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The lateral wall of the cavernous sinus

With special reference to the nerves related to it

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√ In a study of the cavernous sinus in 70 specimens, the lateral wall of the sinus was found to be formed by two layers: a superficial, dural layer and a deep layer. The latter was formed by the sheaths of nerves III, IV, and $V_{1,2}$ plus a reticular membrane extending between the sheaths. This membrane was often incomplete, particularly beween the sheaths of nerves III and IV above, and V_1 below. These findings do not conform with the descriptions of a single dural layer of the lateral wall, with nerves III, IV, and $V_{1,2}$ embedded in it, nor to other descriptions showing the cavity of the sinus divided into two compartments by a septum close to the lateral wall, with nerves III, IV, and V_1 located within the septum. In the present study, the superficial and the deep layers of the lateral wall were found to be loosely attached to each other and easy to separate. In no case was a superficial compartment of the sinus found to be present between the two layers, and the nerves were never found to be running embedded in the superficial layer.

KEY WORDS · **cavernous sinus** · **oculomotor nerve** · **trochlear nerve** · **ophthalmic nerve** · **abducens nerve**

SINCE the first descriptions of the cavernous sinus,[22,37] numerous anatomical studies have emphasized the importance of this paired venous channel, deep-seated at the sides of the body of the sphenoid bone and the sella turcica. It is generally accepted that the sinuses are located between the two layers of the dura mater: the periosteal (endosteal) layer forming the floor and most of the medial wall of the cavernous sinus, and the dural layer forming its roof, lateral wall, and the upper part of the medial wall (Fig. 1a). However, contradictory descriptions are still found in the literature regarding the lateral wall and its relationship to the structures passing through the sinus (Fig. 1). With the introduction of microsurgery and the development of new techniques and surgical approaches,[2,15,21,36,38] a more accurate knowledge of the cavernous sinus and especially of its lateral wall is not only of theoretical academic interest, but may also have practical implications.

In most classical textbooks,[5,23,25,27,34] nerves III, IV, and $V_{1,2}$ are described as being embedded in the lateral wall of the sinus, while the internal carotid artery (ICA) with its sympathetic plexus and sixth nerve are located in the cavity of the sinus[4,9,12,27] (Fig. 1a). Other textbooks[17,19,24] describe the lateral wall as being split into superficial and deep layers (Figs. 1b and 2). The deep layer, according to these descriptions, forms a kind of septum in the sinus cavity and divides it into two compartments: a deep broad main compartment medial to the septum, containing the ICA and the sixth nerve; and a narrow, more superficial one lying lateral to the septum. Nerves III, IV, and $V_{1,2}$ are described by these authors as running through the septum and not in the superficial layer.

Harris and Rhoton[10] and, more recently, Rhoton, *et al.*,[21] in their descriptions of the cavernous sinus and related regions, recognized two "dural leaves" in the lateral wall of the sinus, and described the course and relationships of nerves III, IV, and V_1, running between them (Fig. 1f).

McGrath,[12] in a thorough study of the cavernous sinus by coronal and sagittal sections, reached the conclusion that "the III, IV, and V_1 nerves do not run in the lateral dural wall." Other authors[7,9,26,29] have described the III, IV and $V_{1,2}$ nerves as running in the lateral wall, between an endothelial or connective-tissue lining and the dura mater.

