SURGICAL ANATOMY

Meningeal Architecture of the Cavernous Sinus: Clinical and Surgical Implications

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OBJECTIVE: The meningeal structure of the cavernous sinus (lateral sellar compartment) was anatomically and histologically studied. We discuss the clinical and surgical significance and present clinical examples of cranial base tumors.

METHODS: Ten adult cadaveric heads were used for microsurgical dissection or histological studies. Specimens of the cavernous sinus were continuously sectioned in three dimensions and stained by Masson's trichrome method. The findings are anatomically discussed as they pertain to presented clinical cases.

RESULTS: The cavernous sinus, located in an interdural space between periosteal and meningeal dura, is properly accessed by detachment of the periosteal bridge between the superior orbital fissure and the middle fossa. The lateral meningeal dura is dissected under minimal hemorrhage from the sinus, with a surgically important cleaving plane between the "deep layer," a semitransparent meningeal sheath with which the cranial nerves are covered and protected. It has various degrees of meningeal pockets, of which Meckel's cave is the largest example. Adventitia of the carotid artery in the sinus, uncovered with protective meninges, is considered to contact directly with tumors of the sinus origin. The meningeal wall of the cavernous sinus anatomically has three weak points as far as tumor invasion and extension are concerned: the venous plexus around the superior orbital fissure, the loose texture of the medial wall around the pituitary body, and dural pockets of the IIIrd and Vth cranial nerves. The dural wall is extremely thin or missing at those points.

CONCLUSION: A surgical technique based on the meningeal anatomy is important for cavernous sinus surgery. The cavernous apex and Meckel's cave, which are spaces of convergence of cranial nerves, however, are weak points for surgical dissection. The presence or absence of tumor invasion into those areas may influence the microsurgical results. (Neurosurgery 39:527–536, 1996)

Key words: Anatomy, Cavernous sinus, Cranial base, Meninges

Since Parkinson's trial in 1965 (21), the techniques of cranial base surgery have developed and the cavernous sinus has become a surgical "hot spot" (1, 4, 5, 7, 27, 28). Numerous microsurgical studies have been conducted during the past 15 years (5, 8, 10, 15, 18, 19, 24, 25, 32). How tumors extend from or into the cavernous sinus is important clinically and surgically, as is the method of dissection of the complicated meninges on the cavernous sinus under normal or pathologically abnormal conditions. Information on meningeal structures, such as its layers, thickness, and adhesiveness to the cranial nerves, may be valuable for the understanding of tumor extension and of microsurgical dissection. However, there are few descriptions that focus well on meningeal structure (5, 13, 15, 30, 31). The present study demonstrates histological sections focusing on the meningeal structure of the cavernous sinus, and the discussion extends regarding the clinical and surgical implications of the structure, presenting clinical examples of cranial base tumors. The common usage term "cavernous sinus" is used in this article instead of "lateral sellar compartment" (22, 23).

MATERIALS AND METHODS

Ten adult cadaveric heads were used for this study. Five of those were perfused with colored silicone to observe the vascular structures, and anatomical dissections of both cavernous sinuses, including the petrous apex, were made. In another five, 10 blocks of cavernous sinus were used for histological specimens.

Cadaveric dissection

Cadaveric dissection was performed, and the anterior clinoid process was removed. The superficial layer of the cavernous sinus was dissected, with the dural layer on the middle fossa, according to the method presented by Dolenc (5). The dural dissection was continued on the petrous pyramid, and the apex of the petrous pyramid was resected by the anterior transpetrosal approach (11).

Histological section

Large blocks of cranial base, including the cavernous sinus and apical petrous pyramid, were fixed with 10% formalin and decalcified for 1 month. The specimens were embedded in paraffin and serially sectioned into coronal, sagittal, and axial plane slices of 20-μm thickness. Five to 10 of each of the serial slices were stained by Masson's trichrome method (17) and observed under a low-magnification light microscope. By this method, collagen is stained blue; cytoplasm, keratin, muscle, and intercellular fibers are stained red; and cell nuclei are stained black.

RESULTS

Photographs of cadaveric dissection are presented in *Figure 1*, and histological sections of the cavernous sinus are presented from anterior to posterior in *Figure 2*.

Anterior cavernous sinus

Cadaveric dissection

The anterior half of the cavernous sinus is exposed epidurally. As the anterior clinoid process is located between the superior orbital fissure (SOF) and the optic canal, its resection is the first stage in the opening of the cavernous sinus. On the lateral side of the SOF, periost of the orbital wall (periorbita) bridges to the periosteal dura of the middle fossa, being continuous to the medial wall of the cavernous sinus. The meningeal dura is continuous to the lateral wall of the cavernous sinus (superficial layer). Posterior to the SOF, two layers begin to separate, and amputation of the periosteal bridge leads to the initial point of dissection of the superficial layer (*Fig. 1A*). A thin and semitransparent meninge (deep layer) covers the cranial nerves. Close to the SOF, cranial nerves are wrapped with a common meningeal sheath, which is continuous to the periost of the orbit anteriorly and to the inner layer posteriorly. Venous channels are directly exposed without the covering in the following three points: 1) postero-

