OBJECTIVE: The aim of this article is to describe the anatomy of the cavernous sinus and to provide a guide for use when performing surgery in this complex area. Clinical cases are used to illustrate routes to the cavernous sinus and its contents and to demonstrate how the cavernous sinus can be used as a pathway for exposure of deeper structures.

METHODS: Thirty cadaveric cavernous sinuses were examined using ×3 to ×40 magnification after the arteries and veins were injected with colored silicone. Distances between the entrance of the oculomotor and trochlear nerves and the posterior clinoid process were recorded. Stepwise dissections of the cavernous sinuses, performed to demonstrate the intradural and extradural routes, are accompanied by intraoperative photographs of those approaches.

RESULTS: The anatomy of the cavernous sinus is complex because of the high density of critically important neural and vascular structures. Selective cases demonstrate how a detailed knowledge of cavernous sinus anatomy can provide for safer surgery with low morbidity.

CONCLUSION: A precise understanding of the bony relationships and neurovascular contents of the cavernous sinus, together with the use of cranial base and microsurgical techniques, has allowed neurosurgeons to approach the cavernous sinus with reduced morbidity and mortality, changing the natural history of selected lesions in this region. Complete resection of cavernous sinus meningiomas has proven to be difficult and, in many cases, impossible without causing significant morbidity. However, surgical reduction of such lesions enhances the chances for success of subsequent therapy.

KEY WORDS: Cavernous sinus, Cranial nerves, Craniotomy, Internal carotid artery, Surgical approaches

The microsurgical anatomy of the cavernous sinus has been described extensively (15, 17, 18, 20, 23, 26, 27, 29, 30, 34, 40, 43, 46, 48). Browder (4) and Parkinson (27) performed the first cavernous sinus approaches for the treatment of carotid cavernous fistula, and Taptas (44), Dolenc (7), and Umansky (46) were pioneers in studying this region. Currently, cavernous sinus approaches are performed for basilar tip aneurysms (11, 37), carotid-ophthalmic aneurysms (8), pituitary adenomas (9, 13), some trigeminal neuromas (5), and other tumors in the region (13, 14, 16, 31, 33, 35, 38). Although the anatomy of the cavernous sinus has been well described, the sinus remains a challenging and unfamiliar place for many neurosurgeons.

The cavernous sinuses are venous structures in the middle cranial base, surrounded by dural walls, which contain neurovascular structures and face the sella turcica, pituitary gland, and sphenoid bone on one side and the temporal lobe on the other side (30). A cavernous sinus has five walls: lateral and medial walls, a roof, and posterior and anterior walls. The roof faces the basal cisterns; the lateral wall faces the temporal lobe; the medial wall faces the sella turcica, pituitary gland, and sphenoid bone; and the posterior wall faces the posterior cranial fossa. The lateral walls join inferiorly at the level of the superior margin of the second division of the trigeminal nerve (maxillary nerve), and the narrow anterior edge borders the superior orbital fissure. The cavernous sinus is an envelope containing the cavernous carotid segment and its branches; the sympathetic plexus; the IIIrd, IVth, and Vth cranial nerves;
the first trigeminal division; and multiple venous tributaries and spaces. The intercavernous, basilar, superior, and inferior petrosal sinuses all join with the cavernous sinus. In addition, multiple veins, such as the superior and inferior ophthalmic veins; the veins of the foramen rotundum, foramen ovale, and foramen spinosum; and the deep middle cerebral vein and superficial sylvian veins, empty into the cavernous sinus.

The purpose of this article is to present the detailed anatomy of the cavernous sinus as a guide to increase the safety of the approaches to this area. For this purpose, stepwise dissections of the cavernous sinus and clinical cases illustrating the different approaches to this region are presented. Measurements detailing surgically important landmarks have been performed. Although there are several articles detailing the anatomy of the cavernous sinus, consensus regarding the optimal surgical approach to access this area and the appropriate treatment for many lesions in the area is lacking (2, 3, 6, 9, 10, 12, 13, 22, 24, 25, 28, 31, 33, 35, 38, 39, 42, 47). Because of the complex anatomy and density of critically important neuro-vascular structures within the cavernous sinus, many lesions in the area have been deemed unresectable (12, 19, 25, 47). High cranial nerve morbidity and the advent of newer technology, such as endovascular neurosurgery and radiosurgery, have resulted in a significant decrease in the frequency with which surgical approaches into the cavernous sinus are performed (3, 12, 19, 22, 24, 25, 42, 47). However, in many countries, these newer technologies are not readily available. By improving our knowledge of the anatomy of the cavernous sinus and applying this knowledge during surgery, we have been successful in decreasing the morbidity associated with surgery in this area.

