carotid ring *(long arrow)*. The deep dural layer of the superior wall SW(dl) contributes fibers to the dural sheath *(asterisk)* of the oculomotor nerve (III). The scale is given in millimeters. ICA = internal carotid artery; LW(dl) = lateral wall (deep layer); OA = ophthalmic artery; PG = pituitary gland.

In this study, we divided the superior wall of the cavernous sinus into three areas: the oculomotor trigone, the carotid trigone and the clinoid space. A line parallel to the interclinoid ligament separated the oculomotor trigone posterolaterally from the carotid trigone anteromedially. The drilling of the anterior clinoid process brought into view the third area or clinoid space. Similar to the lateral wall of the sinus,[15] its superior wall was found to be formed by two layers: a smooth, superficial, and well-defined dural layer and a thin and less-defined deep layer. Separation of both layers was easier in the oculomotor trigone than in the carotid trigone. Lateral to the area of the carotid trigone, both layers separated to wrap the anterior clinoid process. The superficial layer contributed to the formation of the distal ring of the ICA whereas the deep layer contributed to the formation of its proximal ring. Medial to the artery, both rings fused with the endosteal dura of the carotid canal. Lateral to the

artery the rings, separated by a distance of 5.4 ± 1.2 mm, joined a layer of loose connective tissue that covered the lateral wall of the artery in this area.

Our observations on the most anterior aspect of the cavernous sinus (clinoid space) accord with those of Dolenc.[3,4] He found that the two layers of dura separated to envelop the anterior clinoid process and a part of the anterior loop of the ICA. The inner reticular layer running inferior to the anterior clinoid process formed the proximal ring of the artery, and the superficial layer continuing over the superior surface of the clinoid process formed the distal ring. He emphasized the fact that the paraclinoid segment of the ICA was extracavernous in location.

In our study, both layers of dura were found not only in the area of the clinoid space but in the areas of the oculomotor nerve and carotid trigone as well. In the clinoid space, the deep layer of dura was found to be incomplete in five specimens. In these cases com-

plete removal of the anterior clinoid process would result in bleeding from the sinus despite the fact that the clinoid space was actually extracavernous.

Using the superior wall of the cavernous sinus as a surgical approach had the advantage of a relative lack of nerve structures crossing it. Both the oculomotor and trochlear nerves entered this wall close to its lateral limit. The main structure crossing the wall was the ICA.

Review of the Literature and Operative Techniques

The presence of a fibrous ring surrounding the ICA was first mentioned by Perneczky, *et al.*,[11] in 1985. By removing the anterior clinoid process and cutting this distal carotid ring, these researchers were able to expose the anterior siphon knee and clip infraclinoid aneurysms without opening the cavernous sinus. Clipping of intracavernous ICA aneurysms via the superior wall approach has also been described by Matsuoka, *et al.*[9] These researchers opened the wall along a line connecting the anterior and posterior clinoid processes "to avoid damage to the cranial nerves running in the lateral wall of the sinus."

Diaz[2] reported that he began the dissection of the roof of the sinus in the entry zone of the oculomotor nerve, identifying sequentially the fourth cranial nerve and the first division of the fifth cranial nerve in a craniocaudal direction. He noted that the process was simplified by opening the distal carotid ring starting from the cavernous sinus area and continuing to the subarachnoid space.

Hakuba, *et al.*,[5] entered the superior wall of the sinus through an area they called the "medial triangle," which is formed by connecting three points: the anterior margin of the C_2 portion of the ICA, the dural entrance of the third nerve, and the anterolateral margin of the posterior clinoid process. Sekhar, *et al.*,[14] described the use of the superior approach to the cavernous sinus in 13 patients with intracavernous neoplasms. In 12 of these cases, the superior approach was undertaken in conjunction with the lateral approach. The unroofing of the optic canal and removal of the anterior clinoid process were performed intradurally. In Dolenc's[3,4] approach to the cavernous sinus, the anterior clinoid process and the bone of the optic canal were removed extradurally.

Kobayashi and colleagues[8] in 1989 described a small dural recess or pouch in the 1 to 6 O'clock position medial to the carotid artery. They called this dural pouch the "carotid cave" because it lies between the carotid artery and the carotid sulcus of the sphenoid bone. This carotid cave should not be confused with either the clinoid space, which is located lateral to the ICA or with the anterior cavernous sinus space. There is some confusion in the literature regarding the location of the "carotid cave" in the superior wall of the cavernous sinus. In 1991, Sadasivan, *et al.*,[12] described the carotid cave as the anterior cavernous sinus space, which they found located anterior and lateral to the cavernous carotid artery. Sekhar, *et al.*,[14] in

their commentary on the article of Inoue, *et al.*,[7] and Day[1] in his article on aneurysms of the ophthalmic segment all referred to the clinoid space as being identical to the carotid cave.

The presence of two layers of dura mater in the superior wall of the cavernous sinus conforms to similar dural architecture that we found in its lateral[15] and posterior wall (our unpublished observations). Further anatomical studies should clarify whether this dural pattern is present in the other walls of the sinus as well.

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