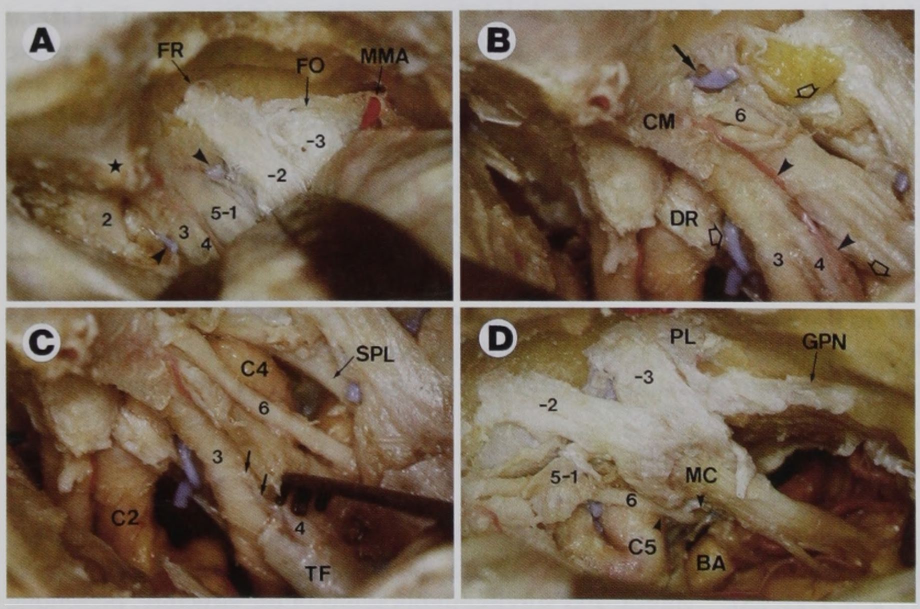

FIGURE 1. Cadaveric exposure of the right cavernous sinus. The meningeal layers are preserved as much as is possible. Cranial nerves are numbered. *A*, epidural exposure. The superficial layer of the lateral wall (meningeal dura) is dissected. The *star* indicates the starting point of dural dissection on the SOF. Note the dural adhesion to the nerves around the foramen rotundum (*FR*) and ovale (*FO*). The deep layer is observed as a semitransparent covering on the cranial nerves. Note the uncovered points of the deep layer, where the venous channel directly appears (*arrowheads*). *MMA*, middle meningeal artery. *B*, cavernous apex is focused. Note the common meningeal covering (*CM*) on the apex continuous to the periost of the orbit, including the superior branch of the inferolateral trunk (*arrowheads*). *Open arrows* indicate the venous channels uncovered with the inner layer. The drainage route from the middle cerebral vein (*arrow*) is close to the abducens nerve. Adipose tissue is observed in the anterolateral triangle. *DR*, dural ring of the carotid artery. *C*, dura is incised along the tentorial fold to the meningeal pocket of the oculomotor nerve. Note that the oculomotor nerve is not covered with the dura at the bottom of the meningeal pocket (*arrows*) but is covered with a thin coverage continuous to the inner layer. The trochlear nerve is tightly covered with the tentorial fold (*TF*) at the portion posterior to the dural pocket. The ophthalmic nerve is retracted to show the abducens nerve. *SPL*, sphenopetrosal ligament. *D*, subtemporal overview to the posterior cavernous sinus and posterior fossa, combined with anterior transpetrosal approach. The tentorium is removed with the lateral wall of the cavernous sinus. The posterior part of the abducens nerve in the course of Dorello's canal (*arrowheads*) can be observed after mobilization of the trigeminal nerve by this method. Near the foramen ovale, the inner layer is adhesive to the periosteal layer (*PL*) covering C6 and the petrous apex. A thin wall of Meckel's cave (*MC*) is removed with the outer layer. *BA*, basilar artery; *GPN*, greater petrosal nerve.

ateral to the SOF, where middle cerebral vein is drained; 2) posterior to the carotid dural ring; and 3) at the posterior part of Parkinson's triangle (*Fig. 1B*).

The upper rim of the cavernous sinus is exposed by incision of the tentorial fold subdurally from the optic canal to the portal of the oculomotor nerve, where the superficial layer is not attached, forming a meningeal pocket (16). The bottom of the meningeal pocket is covered only by a thin meninge, which is continuous to the inner layer (*Fig. 1C*). Posterior to this point, the trochlear nerve is hard to separate from the tentorial fold. Superior to the ophthalmic nerve, Parkinson's triangle is apparent, and a fine arterial branch of the inferolateral trunk of the cavernous sinus artery appears therein. In this portion, the trochlear nerve courses parallel to the oculomotor nerve.

Histological sections

Anterior to the SOF, the cranial nerves are wrapped tightly with annulus tendineus, a consistent periosteal capsule including adipose tissues that are continuous from the orbit (20) (*Fig. 2A*). The frontal nerve, lacrimal nerve, and trochlear nerve course along the outside of the annulus. Posterior to the SOF, all the cranial nerves passing the cavernous apex are wrapped with a common meningeal sheath (*Fig. 2B*). At the crossing point of the carotid artery, the IIIrd and IVth cranial nerves locate superiorly, the Vth in the middle, and the VIth inferiorly. The anterior loop of the carotid artery is suspended superiorly with the dural ring and laterally with the carotico-oculomotor membrane (10), which is referred to as the proximal ring (5), separating the venous route. The medial side of the carotid loop faces the periosteum of the sphenoid sinus without firm adhesion. The portal of the IIIrd cranial nerve forms the so-called "meningeal pocket" (16) or "nerve canal" (5) (*Fig. 2C*). A thin meningeal lining in the bottom of the dural pocket separates the venous channel. Anterior to the gasserian ganglion, the lateral wall is clearly separated into two layers, and each cranial nerve is wrapped with an independent meningeal sheath (*Fig. 2D*). The abducens nerve changes its course medial to the ophthalmic nerve, loosely attached to the carotid siphon.

