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The So-Called Cavernous Sinus: A Review of the Controversy and Its Implications for Neurosurgeons

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The so-called cavernous sinus is a venous pathway, an irregular network of veins that is part of the extradural venous network of the base of the skull, not a trabeculated venous channel. This venous pathway, the internal carotid artery, and the oculomotor cranial nerves cross the medial portion of the middle cranial fossa in an extradural space formed on each side of the sella turcica by the diverging aspects of a dural fold. In this space the venous pathway has only neighborhood relations with the internal carotid artery and the cranial nerves. The space itself must be distinguished from the vascular and nervous elements that it contains. The revision of the anatomy of this region has not only theoretical interest but also important clinical implications. (*Neurosurgery* 11:712–717, 1982)

Key words: Anatomy, Cavernous sinus, Dural fold, Internal carotid artery, Middle cranial fossa, Oculomotor cranial nerve, Venous pathway

According to Bedford (2), the earliest description of the cavernous sinus (CS) was probably made by Ridley in 1695, but it was Winslow in 1732 who compared it to the corpus cavernosum of the penis (32), and the term cavernous sinus has been used ever since. Until the middle of our century, the CS was thought to be a blood-filled channel completely surrounding the internal carotid artery (ICA). In 1949, after numerous dissections of fresh specimens of adults, newborns, and premature infants, I reached the conclusion that the parasellar venous pathway, known as the cavernous sinus, and its relationship with the ICA and the cranial nerves were very different from the classical descriptions (23, 24, 26). It is impossible by dissection alone to understand and conceptualize the anatomy of this particular region and in general the morphology of the cranial dura. Indeed, the adherence of the dura propria (internal layer of the cranial dura) to the intracranial periosteum (external layer of the cranial dura) allows the inspection only of the interior aspect of the pericerebral dura; this description of the cranial dura "from its interior" is probably the cause of many misinterpretations. The only way to understand the morphology of the cranial dura propria is to consider it as a continuous sheath formed around the brain, its nerves, and its vessels that is submitted during embryonic development to duplications and torsions. The internal layer of the dura may be compared to the peritoneum. The principle of the schematic reconstruction that helped anatomists to understand the disposition of the peritoneum and its foldings and their relationship with the gastrointestinal tract and its vessels may also be applied to the pericerebral dura propria. It is evident that the morphology of the cranial dura as well as that of the cranial bones is the consequence of the development of the brain. In the same way the disposition of the cerebral vessels and cranial nerves is also a direct consequence of the development of the brain.

One of the consequences of the development of the brain in regard to the morphology of the dura is the formation of dural folds involving the dura propria while the intracranial periosteum remains attached to the bone. The falx cerebri and the tentorium cerebelli are dural folds and not expansions or fibrous septa or partitions, as classically described. Every dural fold has two aspects, a free border and a peripheral one (Fig. 1). The two aspects of each fold closely adhere except when there are vessels or nerves between them. On each side of the sella turcica, the dura forms a fold with a free border that is in continuity posteriorly with that of the tentorium cerebelli and anteriorly with the free border of the fold formed between the frontal and the temporal lobes (Fig. 2). In the parasellar region, because of the existence of vascular and nervous elements that cross the medial portion of the middle cranial fossa, the two aspects of the fold diverge and form an extradural space that I had called "the space of the cavernous sinus" to distinguish the space itself from its contents in the same way that Meckel's cave is distinguished from the gasserian ganglion that it contains (23, 24, 26). The superomedial dural aspect of the space is in continuity with the dura forming the diaphragma sellae, while its lateral aspect is in continuity with the temporal dura propria. The osseous boundaries of the space are the lateral wall of the sphenoid bone and the apex of the petrous bone with their periosteum (Fig. 3). Anteriorly the space communicates with the orbit through the superior orbital fissure. Included in this interperiosteodural space are a venous pathway (the so-called cavernous sinus); the ICA; the 3rd, 4th, and 6th cranial nerves; and in a lesser way the two first divisions of the trigeminal nerve.