In some studies[3,30,35] the sixth nerve is considered as

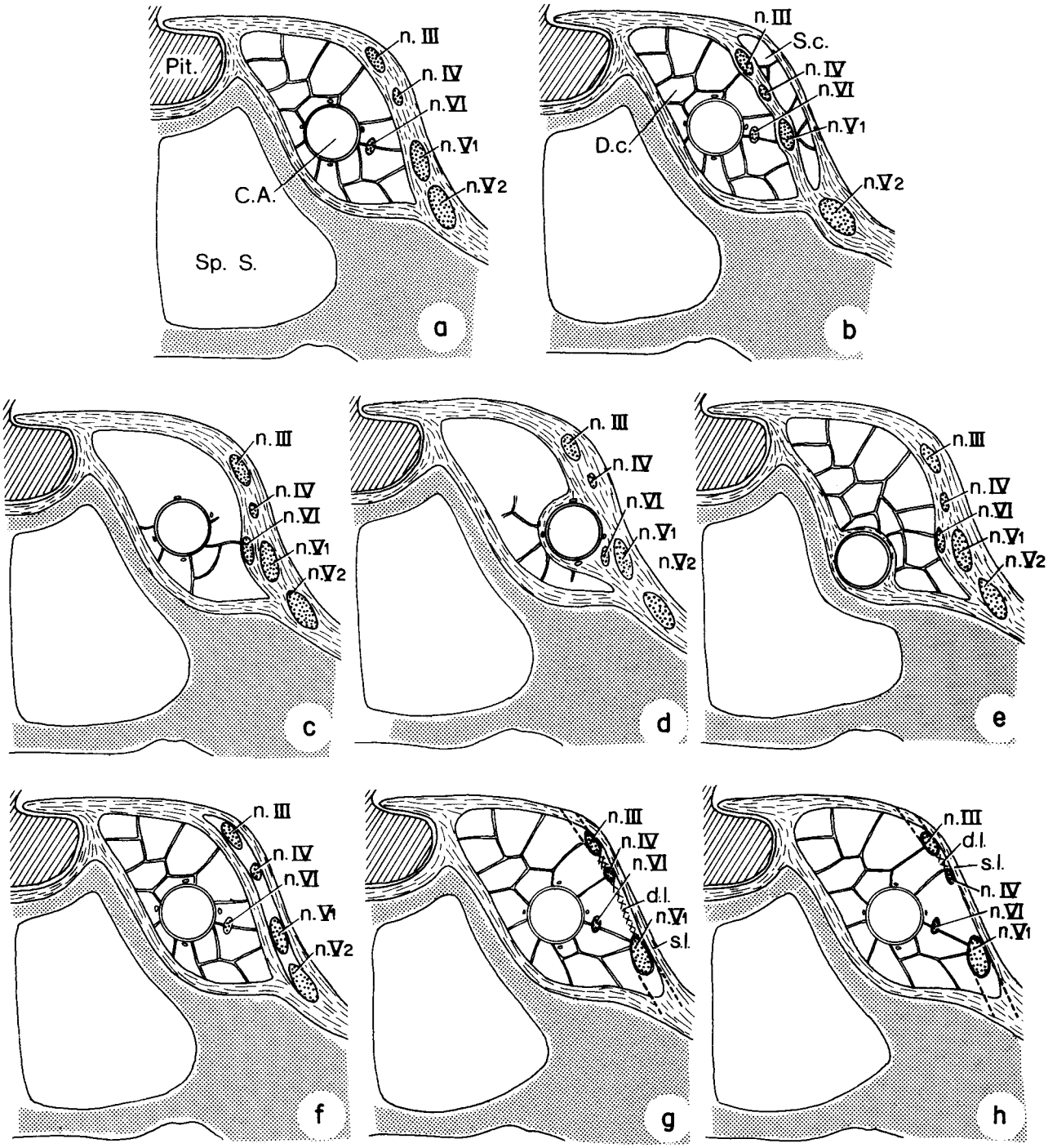


FIG. 1. Diagrams of the cavernous sinus as described by different authors, with special reference to the lateral wall of the sinus and the structures related to it. Pit = pituitary gland; Sp.S. = sphenoid sinus. a: Classic textbooks. The lateral wall is formed by dura mater in which nerves III, IV, and V_1 are embedded. The internal carotid artery (C.A.) and nerve VI pass through the cavity of the cavernous sinus. b: French and Spanish authors. The septum divides the sinus into two compartments. The C.A. and nerve VI pass through the deep compartment (D.c.); nerves III, IV, and $V_{1,2}$ are located within the septum. S.c. = superficial compartment. c: Anatomy similar to (a) except that nerve VI is included in the lateral wall. d: Anatomy similar to (c), except that the C.A. is also included in the lateral wall. e: Anatomy similar to (c), except that the C.A. is included in the medial wall. f: The lateral wall is split into two layers, with nerves III, IV, and V_1 passing between the layers. g: Present observations. The lateral wall is composed of two layers: a superficial (s.l.) dural layer and a deep layer (d.l.) formed by the sheaths of nerves III, IV, and V_1, with a reticular membrane between these sheaths. h: Anatomy similar to (g), except that the membrane of the deep layer is incomplete between nerve IV above and V_1 below.