Posterior cavernous sinus

Cadaveric dissection

The posterolateral wall of the cavernous sinus is formed by Meckel's cave of the Vth cranial nerve. Meckel's cave is covered with a thinner dural wall (superficial layer), and it is occasionally opened by dissection of the superficial layer. The abducens nerve in the course of Dorello's canal is located behind the cave and exposed only by mobilization of the trigeminal nerve laterally, after resection of the petrous apex (*Fig. 1D*). The horizontal portion of the carotid artery (C4) is visualized in Parkinson's triangle without meningeal covering. The inferior part of the venous channels and C5 are separated from Meckel's cave by the sphenopetrosal ligament.

Histological section

The upper half of the medial wall of the cave is covered with a thin meningeal layer, which directly contacts the venous channel (*Fig. 2E*). Meckel's cave is the largest example of a meningeal pocket and is filled with the subarachnoid space. The nerve fibers in the cave are unravelled in the subarachnoid space. Arachnoid villi, protruding into the venous drainage route along the mandibular nerve, are observed on the medial wall of the cave and verify the function of the cave as cerebrospinal absorbed. The carotid artery (C4–C5) is exposed in the sinus without meningeal covering and loosely suspended on its medial side with periosteal tissues. Therefore, tumors originating from the cavernous sinus easily encase the carotid artery and invade Meckel's cave. The cavernous sinus medial to the carotid artery is continuous to the intercavernous sinus along the pituitary base. A loose meningeal dura covering the pituitary body allows easy invasion of the pituitary tumor into the parasellar space (*Fig. 2F*). Reticular interstitial connective tissues are commonly seen between the pituitary body and the carotid siphon, involving adipose tissues and arterial branches of the meningohypophyseal trunk. This connective tissue may be minimally defensive against tumor involvement of the carotid artery. The venous space is smaller in the juvenile specimen than in the elderly specimen, being occupied by a large amount of adipose tissues. The inferomedial wall of Meckel's cave is protected by the sphenopetrosal ligament, which forms the lateral wall of the foramen lacerum (*Fig. 2G*). The posterior cavernous sinus commonly has the largest venous space, as a confluence of the venous drainage routes to the pterygoid plexus and to the superior and inferior petrosal sinuses. The carotid artery (C5) is loosely suspended on its medial side with periosteal tissues. The periosteal suspension is thickened and wraps the total surface of the carotid artery in the foramen lacerum. The posterior part of the trochlear nerve is wrapped tightly in the tentorial fold (*Fig. 2H*). The abducens nerve courses in the venous channel between the carotid artery and the medial wall of Meckel's cave.

DISCUSSION

Dissection technique of the lateral wall to spare cranial nerve injury

Because it is widely admitted that venous sinuses are situated between the periosteal and meningeal dura (dura propria) (30), the cavernous sinus is considered to be venous plexus in interdural space (22, 29). On the lateral side of the SOF, the two periosteodural layers form a periosteal bridge from the SOF to the middle fossa. Detachment of the periosteal bridge parallel to the SOF introduces the interdural space, where the cavernous sinus is present, without opening the meningeal dura (6) (*Fig. 3*). The semitransparent inner layer protects the cranial nerves and venous channels; however, surgeons have to know the venous bleeding points where the venous channel directly appears without coverage of the deep layer (*Fig. 1A*). Overpacking hemostatic material in the venous channel may cause palsy of the cranial nerve coursing nearby.

Three surgical points are described to avoid cranial nerve injury. The first one is the dural dissection around the foramen rotundum and ovale. By previous technique, the dura was completely dissected from the Vth cranial nerve (4, 5, 32) because of its easy cleaving from that nerve. However, the dissection should be minimized around the foramina because the superficial layer is adhesive to the nerves near the foramina, similar to that near the SOF.

The second point is the dissection of cranial nerves in the cavernous apex. After the dura is opened, the dural ring of the carotid artery is incised. If the dural (superficial layer) incision is extended a few millimeters along the carotid artery (C3), a crossing point of the nerve bundle is observed. In patients with normal extraocular function, those cranial nerves should not be separated anteriorly from this point but dissected as one nerve bundle, because they are wrapped in a single meningeal sheath, including the lateral trunk of the cavernous sinus artery (*Fig. 1B*) (14, 19). The presence of tumor invasion in the meningeal sheath may be a limitation of the tumor radicality, without sacrifice of the extraocular function, as shown in *Figure 4*.

The third point is the posterior part of the IVth cranial nerve, which must be carefully located as it courses under the tentorial fold, firmly adhesive to it (*Figs. 1B* and *2H*). It is