MATERIALS AND METHODS

Thirty cavernous sinuses were examined in 21 adult cadaveric specimens using ×3 to ×40 magnification of the surgical microscope. The heads were injected with colored silicone, and the distance between the oculomotor and trochlear porus and the posterior clinoid process was measured. Clinical cases of lesions in the region of the cavernous sinus, operated on by one of the senior authors (EdO), are presented to illustrate the different approaches to this area.

RESULTS

Anatomic Considerations

Osseous Relationships

The cavernous sinuses rest on the intracranial surface of the sphenoid and temporal bones (Fig. 1). The anterior edge of the cavernous sinus extends downward from the lower surface of the anterior clinoid process along the anterior edge of the carotid sulcus and the posterior edge of the optic strut and superior orbital fissure. The posterior edge extends from the posterior clinoid process above to the junction of the petrous apex with the body of the sphenoid bone below. After defining the anterior and posterior limits, the upper and lower limits of the cavernous sinus are defined by lines extending from the upper and lower ends of the anterior and posterior edges. The inferior limit extends backward from just below the inferior edge of the superior orbital fissure and lower edge of the carotid sulcus, passes along the lateral edge of the intracranial end of the carotid canal, and ends at the superior end of the petroclival fissure. The superior limit extends from the lower surface of the base of the anterior clinoid process along the lateral margin of the sella to the posterior clinoid process.

The carotid sulcus is a groove on the lateral aspect of the body of the sphenoid bone along which the intracavernous segment of the internal carotid artery courses. The horizontal segment of the intracavernous carotid artery sits against and is separated from the carotid sulcus by the dura forming the medial wall of the cavernous sinus. The carotid sulcus begins below and lateral to the dorsum sellae at the intracranial end of the carotid canal. After an initial short and vertical section, the carotid sulcus turns forward just below the lateral edge of the floor of the sella on the body of the sphenoid bone. The carotid sulcus turns upward and courses just anterior to the anterior sellar wall and along the posterior edge of the optic strut and medial edge of the anterior clinoid process. The segment of the internal carotid artery coursing along the medial side of the anterior clinoid process is referred to as the clinoidal segment.

The anterior clinoid process is a bony projection directed posteriorly from the lesser sphenoid wing. The base of the anterior clinoid process is attached to the sphenoid bone at three sites. Anteriorly, the base is attached to the lateral edge of the sphenoid ridge, which is formed by the lesser sphenoid wing. Medially, there are two attachments: the anterior and posterior roots of the anterior clinoid process. The anterior root extends medially from the base of the clinoid above the optical canal to the body of the sphenoid bone and forms the roof of the optic canal. The posterior root of the anterior clinoid process, also called the optic strut, extends medially below the optic nerve to the sphenoid body and forms the floor of the optic canal. The optic strut has a triangular shape in cross section and separates the medial part of the roof of the superior orbital fissure from the optic canal. The anterior bend of the internal carotid artery sits against the concave posterior surface of the optic strut. The medial edge of the base of the anterior clinoid process forms the lateral edge of the optic canal. The anterior clinoid process is the site of attachment of the anteromedial part of the tentorium and the anterior petroclinoid and interclinoid dural folds. The falciform ligament is a dural fold that extends medially from the base of the anterior clinoid process above the optic nerve and blends into the dura covering the planum sphenoidale (Fig. 2). There are often venous channels inside the base of the anterior clinoid, lesser sphenoid wing, and optic strut that connect the diploic veins of the orbital roof to the cavernous sinus.

The middle clinoid process is an upward bony projection on the body of the sphenoid bone medial to the terminal portion.
of the carotid sulcus, inferolateral to the tuberculum sellae, and medial to the anterior clinoid process. An osseous bridge sometimes connects the anterior and middle clinoid processes to form a bony canal, called the carotico clinoidal foramen, through which the internal carotid artery passes (Fig. 1).

The posterior clinoid process is an osseous prominence located at the superolateral aspect of the dorsum sellae. An osseous bridge, called the interclinoidal osseous bridge, may connect the anterior and posterior clinoid processes (Fig. 1). These bridges between the anterior, middle, and posterior clinoid processes may make it difficult to remove the anterior clinoid process and to mobilize the carotid artery at the sinus roof.