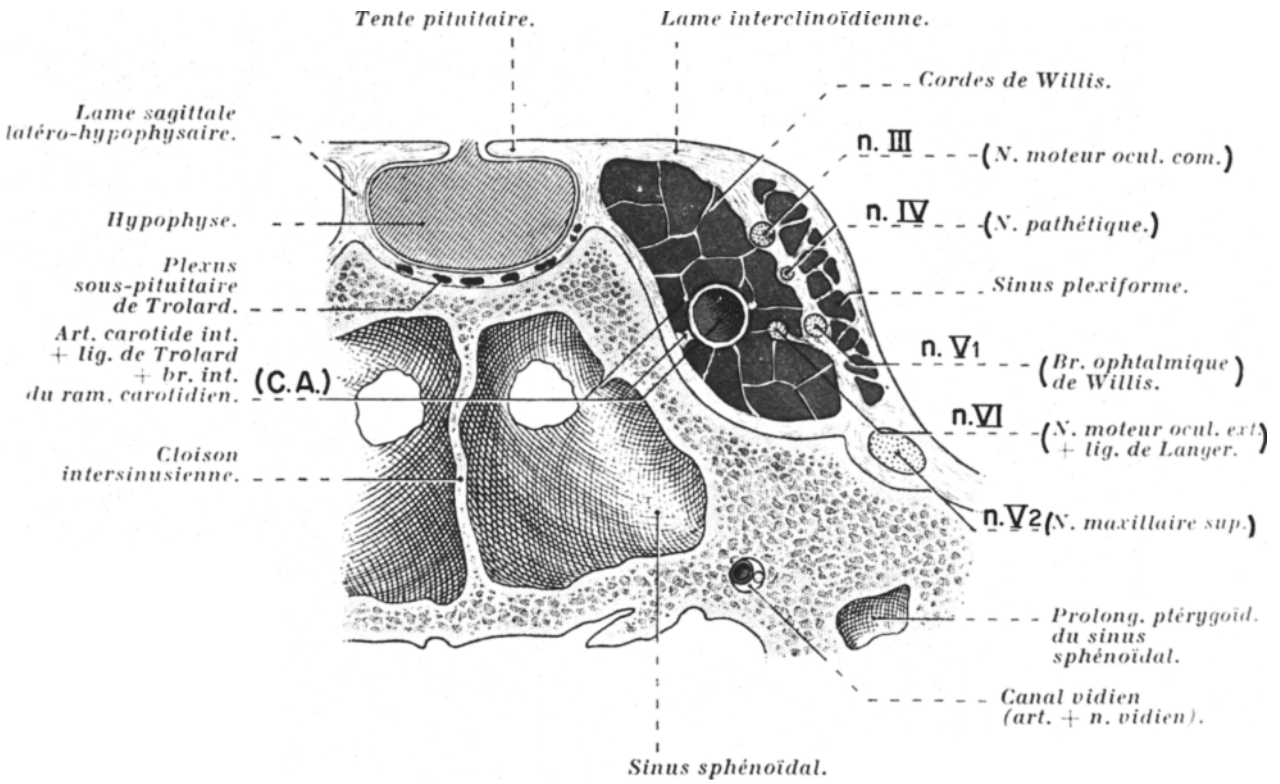


FIG. 2. Diagram showing a septum dividing the sinus cavity into two compartments: a deep compartment with the internal carotid artery (C.A.) and nerve VI; and a superficial compartment; Nerves III, IV, and V_1 lie within the septum. (Modified from Paturet G: *Traité d'Anatomie Humaine. Tome IV. Système Nerveux.* Paris: Masson et Cie, 1964, with permission.)

running in the lateral wall, together with the other nerves (Fig. 1c). Differences in descriptions were also found regarding the presence or absence of nerve V_2 and the trigeminal ganglion in the lateral wall. Some books[8,18] restrict their descriptions, saying only that nerves III, IV, $V_{1,2}$, and VI pass through the cavernous sinus without elaborating on their exact relationship to the walls and cavity of the sinus.

Our findings in hundred of routine dissections with students, as well as in previous special studies[13,14] on the cavernous sinus, generally did not conform with either of these classic descriptions. On the present paper, we present the results of our studies on the lateral wall of the sinus.