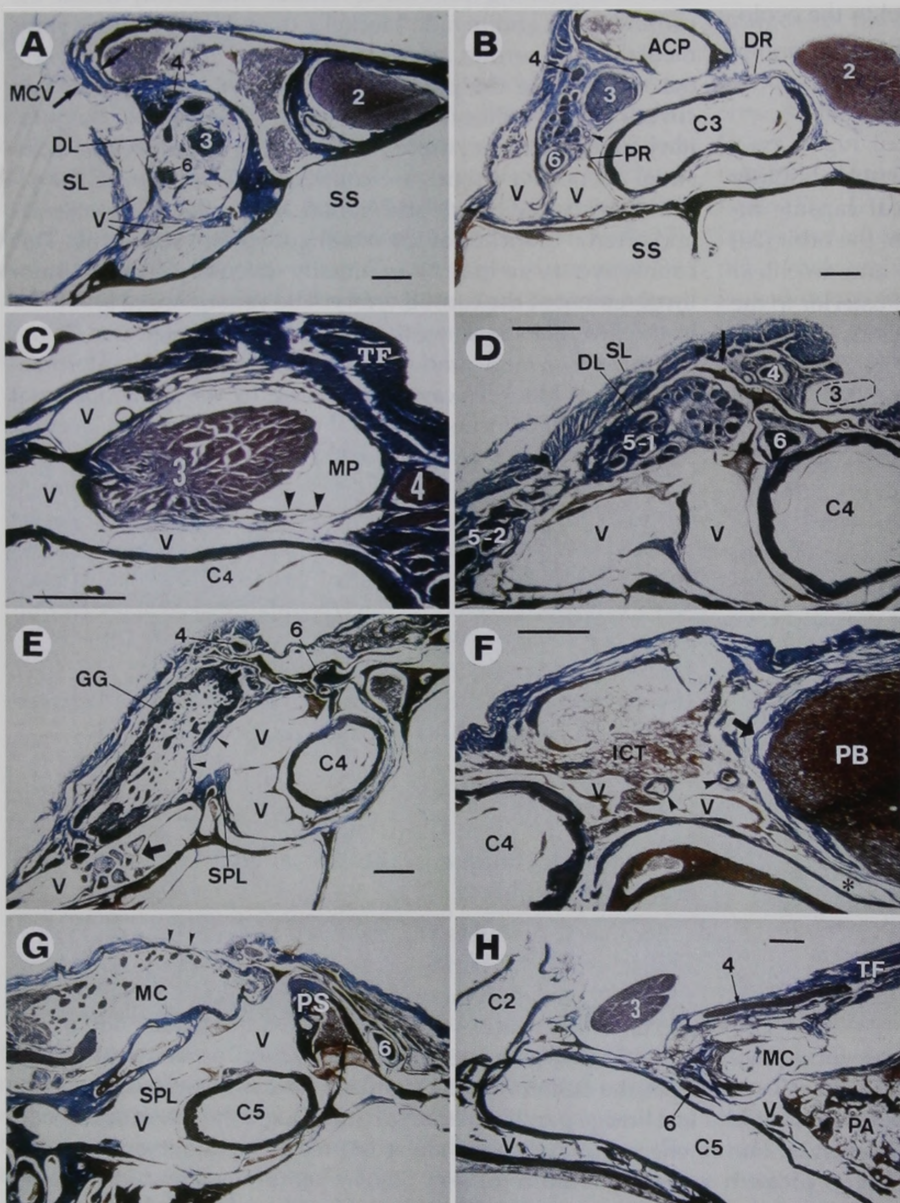

FIGURE 2. Histological sections of the cavernous sinus (lateral sellar compartment) (Masson's trichrome stain). Scale bars are 2 mm. The cranial nerves are numbered. *A*, coronal section through the SOF. Note the double layers of meninges on the lateral side (*arrows*). The lateral layer is the dura on the middle fossa, forming the superficial layer (*SL*) of the lateral wall. The medial layer is a periost of the sphenoid bone, firmly attached to the deep layer (*DL*), forming annulus tendineus. Rich venous channels (*V*) are observed in the inferolateral side, being continuous to the middle cerebral vein (*MCV*) and ophthalmic veins. The deep layer contains adipose tissues continuous to the orbit. The frontal nerve, lacrimal nerve, and trochlear nerve course outside of the annulus. *SS*, sphenoid sinus. *B*, coronal section through the anterior loop of the carotid artery. All the cranial nerves are wrapped with a common meningeal sheath, including the lateral trunk of the cavernous sinus artery (*arrowhead*). Note the multiple venous channels (*V*), present even below the superficial dural layer to which the abducens nerve has close proximity. The carotid artery (*C3*) is suspended by the dural ring (*DR*) superiorly and by the proximal ring (*PR*) laterally but freed from the sphenoid sinus (*SS*). *ACP*, anterior clinoid process. *C*, sagittal section through the meningeal pocket (*MP*) of the oculomotor nerve (labeled *3*). Anterior part of the cavernous sinus is composed of venous plexus (*V*). Note a thin meningeal coverage (*arrowheads*) between the pocket and the venous channel. *C4*, carotid artery; *TF*, tentorial fold. *D*, coronal section of the lateral wall through the portal of the oculomotor nerve (labeled *3*), which is lost in this section. A clear cleavage is seen between the superficial dural layer (*SL*) and the deep layer (*DL*). Cranial nerves are separated and wrapped in their own meningeal sheath. Venous channels (*V*) are medial to the deep layer but appear superficially in the Parkinson's triangle (*arrow*). The abducens nerve (labeled *6*) is located between the ophthalmic nerve (labeled *5–1*) and the carotid artery (*C4*). The trochlear nerve (labeled *4*) is adhesive to the tentorial fold. *E*, coronal section through the gasserian