The parasellar venous pathway

The parasellar venous pathway is not a trabeculated channel, but is a network of small caliber veins that drain the venous blood of the ophthalmic veins, the sphenoparietal sinus, and the intercavernous sinuses posteriorly and inferiorly toward the petrosal sinuses and the jugular vein. This extradural venous pathway is part of the venous network of the base of the skull

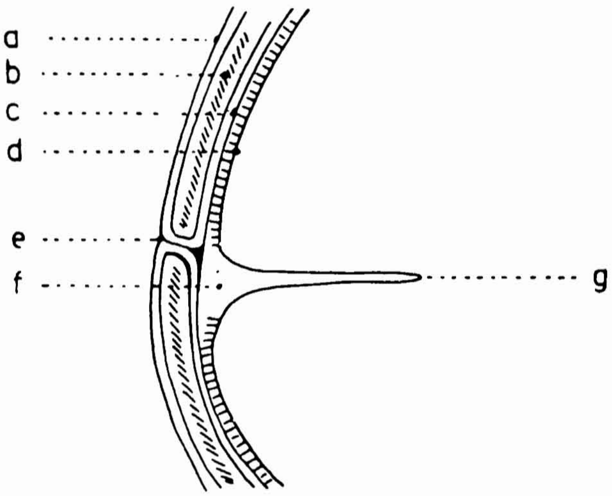

FIG. 1. A dural fold: *a*, extracranial periosteum; *b*, cranial bone; *c*, intracranial periosteum (external layer of the dura); *d*, dura propria adhering to the intracranial periosteum; *e*, suture; *f*, peripheral border; *g*, free border.

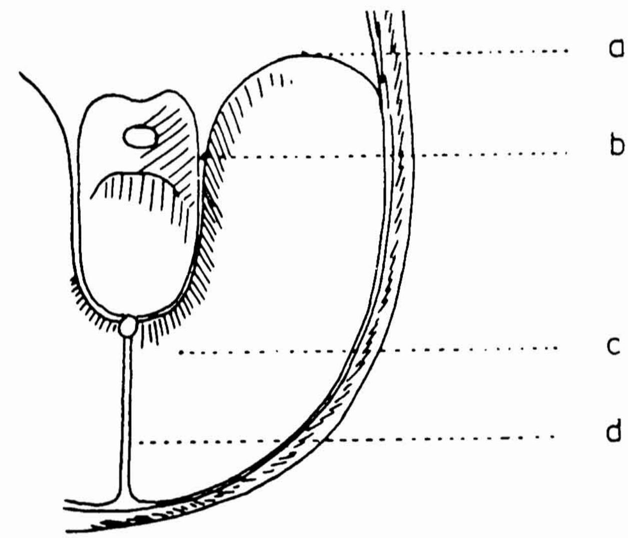

FIG. 2. The parasellar dural fold: *a*, dural fold between the frontal and temporal lobes; *b*, the parasellar fold forming the space of the cavernous sinus; *c*, tentorium cerebelli; *d*, section of the interhemispheric fold (falx cerebri).

and what remains of the primary venous plexus described by embryologists.

The internal carotid artery

After its petrous segment, the intracranial ICA is included in the laterosellar extradural space without having to pierce a floor, which does not exist (Fig. 3). The artery is at first against the sphenoid bone and marks a groove on the bone. Higher up, the artery courses among the veins forming the venous pathway, but has only a neighborhood relation with them. After a first curve, the artery may be medially in contact with the intrasellar dura surrounding the hypophysis (Fig. 4), as was noted in 1695 by Ridley. At the level of the base of the anterior clinoid process, the carotid artery forms another curve and continues its course intradurally. The curves of the artery (carotid siphon) are the consequence of the formation of the middle cerebral fossa (MCF). Small dural branches arise from the extradural segment of the ICA: the more common are the meningohypophyseal trunk, the trunk of the inferior lateral aspect of the CS, and the capsular arteries of McConnel. According to Parkinson, "these small and short branches are exceedingly thin walled and may be mistaken for trabeculae" (17). The ophthalmic artery may also arise from the extradural portion of the ICA. To become intradural, the ICA does not "pierce" or "perforate" the dura, as is so improperly stated in anatomy textbooks. During embryonic development, the brain, its vessels, and the cranial nerves are enclosed by the original ectomeninx, from which derive the dura propria and the cranial bones. The ICA is thus enclosed by the petrous bone and then