Materials and Methods

Procedure

Seventy cavernous sinuses were dissected in cadavers and in autopsy material. All were of adults, male and female. Before starting the dissection in each case, the third and fourth nerves were identified and their points of entry into the roof of the sinus and lateral wall, respectively, localized. While no difficulties were encountered with the third nerve, the fourth nerve and its site of entry into the sinus wall was often difficult to find. This is due to the small size of the nerve and the fact that, close to its entry, the nerve is hidden beneath the free margin of the tentorium cerebelli. The nerve pierces the dura under this margin, exactly where it crosses the attached border at the apex of the petrous temporal bone (Fig. 3A). To locate the nerve, it is necessary to evert the free border. Beginning the dissection at the posterosuperior angle of the lateral wall where the fourth nerve enters the sinus, and continuing the incision forward along the superior border of the wall, a layer of dura mater could be separated from a deeper layer containing nerves III, IV, and V_1 (Figs. 3, 4, and 5). Two additional incisions were made downward from the entrance of the fourth nerve and from the anterior clinoid process, in order to allow reflection of this layer laterally toward the floor of the middle cranial fossa, enough to uncover nerve V_1 in its sheath. The presence of nerve V_2 and the trigeminal ganglion, and their relationship to the lateral wall, were not investigated here.

Observations

The lateral wall of the cavernous sinus was consistently found to be formed of two layers: a smooth superficial layer formed by the dura mater, and a deep layer containing nerves III, IV, and V_1 (Figs. 3,

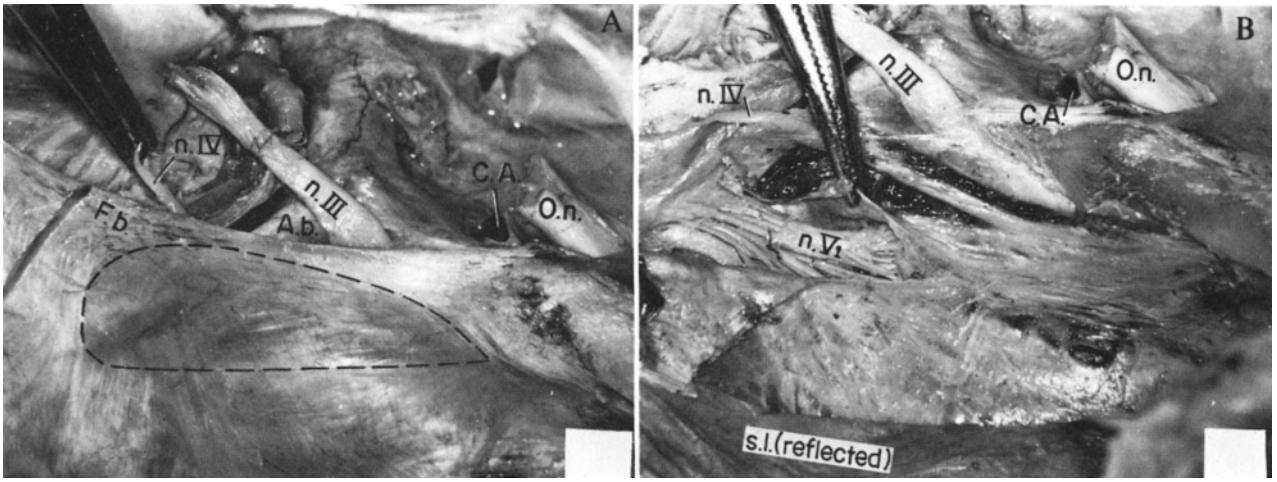


FIG. 3. Unopened right cavernous sinus as seen from the right. A: Nerve III enters the sinus through its roof; nerve IV, slightly raised by the forceps, is seen disappearing under the free border of the tentorium (F.b.) to enter the lateral wall where this border crosses the attached border of the tentorium (A.b.). The triangular darker area (surrounded by *broken line*) of the lateral wall, corresponds to the area between nerves III and IV above, and nerve V_1 (not seen here) below, where the wall is thinner and formed only by the superficial dural layer. O.n. = optic nerve; C.A. = internal carotid artery. B: The superficial dural layer of the lateral wall (s.l.) has been separated from the deeper layer (d.l.) and reflected downward. Nerves III and IV are clearly seen in their dural sheaths; the sheath of V_1 was opened, and its upper lip lifted by the forceps to expose the nerve, which appears here split into many isolated fascicles. Note the window between nerve III above and V_1 below, through which the dark contents (blood) of the cavernous sinus are seen. Nerve IV crosses the window and divides it into an upper narrow space and a lower broader one. The window corresponds with the shaded triangular area of the wall (seen in A, marked by *broken line*).