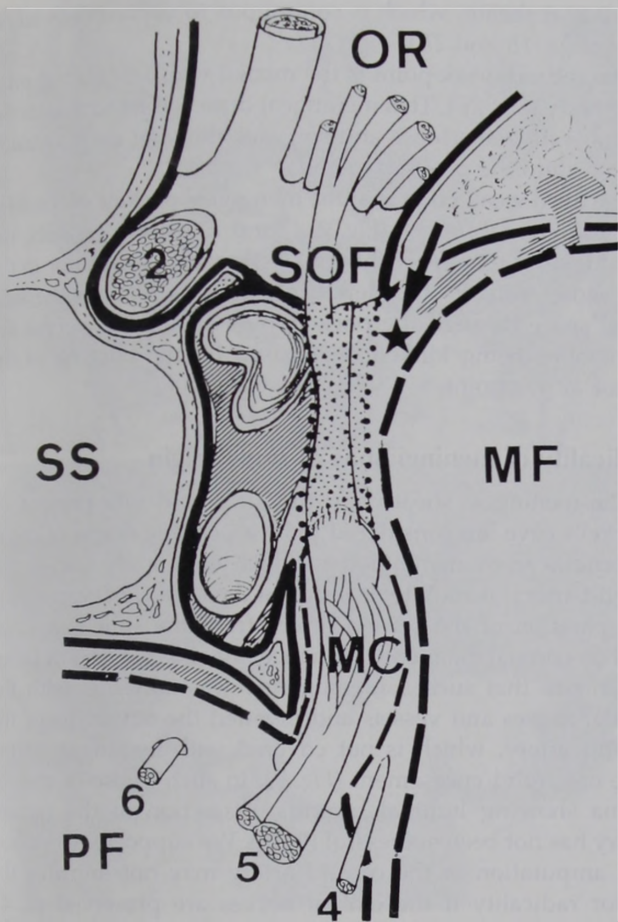

FIGURE 3. Schematic illustration of the meningeal architecture of the cavernous sinus. *Broad line*, periost of the sphenoid bone; *broken line*, dura propria; *dotted line*, deep layer; *shaded areas*, venous channels. The *star* indicates a cleaving plane that is accessible between the superficial and deep layers by incision of the periosteodural bridge of the SOF (*arrow*). *OR*, orbit; *MC*, Meckel's cave; *SS*, sphenoid sinus; *MF*, middle cranial fossa; *PF*, posterior fossa.

possible to expose it totally on cadavers but difficult in clinical cases. Therefore, the trochlear nerve should be preserved in the tentorial fold without dissection (*Fig. 5*).

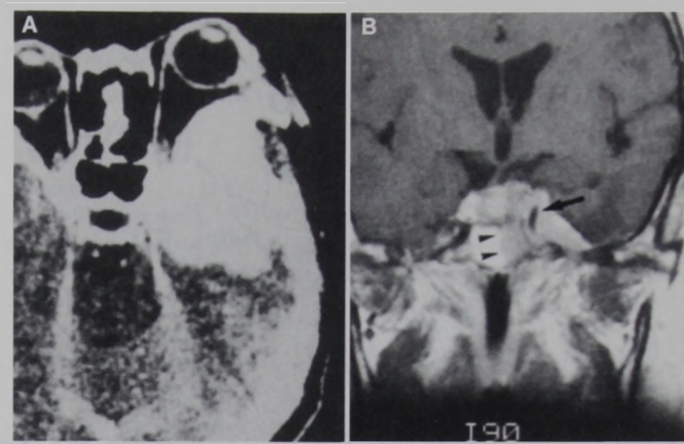

FIGURE 4. *A*, Patient 1. Left sphenoid wing meningioma (meningotheliomatous meningioma) invading the orbitocavernous sinus complex. A 45-year-old woman complained of exophthalmos without extraocular palsy. She was operated on; the orbitozygomatic approach was used. The cavernous apex was invaded by the tumor but was not opened so that orbital function could be preserved. *B*, coronal magnetic resonance imaging 3 years after the operation. Tumor regrowth was seen in the cavernous apex with encasement of the carotid artery (*arrow*) and with extension into the sphenoid sinus (*arrowheads*). Radical subsequent operation, including amputation of the carotid artery and the extraocular nerves, was necessary.

Exposure of the posterior cavernous sinus

The carotid artery and the abducens nerve are accessed mainly from Parkinson's triangle. It is still an important access route, although it is not always seen as a large space in cadavers (10, 19). In the case of a narrow triangle, the apical petrous pyramid is resected to mobilize the Vth cranial nerve with Meckel's cave inferiorly. This technique offers an overview of Dorello's canal (*Fig. 1D*). In fully packed intracavernous sinus lesions, Parkinson's triangle is commonly widened, because IIIrd and IVth cranial nerves are fixed superiorly and the Vth is fixed inferiorly. When tumor is present, the abducens nerve is commonly displaced medially with the carotid siphon, because it is attached to the siphon by connective tissues (*Fig. 2D*).

ganglion (*GG*). Arachnoid villi are seen in the venous drainage route to the pterygoid plexus (*arrow*). Note the thin medial wall of Meckel's cave (*arrowheads*), exposed to the venous channel (*V*). A sympathetic branching is seen from the abducens nerve. The medial side of the carotid artery (*C4*) is loosely attached on the sphenoid sinus, without meningeal coverage on its lateral side. *SPL*, sphenopetrosal ligament. *F*, coronal section between the pituitary body (*PB*) and the carotid artery (*C4*). The medial wall of the cavernous sinus is extremely thin and loose (*arrow*). The interstitial connective tissues (*ICT*) are abundant between the venous channels (*V*), involving arterial branches (meningohypophyseal trunk, *arrowheads*) and adipose tissue. The intercavernous sinus (*asterisk*) is seen under the pituitary body. *G*, coronal section through the petroclinoid synchondrosis (*PS*). Lower part of Meckel's cave (*MC*) is separated from the venous channel (*V*) by the sphenopetrosal ligament (*SPL*). Note the thin dural layer on Meckel's cave (*arrowhead*) and the scattered Vth cranial nerve fibers in it. The abducens nerve courses in Dorello's canal. The venous space is the largest in this section. *H*, sagittal section along the trochlear nerve. Note the trochlear nerve wrapped tightly in the tentorial fold (*TF*). The abducens nerve courses in the venous channel (*V*) between the carotid artery (*C5*) and Meckel's cave (*MC*). *PA*, petrous apex.