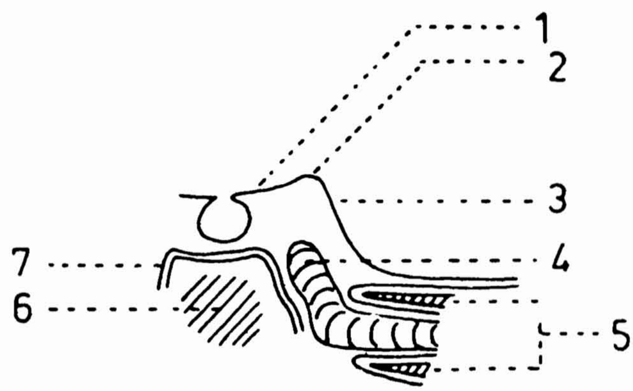

FIG. 3. The walls of the space of the cavernous sinus: *1*, superomedial aspect of the fold in continuity with the diaphragma sellae and the intrasellar dura; *2*, free border of the dural fold; *3*, lateral aspect of the fold in continuity with the temporal dura propria; *4*, internal carotid artery entering the space; *5*, apex of the pyramid of the petrous bone; *6*, the sphenoid bone; *7*, intracranial periosteum.

FIG. 4. Section of the skull at the level of the horizontal segment of the laterosellar internal carotid artery. The artery is in contact with the intrasellar, perihypophyseal dura.

higher up by the dura propria, and the artery, from extracranial, becomes intracranial but extradural, and then intradural without piercing the bone or the dura. The involvement of the ICA by the dura corresponds to the base of the anterior clinoid process and, because of the adhesion of the dura propria to the intracranial periosteum, the artery at this level is "fixed" to the bone, whereas in its extradural and intradural segments the carotid artery has some mobility. In its intradural segment, the ICA has a thin fibrous (dural) sheath and a leptomeningeal sheath which, when distended by cerebrospinal fluid (CSF), form a cisterna, as described by Yasargil et al. (33). It has been known since 1850 that the leptomeningeal periarterial sheaths continue around the intracerebral arteries and contain CSF, not lymph, as had been originally believed (31).

The cranial nerves in the middle cerebral fossa

As a consequence of the formation of the frontal and temporal lobes of humans, the oculomotor 3rd, 4th, and 6th cranial nerves to reach the orbit must pass through the medial portion of the MCF included in the laterosellar extradural space. To enter this space, the nerves do not "pierce" the dural walls of the space; the dura forms a sheath around each nerve and in the MCF the nerves have two sheaths, a leptomeningeal sheath or epineurium and a dural sheath or perineurium. (In the posterior fossa the leptomeningeal sheath around each cranial nerve, when distended by CSF, forms a cisterna (33).) In the MCF, the 6th nerve is generally in the extradural space between the ICA and the temporal wall. The 3rd and 4th nerves are very close to this wall, and the contact of the sheaths of these nerves with the dura explains why the temporal wall appeared multilayered to Hovelacque (7). This author had noticed that the 3rd and 4th nerves were separated by fibrous membranes as if each nerve had its own sheath. The gasserian ganglion and the branches of the trigeminal nerve also have two sheaths, leptomeningeal and dural. The dural sheath of the ganglion is Meckel's cave. The ophthalmic and to a lesser extent the maxillary division of the trigeminal nerve with their sheaths are in proximity to the lateral dural wall of the space and are between the dura propria and the periosteum of the petrous bone.

DISCUSSION

Literature review

In 1951, Olivier and Papamiltiadis wrote that only 5% of the specimens they studied were similar to the classical concept of the ICA being free in the interior of a venous channel (13). In 1955, Bonnet stated that the CS as such does not exist (3). In 1966, Hamby described the CS as a conglomeration of veins surrounding the siphon of the carotid artery within a roughly triangular space between the dura and the periosteum of the parasellar area (5). Parkinson in his first publications about the repair of carotid-cavernous fistulas repeated the classical conception of the carotid artery "hanging freely within the CS" (15, 16).