4, and 5). The two layers of the wall were only loosely attached to each other and could therefore be easily separated. In no case was a separate superficial compartment of the sinus found between the layers.

The deep layer was less defined than the superficial layer and was more irregular and variable in its texture and morphological characteristics. It was found to be formed by the sleeves or sheaths of dura mater accompanying the corresponding nerves from their points of penetration into the sinus walls, that is, nerve III through the roof close to the lateral wall in front of and slightly medial to nerve IV; nerve IV at the posterosuperior angle of the lateral wall, exactly where the free and attached borders of the tentorium cerebelli cross each other; and nerves $V_{1,2}$ through the posteroinferior angle of the lateral wall. The sheaths of these latter nerves are extensions forward of Meckel's cave where the trigeminal Gasserian ganglion is located. The sheaths around nerves III and $V_{1,2}$ were rather thick and constantly distinct, while that of nerve IV was thin and often inconspicuous. A membrane of a reticular texture extended between the sheaths of the nerves, thus completing the deep layer (Fig. 5). This membrane seemed to be composed of the connective tissue forming the trabeculae of the sinus cavity. In 42 specimens (60%), it was found as a thin but definitely complete membrane. In 28 (40%), it was incomplete, and often missing in the space between nerves III and V_1. In these cases (Figs. 3B and 4), a kind of window between these two nerves appeared when the superficial layer was dissected and reflected; through this window, the cavity of the sinus was revealed with its trabeculae and blood remnants. When these were cleared away, the ICA and sixth nerve could be seen in the cavity. The window was generally triangular in shape with its base situated posteriorly, corresponding to the posterior border of the wall. The superior border of the triangle corresponded to nerve III with its meningeal sheath, and the inferior border to nerve V_1 with its sheath. The apex of the triangle corresponded to the point where the two nerves met and decussated in the anterior part of the sinus wall. Nerve IV generally ran parallel with and close and inferior to nerve III at the superior limit of the window. When nerve IV was at a distance from III (Fig. 3B), it crossed the window anteroposteriorly, dividing it into a narrow superior and a broader inferior part. In these cases, nerve IV was generally found loosely attached to the inner surface of the superficial layer, where the latter was dissected and reflected laterally. In the area of the window, the lateral wall of the sinus was much thinner than at the level of nerves III and V, since it was formed here only by the superficial layer (Fig. 5). Due to its

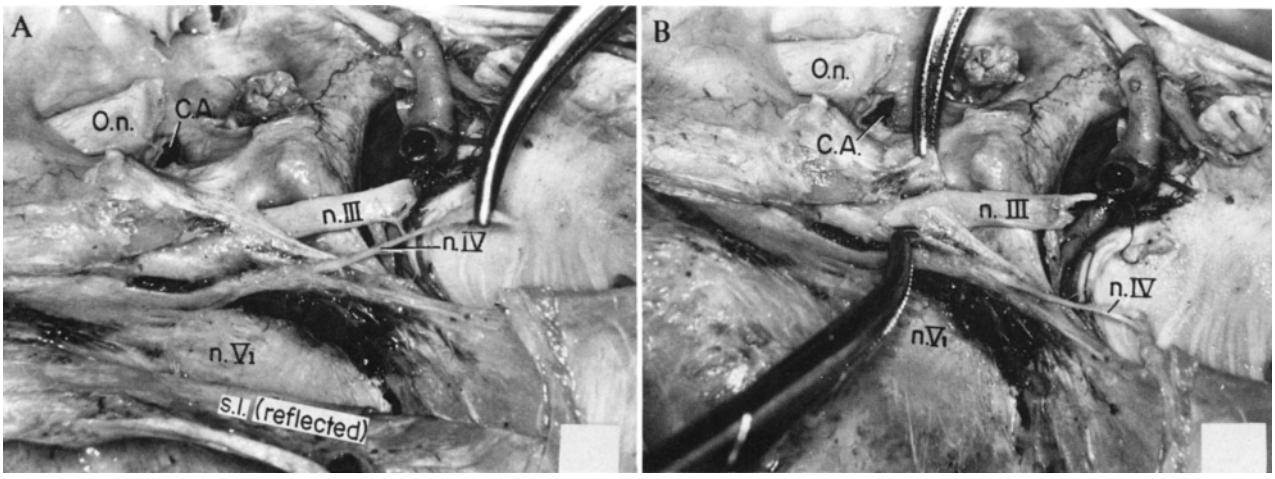


FIG. 4. Left cavernous sinus, with the superficial dural layer (s.l.) separated and reflected downward. A: Nerves III, IV, and V_1 are seen in their corresponding dural sheaths; nerve IV is lifted up by the forceps. The triangular window between the sheaths of nerves III and IV above, and V_1 below, is clearly seen. B: The sheath of nerve III has been opened and its lips grasped by forceps. O.n. = optic nerve; C.A. = internal carotid artery.

transparency, it could generally be recognized even by direct observation before the wall was opened because of the darker color of its area* (Fig. 3A).