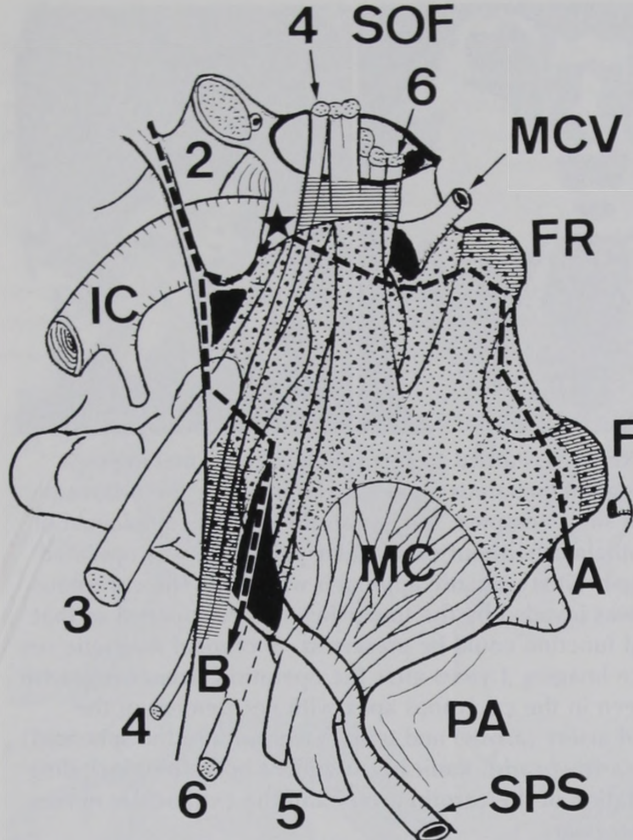

FIGURE 5. Schematic illustration of a minimally invasive method to open the lateral wall of the cavernous sinus. *Dotted area*, covered with the deep layer. *Broken lines A* and *B*, incision lines of the superficial layer for epidural approach and subdural approach, respectively. The adhesive points (*shaded*) are spared. Venous channels are exposed in three points (*black*). Subtemporal resection of the petrous apex (*PA*) is added to mobilize the trigeminal nerve for exposure of the posterior cavernous sinus. *Star*, starting point of dissection; *IC*, carotid artery; *MCV*, middle cerebral vein; *FR*, foramen rotundum; *FO*, foramen ovale; *MC*, Meckel's cave; *SPS*, superior petrosal sinus.

Weak points of the cavernous sinus wall against tumor invasion

The cavernous sinus is protected against tumor outside by the thick dura propria laterally and by the periosteal layer inferiorly. However, we found three weak points in the cavernous sinus wall.

The first one is the venous plexus around the SOF. In cases of medial sphenoid wing meningioma, the tumor occasionally extends into the orbit (*Fig. 4*). In these cases, incidence of tumor invasion into the cavernous apex was high (3, 12) because diploic and epidural venous channels through the SOF communicate directly with the cavernous sinus (22). Removal of the periosteodural layer continuous from the orbit (periorbita) to the lateral wall of the cavernous sinus is essential for complete tumor removal. The morbidity may be influenced by the degree of infiltration of the tumor in the common meningeal sheath, which is continuous to the annulus tendineus (*Figs. 1B* and *2B*).

The second weak point is the medial wall around the pituitary body (*Fig. 2F*). This meningeal dura is different from the lateral wall, being loose and soft and allowing easy invasion from or into the pituitary gland.

The third weak point is at the meningeal pockets of the IIIrd and Vth cranial nerves (*Fig. 2, C* and *E*). In the pockets, the dural layer is extremely thin or missing, and the tumor in the cavernous sinus is considered to extend easily into the subdural space through the pockets (*Fig. 6*). Cranial nerves are vulnerable, being kinked or encased by the bulging of the tumor at this point.

Radicality of meningiomas of sinus origin

The meningeal sheath and the arachnoid villi present on Meckel's cave are considered to be a possible origin of intracavernous sinus meningioma, which commonly encase the carotid artery. A radiological sign of the "carotid encasement" is separation of the carotid artery from the sphenoid sinus wall on coronal magnetic resonance imaging sections. It is our experience that such a meningioma was adhesive with the cranial nerves and vessels and invaded the adventitia of the carotid artery, which is not covered with meninges, at the time of carotid encasement (*Fig. 7*). In such a case of meningioma showing luminal stenosis, dissection of the carotid artery has not been successful (9, 26). We support the opinion that amputation of the carotid artery may not improve the tumor radicality if the cranial nerves are preserved (2, 4), because microscopic tumor deposits remain along the cranial nerves as well. Additional sacrifice of the cranial nerves may not be avoided with sacrifice of the carotid artery. Meningiomas invading the cavernous apex, where nerve fibers are concentrated, may result in a higher tumor recurrence rate than expected, as indicated by long-term follow-up (*Fig. 4*).

Based on the meningeal architecture, it is concluded that epidural dissection of the lateral wall provides anatomically reasonable access to the cavernous sinus with minimal nerve injury. However, there are three weak points of the meningeal wall for tumor invasion to or from the cavernous sinus: the SOF, meningeal capsule of the pituitary body, and medial wall of Meckel's cave. It must be noted as well that tumors are

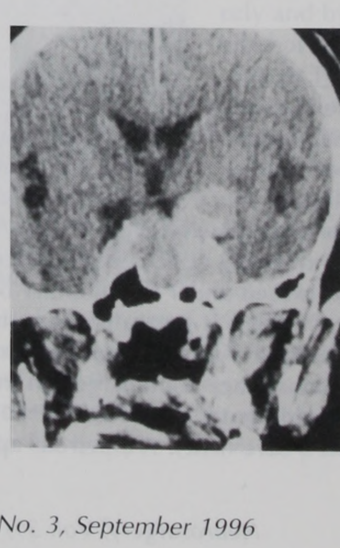

FIGURE 6. Patient 2. Pituitary adenoma (prolactinoma) invading the cavernous sinus. A 53-year-old man complained of headache. The tumor extended into the cavernous sinus, with bulging in the subdural space from the dural pocket of the IIIrd cranial nerve.