Bedford in 1966 investigated 35 CSs with special regard to the presence of trabeculae within the sinus (2). His conclusions were that the CS was virtually an unbroken channel in 80% of his specimens and that the trabeculae were so insignificant in the majority of subjects that there is a case for deleting the term cavernous from the description of the sinus (2). In 1972 Patouillard and Vanneuville studied the walls of the sinus and wrote that "thanks to the principle of the dural folds the CS had been integrated in an architectural system common to the other intracranial dural formations" (21). In 1973 Parkinson, after using various corrosion specimens, reached the conclusion that the parasellar venous pathway known as the CS is an irregular plexus of varyingly sized veins (18). In 1973 the 29th Edition of *Gray's Anatomy* described the CS as an irregularly shaped, trabeculated structure, "so named because of the resemblance of its trabeculated structure to that of the corpus cavernosum penis." In the sinus, "the blood flows around the ICA and the abducens nerve but is separated from them by fibrous sheaths and endothelium" (4). In 1976 Harris and Rhoton, after microsurgical dissection, described the CS as an "unbroken trabeculated venous channel" with three major spaces within the sinus, posterosuperior, anteroinferior, and medial to the intracavernous portion of the ICA (6). During that same year, Kaplan et al. published photographs of Vinylite casts that gave the impression that the CS was but part of the extradural venous network of the base of the skull (8). However, in 1977 Parkinson, reviewing the book by these authors about dural sinuses, wrote that Kaplan's casts of the CS did not show the same features as his or, if they did, the photographs were such that one could not delineate the plexiform nature of the vascular pattern (19). In 1976, Papadakis and Lukl reported the results of their study of 30 CSs by dissection after injection of the ophthalmic veins and the superior petrosal sinus with methylene blue and Silastic (The Dow Chemical Co., Midland, Michigan). Their findings confirmed that the so-called CS is an epidural space containing the ICA and the 6th nerve and that there is no blood or fibrous septa contained in this space. A few small veins traverse the space. The authors concluded that the ophthalmic veins join a rich network of dural veins, which again converge to form the petrosal sinus (14). In 1978, Parkinson et al. reiterated that the laterosellar venous pathway is a venous plexus (20). In 1978 in the *Atlas of Medical Anatomy* by Langman and Woerdeman, the CS is described as being formed by a large plexus of communicating veins forming a cavernous, almost trabeculated structure (9). During the same year Monod and Duhamel in a book of anatomical drawings schematically figured the CS as a rectangular space containing the ICA surrounded by three venous cavities (11). In 1979, Mullan mentioned Parkinson's description of multiple interconnected veins as typical of the normal sinus, but stated that he considered the CS to be formed by two venous cavities or sacs that eventually connect to form a single cavity (12). Manelfe in 1980 also stated that the CS has compartments and that the posterosuperior compartment can be reached by venous catheterization, as Mullan had proposed (10). In 1982 Umansky and Nathan studied particularly the lateral wall of the CS and found that it was formed by two layers, a superficial dural layer and a deep layer formed by the sheaths of the 3rd and 4th cranial nerves and of V_1 and V_2, plus a reticular membrane (often incomplete) between the sheaths (30). During the same year, Barrow et al. mentioned that the oculomotor nerves "travel through the sinus" (1).

Thus, some authors have also reached the conclusion that the parasellar venous pathway is a network of veins, while others continue to consider it as a venous channel, unbroken for some, with compartments for others, trabeculated or not (Table 1). No other author has mentioned the relationship of the ICA and the cranial nerves with the dura as described in this report.

Importance of the revision of the anatomy of the parasellar region

The revision of the anatomy of the parasellar region known as the CS has not only a theoretical interest. Of practical importance for the neurosurgeon are the following points:

1. The ICA in the laterosellar space is extradural.
2. The possibility that the ICA is in contact with the intrasellar dura must be taken into consideration during a transsphenoidal approach to the hypophysis.

TABLE 1

Descriptions of the "Cavernous Sinus" since 1949

1949—Taptas: The so-called CS is an extradural space formed by the diverging aspects of a dural fold. There is no sinus, but there is a venous plexus. The ICA and this plexus have only neighborhood relations.

1951—Olivier and Papamiltiades: 5% of the studied cases are of the classical type with the ICA free in a venous channel.

1955—Bonnet: There is no CS as such, but there is a venous plexus.

1965, 1967—Parkinson: The carotid artery is hanging freely within the CS.