As stated above, the two layers of the wall were only loosely attached to each other, and a cleavage plane between them could easily be recognized (Fig. 5). Only in its more anterior part, where nerves III, IV, and V_1 met, crossed, and branched before entering the superior orbital fissure, did the layers of the wall merge and become difficult to separate, resulting in a uniformly thick single wall.

Discussion

From this study, it appears that the structure of the lateral wall of the cavernous sinus does not conform either to descriptions that include a septum dividing the cavity into two compartments,[17,19,24] or to other descriptions of a single dural layer of the wall with nerves embedded in it.[5,23,27,34]

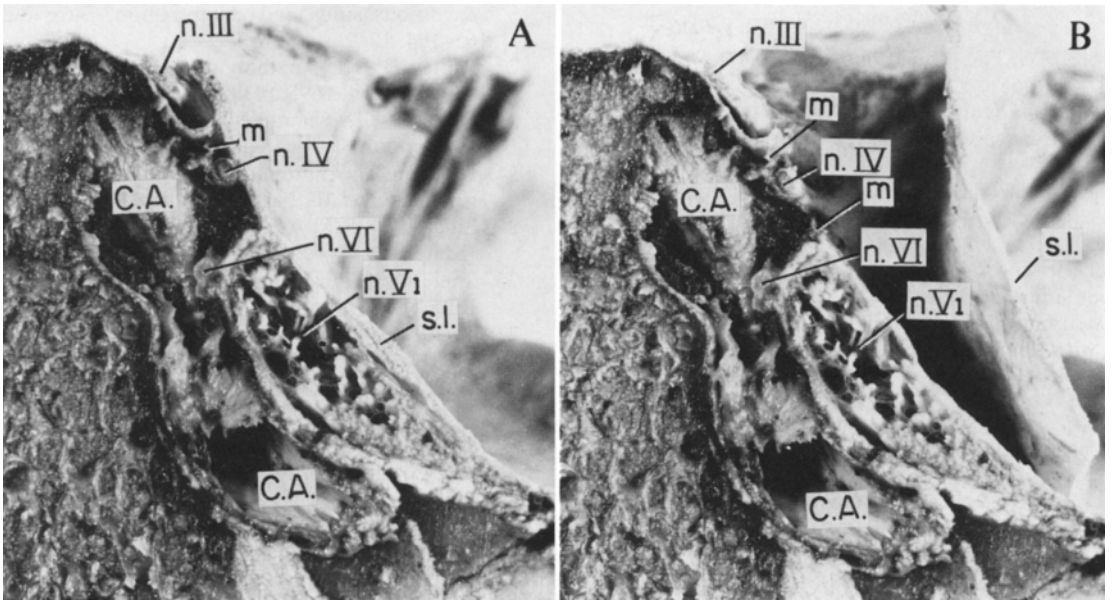
Our findings are similar to those of Patouillard and Vanneuville,[16] who, in their study of 30 sinuses, described an inner deep layer of the lateral wall through which nerves III, IV, and V_1 passed. They described this layer as a "laminated screen" with holes, and stressed the fact that it is adjacent to the external layer, with a clear cleavage plane between the two layers.

Our observations are the same as those of McGrath[12] regarding the fact that nerves III, IV, and V_1 do not run within the dural layer of the lateral wall; however, these nerves run in a deep layer of the wall as we have described. The descriptions of Gardner, *et al.*,[9] Thompson,[29] Crafts,[7] and Snell,[26] which represent nerves III, IV, and V_1 as running within the lateral wall between the dura mater and an endothelial or connective tissue layer that separates them from the sinus cavity, also coincide with our findings.

Parkinson[15] defined a triangular space between nerves III and IV above and V_1 and VI below, which corresponds with the area we have described here where the lateral wall is much thinner because the deep layer is incomplete or missing. He described his surgical approach through this triangle in order to reach the ICA and some branches in the cavernous sinus.