Dural Relationships

The consistent nature of the dural layers and folds in the walls and roof of the cavernous sinus provides important landmarks used in surgery. The dural structures include the upper (or distal) and lower (or proximal) carotid dural rings, the carotid collar, and the triangles of the roof of the cavernous sinus (Figs. 2 and 3). The roof and lateral wall of the cavernous sinus can be divided into four triangular areas: two in the roof and two on the lateral wall. The triangles on the roof are the clinoidal and oculomotor triangles (Fig. 2). The triangles on the lateral wall are the supratrochlear and infratrochlear triangles (or Parkinson’s triangle) (Fig. 3E). The borders of the
carotid. The artery courses along and may groove the medial half of the lower aspect of the anterior clinoid before turning upward along the medial edge of the clinoid. The air cells in the sphenoid sinus may extend into the optic stratum and anterior clinoid. The air cells in the sphenoid sinus may extend into the optic stratum and anterior clinoid.

The dura that lines the lower surface of the anterior clinoid is grooved to accommodate the clinoid segment of the internal carotid artery, including the anterior clinoid laterally, the optic stratum anteriorly, and the carotid sulcus medially. The carotid sulcus begins lateral to the dorsum sellae at the intracranial end of the carotid canal, extends forward just below the sellar floor, and turns upward along the posterior surface of the optic stratum. The anterior clinoid process projects backward from the lesser wing of the sphenoid bone, often overlapping the lateral edge of the carotid sulcus. The anterior root of the lesser sphenoid wing extends medially to form the roof of the optic canal. The posterior root of the lesser wing, referred to as the optic strut, extends from the inferior orbital antrum of the anterior clinoid to the sphenoid body. The bony collar around the carotid artery formed by the anterior clinoid, optic strut, and carotid sulcus is inclined downward as it slopes medially from the upper surface of the sphenoid body to the carotid sulcus.

Another small prominence, the middle clinoid process, situated on the medial side of the carotid sulcus at the level of the tip of the anterior clinoid process, projects upward and laterally. In some cases, there is an osseous bridge extending from the tip of the middle clinoid to the tip of the anterior clinoid. G, posterior view showing the optic stratum, optic canal, and superior orbital fissure. The optic strut separates the optic canal and superior orbital fissure and forms the floor of the optic canal and the superomedial part of the roof of the superior orbital fissure. The posterior surface of the strut is shaped to accommodate the anterior wall of the clinoid segment and the anterior border of the intercavernous sinus.

Triangles in the roof of the cavernous sinus are formed by dural folds, whereas the borders of the triangles on the lateral wall are defined by neural structures. The triangles are described in greater detail later in this section. The middle fossa dura that extends medially to form the walls of the cavernous sinus consists of an inner layer and an outer layer, which are important when performing surgical explorations of the cavernous sinus.

The dura lining the upper and lower surface of the anterior clinoid process extends medially to form the upper and lower dural rings that define the upper and lower margins of the clinoid segment of the internal carotid artery (Figs. 2 and 3). The dura extending medially from the upper surface of the anterior clinoid forms the lateral part of the upper dural ring. This dura extends forward and medial, below the optic nerve, to line the upper surface of the optic stratum and form the anterior part of the upper dural ring. Finally, the dura lining the upper surface of the optic stratum extends medially to the carotid artery and posteriorly at the level of the carotid sulcus to form the medial part of the upper ring (Fig. 2). There is no posterior part of the upper dural ring, because at the most posterior portion of the upper dural ring at the level of the tip of the anterior clinoid process, the upper ring joins with the lower dural ring to form the apex of the clinoidal triangle of the roof of the cavernous sinus (Fig. 2, H–J).

The dura that lines the lower surface of the anterior clinoid process and separates the clinoid from the oculomotor nerve extends medially to surround the carotid artery. This dura, called the carotidoculomotor membrane, forms the lower dural ring (Fig. 2, H–J). It extends medially and forward, lining
the lower surface of the optic strut, to form the anterior part of the lower ring. Medially, the carotidoculomotor membrane blends with the dura that lines the carotid sulcus. This membrane turns upward to form a collar around the carotid artery between the upper and lower rings, called the carotid collar. At the posterior tip of the anterior clinoid process, the upper dural ring joins with the lower dural ring to form the apex of the clinoidal triangle (Figs. 2, H–J, and 3, E–G).

The carotid collar is formed by the dura of the lower ring turning upward to surround the segment of the internal carotid artery between the upper and lower rings (Fig. 2, H–J). The carotid collar does not become tightly adhered to the wall of the carotid artery until it reaches the upper dural ring, where it is bound tightly to that artery. The clinoid venous plexus, a small venous plexus that courses between the carotid collar and the outer wall of the clinoidal segment of the carotid, communicates with the anterior venous plexus of the cavernous sinus. For this reason, we consider the clinoid segment to be intracavernous.