1966—Bedford: The CS is an unbroken venous channel in 80% of the cases. The trabeculae are so insignificant that there is a case for deleting the term "cavernous."

1966—Hamby: The CS is a conglomeration of veins surrounding the siphon of the ICA and contained within a roughly triangular space between the dura and the periosteum of the parasellar area.

1972—Patouillard and Vanneuville: The walls of the CS are the aspects of a dural fold.

1973—*Gray's Anatomy:* The CS is an irregular, trabeculated structure. In the sinus, the blood flows around the ICA and the 6th nerve, but is separated from them by a fibrous sheath and trabeculae.

1973—Parkinson: The CS is an irregular plexus of various size veins.

1976—Harris and Rhoton: The CS is an unbroken, trabeculated venous channel with three major spaces.

1976—Kaplan et al.: Vinylite casts show the CS as part of the extradural venous network of the base of the skull.

1976—Papadakis and Lukl: There is no CS as such, but there is an epidural space containing the ICA and a rich network of dural veins.

1978—Langman and Woerdeman: The CS consists of a large plexus of communicating veins forming a cavernous, almost trabeculated structure.

1978—Monod and Duhamel: The CS is a rectangular space containing the ICA surrounded by three venous cavities.

1978—Parkinson et al.: The lateral sellar venous pathway is a venous plexus.

1979—Mullan: The ICA divides the quadrilateral cavity of the CS into two cavities or sacs, which may connect into one cavity.

3. An injury of the parasellar venous pathway is rare and generally does not present a serious surgical problem, contrary to an injury of the ICA.

4. Aneurysms developing in the laterosellar segment of the ICA, with the exception of giant ones, cannot bleed in the subarachnoid space, but may compress the oculomotor nerves to cause partial or total ophthalmoplegia. The ophthalmic division of the trigeminal nerve may also be irritated. Partial thrombosis of the aneurysm or of the ICA above the aneurysm, as well as emboli from the aneurysm, may lead to localized cerebral ischemia with contralateral symptoms which, in association with the homolateral ophthalmoplegia, constitute a "crossed syndrome of the middle cerebral fossa" (22). Because of the close relation of the ICA with the osseous boundaries of the laterosellar space, aneurysms of the siphon may erode the base of the MCF, the lateral wall of the sphenoid bone, and the medial portion of the orbital fissure (22).

5. The radiological landmark of the origin of the intradural ICA is the base of the anterior clinoid process (28).

6. The fixation of the ICA to the base of the anterior clinoid process may result in the compression and occlusion of the artery by sellar or parasellar expansive lesions (29). The fixation of the artery also contributes to its plication in cases of arteriosclerosis with consequent possible cerebral ischemia.

7. The fact that the ICA does not pass through a venous channel refutes the concept that carotid-cavernous aneurysms result from rupture of the artery into the sinus. For 30 years, I have disputed this pathogeny and have stated that the arteriovenous (AV) fistulas known as carotid-cavernous, spontaneous as well as traumatic, are due to the dilatation of pre-existing channels between veins of the parasellar region and dural branches of the internal and/or external carotid arteries, simultaneously or separately (25, 27). These AV fistulas can be compared to the other AV dural malformations admittedly of congenital origin. However, a traumatic AV fistula could be the consequence of a simultaneous tear of a parasellar epidural vein and of an artery belonging to the internal or external carotid system.

8. As there is no cavernous sinus as such, a retrograde catheterization of the sinus is not possible. When treating an AV fistula with an exclusive or predominantly posterior petrosal drainage, a transjugular, transpetrosal balloon-tipped catheter may approach the fistula and occlude it (10, 12).

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COMMENTS

Dr. Taptas is to be congratulated for his excellent review of the anatomy of the cavernous sinus. The controversy regarding whether the cavernous sinus is a plexus of veins or an unbroken trabeculated space has important consequences for neurosurgeons. It is my impression that the venous compartments surrounding the cavernous portion of the carotid artery are formed by the coalescent central ends of the dural sinuses that converge on the area and pass in close proximity to the carotid artery. These coalescent venous channels form several large venous sinuses that course around but do not completely encircle the carotid artery (1).