Regarding the relationship of the ICA and sixth nerve in the sinus, most authors describe both these structures as passing through the cavity. However, other opinions differ. Thus, Bedford[1] considers the ICA and sixth nerve as being in the cavity of the sinus in only 8% of cases studied. In the great majority, he considers them to be outside the lumen of the sinus, forming its lateral boundary (Fig. 1d). McGrath[12] states that the relationship of the ICA to the medial and lateral walls of the sinus is variable. Even in the same individual it may change at different levels. Indeed, we also very frequently found the ICA displaced toward the medial or the lateral wall of the sinus, with nerve VI in these latter cases being pushed against the lateral wall at the level of V_1. We interpret these changes in many cases as a displacement of the ICA due to the enlargement, elongation, and tortuosity of the vessel as a result of arteriosclerosis, and not as a normal basic anatomical relationship. It should be kept in mind that most dissected cadavers are of elderly people affected by this condition. In the fetuses studied by Bedford,[1] the ICA was found "clearly in

* The shades of colors differ among different individuals and in preserved and fresh specimens.



the sinus." Weizenhoffer[36] describes the ICA as running in the medial wall of the sinus (Fig. 1e), and Rhoton, *et al.*,[21] state that the ICA may protrude through the medial wall of the cavernous sinus and indent the pituitary gland or produce a prominence of the wall into the sphenoid sinus. We have very often observed similar changes during our dissections. In a previous paper,[14] we also described nerve VI as being split into two or more branches in its course lateral to the ICA, as mentioned by Rhoton, *et al.*[21]

The differences in description regarding the presence or absence of nerve V_2 and part of the trigeminal ganglion in the lateral wall of the sinus can be explained by individual variations, and only in some cases are these structures located partially in the wall. In such cases they are found in the deep layer, similar to nerve V_1. For this reason, we do not refer especially to these structures in the present study.

Detailed and more precise anatomical investigations of the sinus and of the structures related to it may still contribute to a better understanding of the hemodynamics[20] of the sinus as well as being helpful for correct interpretation of the pictures obtained either by arteriography or phlebography,[6,11,28,31–33] or by the more sophisticated modern computerized tomography and ultrasound techniques. Many studies of this kind are currently being carried out.

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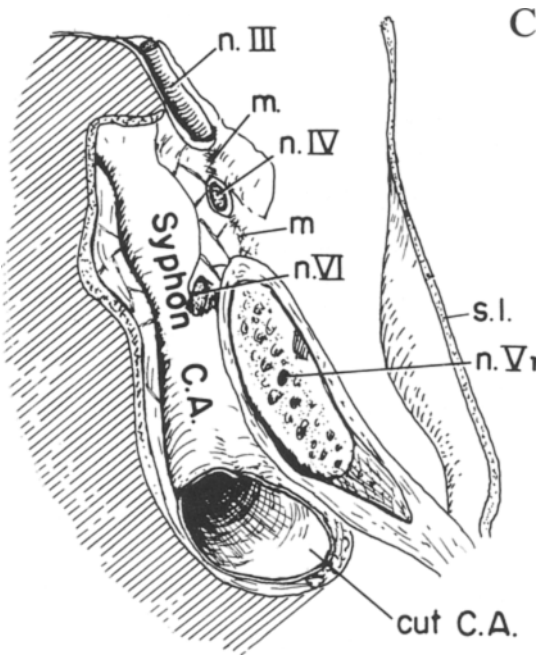

FIG. 5. Frontal (coronal) section of the right cavernous sinus at the site of entrance of nerve III, as seen from behind. A: The superficial layer (s.l.) is attached in place to the deep layer. B: The superficial layer (s.l.) of the lateral wall has been incised and separated from the deep layer. The latter is clearly seen to be formed by the sheaths of nerves III, IV, and V_1, connected by an irregular reticular membrane (m). Note that this membrane is incomplete between nerves III and V_1. Here the contents of the sinus come in contact with the superficial layer. Nerve V_1 is seen in its sheath, split into a number of small fascicles (see Fig. 3B). The internal carotid artery (C.A.) is cut in its inferior portion, while its "siphon" can be seen within the cavity of the sinus, surrounded by trabeculae. Nerve VI passes between the artery and nerve V_1. C: Artist's drawing of the anatomical features shown in B.

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