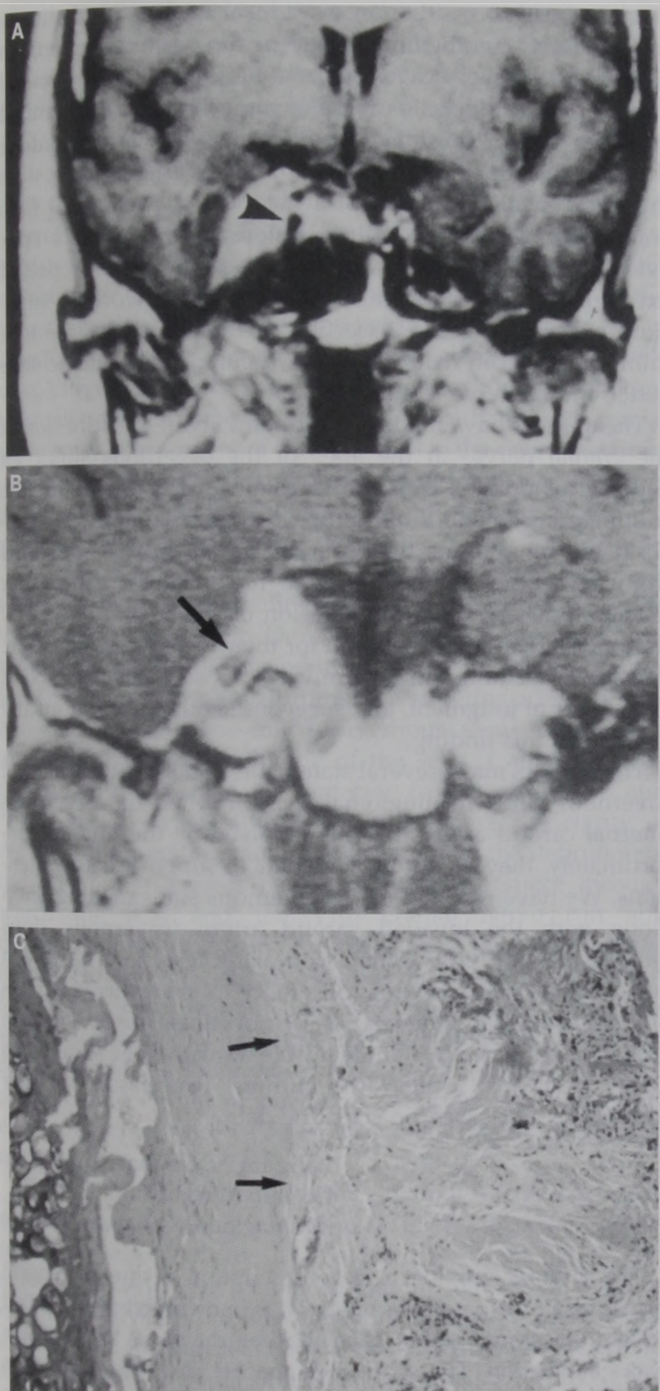

FIGURE 7. Patient 3. A 42-year-old woman complained of right visual disturbance. *A*, intracavernous sinus mengioma. A coronal magnetic resonance imaging section showing encasement of the carotid artery (*arrowhead*). *B*, tumor also invaded Meckle's cave (*arrow*). *C*, pathological specimen of the carotid artery amputated in the operation. Note the tumor invasion in the adventitia (*arrows*) (hematoxylin and eosin stain; original magnification, ×60).

more adhesive with the stripped carotid artery or cranial nerves in the cavernous sinus than with those in the subarachnoid space.

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COMMENTS

Many anatomic studies of the cavernous sinus area have been performed recently. The specific purpose of this report by this experienced group of neurosurgeons and neuroanatomist seems to be to define the meningeal architecture and develop practical applications from the study. It is often difficult to extrapolate the results of a study such as this to operative techniques in patients, because their pathological anatomy is different. This is why we also think that the various "triangles" of the cavernous sinus are of use mainly in cadavers; neoplastic and vascular lesions often distort the anatomy, making the "triangles" unrecognizable.

With regard to the dissection of the dura mater of the cavernous sinus, we do not follow a fixed pattern but vary it according to the configuration of the lesion. For instance, meningiomas invading the anterosuperior portion of the cavernous sinus necessitate an extradural to intradural dissection, whereas meningiomas invading the posterior cavernous sinus from Meckel's cave require a dissection starting lateral and medial to Meckel's cave. For tumors such as trigeminal schwannoma or chordoma, the dural opening can be made at the most prominent bulging area of the cavernous sinus, with the dural peeling being kept away from the IIIrd and IVth cranial nerves. For extradural lesions in the petrous apex extending toward the cavernous sinus, the dura is peeled extradurally, starting from the exit of V3 and working superiorly. By keeping the dissection of the cranial nerves to a minimum, we can reduce their devascularization and achieve better cranial nerve results.

The authors have made a good point about the adhesion of the cranial nerves at the apex of the cavernous sinus. Of course, this point is well known to all surgeons who operate routinely inside and around the cavernous sinus. As emphasized by the authors, these nerves should not be separated from each other in patients who have normal extraocular muscle function. Also, the invasion of the cranial nerves by tumors is an occasional reason for their incomplete resection. However, deciding intraoperatively that such invasion exists is a matter of judgment, and surgeons should be cautious not to overcall this finding.