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I am very pleased to see that the work of Taptas is being published in a place of prominence. I certainly agree with him that this is a difficult area, not only to visualize and understand, but even to conceptualize. His postulations regarding the theory of the formation of Meckel's cave are very intriguing. He compares it with the various peritoneal foldings and pockets, a good comparison. However, as we have often wondered, does the dura start in one place and then go down much as wallpaper might cover a wall, surfacing all of the intracranial structures, or does it start in many separate covers? We have speculated considerably as to whether Meckel's cave might start as a separate entity, and we have not been able to find any embryologist who can help us one way or the other. For instance, if the gasserian ganglion starts at a separate focus, as we believe some other ganglia start, and then extends in both directions—on the one hand, joining with the brain and, on the other, extending peripherally—then, quite possibly, the membrane surrounding it also starts as a separate nidus. The thin fibrous tissue that constitutes the medial wall of this space (including the lateral wall of the pituitary fossa) extending on down over the roof of the bones of the sphenoid sinus and becoming continuous laterally with the much thicker dura of the floor of the middle fossa, encompassing the space known as the cavernous sinus, has puzzled us as to its origin. Our work confirms the different layers in the lateral coverings, which Taptas so beautifully describes (1, 3).

The argument about trabeculations is still rampant. Our injection and corrosion specimens strongly indicated the presence of a plexus of veins. It is readily recognized by anyone who pauses to think that a two-dimensional cross section of a plexus of veins would look no different than a single venous channel with multiple trabeculi. It takes very little more conceptualization to realize that a three-dimensional cross sectional view could also give the impression of trabeculi if the section cut across points of bifurcation of any of the venous channels, leaving a piece of tissue that you could "look around," but that would actually be the joining of the two walls of the bifurcating vessels.

There is no doubt that there are some veins within the lateral walls of the cavernous sinus, which lateral wall is made up of two layers of dura, or two layers of connective tissue at any rate. Our sections indicate that the outer layer is much thicker than the inner layer (1, 3) and becomes very thick superiorly where somehow it is an extension of the two layers of the tentorium going forward to join the anterior and posterior clinoid processes.

Dr. Taptas is quite correct in stating that for 30 years he has argued against the conception of a carotid-cavernous fistula resulting from a rupture of the artery into the sinus. We very definitely agree that, if there is a tear in the anastomosing branch between the internal and the external carotid systems in the parasellar region, it will create a fistula that gives the appearance of filling from either the internal or the external carotid artery, or even from the contralateral internal carotid artery. Even if the opening is considerably lateral to the space known as the cavernous sinus, the retrograde venous filling will be predominantly into this system of veins and the opacification will be maximal in this area. We emphasize that all of this can be apparent with a single opening in the connecting artery. It does not presuppose the necessity of multiple openings just because one can obtain filling of the venous passages from multiple directions.

One feature emerges very clearly from the work of the many investigators and from the numerous corrosion specimens that we have made—namely, that in no two individuals are these parasellar venous channels anywhere near as similar as are, for instance, the straight sinuses or the inferior sagittal sinuses or any of the other sinuses in the head. This lends additional credence to the belief stated by Taptas that this area is a plexus of veins (or several separate veins), and this remains our own belief, although we are continuing to work on the problem. We agree that the numerous fine primary and secondary branches of the parasellar carotid artery, i.e., the meningohypophyseal artery and the artery to the inferior cavernous sinus, all appear as trabeculae in noninjected specimens. In addition, the numerous fine sympathetic branches have a similar appearance (2). Some photographs would be much more convincing than drawings, but no one appreciates better than we do the extreme difficulty in getting suitable specimens because of the extreme thinness of these venous walls.

I question the validity of Taptas' statement that, "as there is no cavernous sinus as such, a retrograde catheterization of the sinus is not possible." This simply doesn't follow logically. If, as we believe and as Sean Mullan pointed out in different terminology, this is a plexus of varyingly sized veins, then there is no reason why a retrograde catheter couldn't get into the larger or even smaller veins, just as an antegrade catheter could. Several of the workers mentioned by Taptas have used different words, yet have described a plexus, merely noting that some of the components of this plexus may be very large. We noted in our studies that the larger segments tended to be the uppermost, and some of these would most assuredly accommodate a catheter even if they weren't dilated.

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