The authors make several statements about the radicality of cavernous sinus meningioma excision when the cavernous internal carotid artery (ICA) is involved by the tumors. Unfortunately, they do not provide data to support their contentions. We have resected many cavernous sinus meningiomas along with the invaded carotid artery (cavernous sinus Grades III and IV). When complete resection has been achieved, there has been no difference in the recurrence rates of these tumors and tumors that do not encase the ICA (Grade I) or encase it partially (Grade II). We think that the statements about "radicality" reflect the authors' bias based on their experience, not based on scientific data.

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The authors provide a clear description of the meningeal structures in the parasellar region. It is known that the so-called "cavernous sinus" is the space between the dural layers in the parasellar region. The space is connected with the orbit, as is likewise known, and the connection is elegantly demonstrated in the present study. Because of the connection between the orbit and the cavernous sinus, both cavities together may be described as an orbital suite. Fatty tissue, which is abundant in the orbit, is found in most cavernous sinuses as well (as can be observed in postmortem dissections).

The entry points of the cranial nerves into the lateral wall of the cavernous sinus, described as the pockets of the subdural space, represent merely the beginning of various canals through which, along the dural folds, the nerves course through the lateral wall to the opposite (peripheral) exit points from the dural canals. All these connections with the intradural space on one side and the intraorbital space on the other, as well as intercavernous connections and connections along the foramina of nerves V2 and V3, are the so-called "weak points" through which tumors can extend in either direction (i.e., into the cavernous sinus or out of it).

That the proximity of the VIth cranial nerve to Meckel's cave on its medial side may be a possible cause of VIth cranial nerve palsy during surgery of Meckel's cave lesions does not stand up to scrutiny. In cases of Meckel's cave lesions, VIth cranial nerve palsy is the first symptom of the lesion that compresses the VIth cranial nerve anterolaterally over the edge of the bone in the corner between the bone and the petroclinoid ligament (1). In cases of Vth cranial nerve neuromas originating in Meckel's cave, VIth cranial nerve palsy improves after complete and appropriate removal of the lesion. On the other hand, VIth cranial nerve palsy after surgery of meningiomas in the cavernous sinus proper is no doubt the result of a surgical trauma of the nerve that was encased in the tumor and fixed with the tumor and sympathetic fibers to the artery wall.

The two most critical points in intracavernous tumorous surgery (especially of meningiomas) are the exit point of the VIth cranial nerve from Dorello's canal into the cavernous sinus and, anteriorly, the point at which the nerves course from the cavernous sinus through the superior orbital fissure into the orbit. The so-called cavernous sinus is a paired interdural space on each side of the sella. I am convinced that descriptions such as "anterior cavernous sinus" and "posterior cavernous sinus" do not enhance the clarity of the parasellar region so long as we adhere to the definition of the cavernous sinus as being an intradural space through which the ICA and the VIth cranial nerve run and through whose wall run the IIIrd, IVth, and Vth cranial nerves. However, when we consider the structure of the ICA to be the central structure and start the description of the space on each side of the artery, we can talk about the venous compartments on different sides (i.e., anterior, posterior, etc.) of the ICA. Does the nomenclature "anterior" and "posterior" cavernous sinus add to a better understanding of the parasellar space?

There is no doubt that surgical anatomy of the parasellar space, especially when this space is filled with a vascular or tumorous lesion, can be dealt with only when the normal anatomy is clear. I am convinced that the detailed description of the dural folds around the bony, vascular, and neural structures of the parasellar region, as presented in this article, will contribute to better understanding and to improved surgery of such demanding lesions of the cranial base.

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1. Dolenc VV: Frontotemporal epidural approach to trigeminal neurinomas. **Acta Neurochir (Wien)** 130:55–65, 1994.

This article presents an interesting approach to apply existing anatomic knowledge to surgical problems. The photographs of microscope sections are superb. In 1963, we were trying to find what vessels normally present serve to perpetuate a completely trapped carotid "cavernous" fistula. We found, described, and named the branches, still thinking that there was a "cavernous sinus" (2). It is pleasant to see the word "meningohypophyseal" in common usage and equally pleasant to see that these authors and others have seen fit to drop the name we gave to the lateral branch (artery of the inferior "cavernous sinus"). We first realized that the lateral sellar compartment was not a dural sinus when we operated on our first post-trapping persistent fistula and found we could be within that compartment and outside the venous channels; an impossibility in a true dural sinus (3). For years, some investigators have suspected that the venous anatomy in this area is a plexus of veins continuous with the veins of Batson's plexus, with the orbital veins and the other intracranial plexi (1, 3, 7, 8). We now know this to be true. This relationship is beautifully shown in stylized drawings in Pernkopf's anatomy text of 1963 (8).

It is clumsy and anatomically incorrect to refer to the entire lateral sellar compartment and its contents of veins, arteries, meninges, connective tissue, fat, and nerves as "cavernous sinus" and at the same time refer to the individual venous channels therein as "cavernous sinus." The anatomy in this area is difficult enough for the students. Our choice would be "lateral sellar compartment" for the dural compartment containing all these structures and "lateral sellar venous plexus" for the veins that are continuous with Batson's plexus, the orbital veins, and the other intracranial venous plexi (4–6). Changing a name of such long standing will take great courage and persistence. The three small nerves adjacent to the VIth cranial nerve in *Fig. 2E* of the article are probably sympathetic branches, but with a trichrome stain, this is only conjecture.

The authors combine great anatomic knowledge and interest with superb surgical skills. I urge them to further our knowledge of the sympathetic pathways beyond the superior cervical ganglion by documenting the sweating pattern in every case in which the pathways could have been interrupted at surgery. This would include ligation or section of the external carotid branches. To date, even with molecular probes, we have been unable to pursue the course that we think them to take. Combining clinical observations with known lesion locations will eventually prove us right or wrong, just as so much neuroanatomy has been learned in the past.

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