The dura forming the upper and lower rings, the clinoidal triangle, and the carotid collar form the anterior portion of the
The dura lining the middle fossa lateral to the cavernous sinus, which has borders defined by dural structures. The dural structures forming the borders of the oculomotor triangle are the anterior and posterior petroclinoid and the interclinoid dural folds (Fig. 2). The anterior petroclinoid dural fold extends from the petrous apex to the anterior clinoid process, the posterior petroclinoid dural fold extends from the posterior clinoid process to the petrous apex, and the interclinoid dural fold extends between the anterior and posterior clinoid processes. The oculomotor and trochlear nerves pierce the roof of the cavernous sinus in a “keel-like” formation at the level of the superior margin of the maxillary nerve (Fig. 3). The dura forming the roof of the cavernous sinus can be divided into two triangles: the clinoidal triangle (or the anterior portion of the roof of the cavernous sinus) and the oculomotor triangle (or the posterior portion of the roof of the cavernous sinus).

The dura lining the middle fossa lateral to the cavernous sinus has an inner layer that adheres to the bone and is called the endosteal layer, and the outer layer faces the brain and is called the meningeal layer (Figs. 3 and 4). At the lower lateral edge of the cavernous sinus, the layers separate, with the meningeal layer and outer part of the endosteal extending upward to form the lateral wall of the cavernous sinus, whereas the inner part of the endosteal layer continuous medially to form part of the medial sinus wall. Dissections of the lateral sinus wall reveal that the thicker outer layer (a continuation of the meningeal layer) peels away, leaving the thin inner layer (a continuation of the endosteal layer) that invests the nerves in the lateral wall. The lateral sinus wall blends into the dura covering Meckel’s cave (Fig. 3, A–C). The lower edge of the lateral wall of the cavernous sinus joins the medial wall of the cavernous sinus in a “keel-like” formation at the level of the superior margin of the maxillary nerve (Fig. 3, C–G). The inner layer, an extension of the endosteal layer, invests the nerves running within the lateral wall of the cavernous sinus. The triangles of the lateral wall of the cavernous sinus, revealed after removing the outer layer, are the supratrochlear triangle located between the oculomotor and trochlear nerves and the infratrochlear triangle, also called Parkinson’s triangle, located between the trochlear and upper edge of the trigeminal nerve (Fig. 3C).
The limits of the medial sinus wall are the superior orbital fissure anteriorly, the dorsum sellae posteriorly, the junction with the lateral wall at the level of the superior margin of the maxillary nerve inferiorly, and the diaphragma sellae superiorly (Fig. 5) (50). The medial wall of the cavernous sinus is divided into a sellar part and a sphenoidal part (Fig. 5F). In our anatomic dissections, we have found the sellar part of the medial wall to be a continuation of the diaphragma sellae that folds downward around the lateral surface of the anterior lobe of the pituitary gland and is constituted by the meningeal layer (Figs. 4 and 5, H–L). The sellar part of the medial wall is not continuous with the sphenoidal part, which is formed by the endosteal layer that covers the body of the sphenoid bone and continues medially across the sellar floor. In our dissections, we found that the sellar part, an extension of the meningeal layer that lines the lower surface of the pituitary gland,
is easily separated from the sphenoid part, which lines the floor of the sella and is an extension of the endosteal layer. The intercavernous sinuses course between the two layers (Fig. 5). Therefore, the anterior, posterior, and inferior surfaces of the sella are formed by two layers of dura, and the wall lateral to the pituitary gland is formed by one dural layer, the meningeal layer. The posterior lobe of the pituitary gland does not face the sellar part of the medial wall because it sits in the concavity of the dorsum sellae behind the sellar part of the medial wall. Our anatomic dissections allow us to say that the medial wall has one layer that is constituted by the meningeal dura layer on its sellar part and by an endosteal layer (or intracranial periosteum) on its sphenoidal part.

The posterior part of the cavernous sinus has a large venous confluence located lateral to the dorsum sellae that opens into the basilar and superior and inferior petrosal sinuses (Fig. 6). The basilar sinus sits on the posterior surface of the dorsum sellae and upper clivus and is the largest connection between the two cavernous sinuses. The inferior limit of the posterior wall of the cavernous sinus is situated at the upper margin of the petroclival fissure just below the petrosphenoidal ligament (Gruber’s ligament), which runs between the petrous apex and the lower lateral edge of the dorsum sellae to roof Dorello’s canal. The VIth cranial nerve pierces the dura of the clivus below the petrosphenoidal ligament and ascends to pass through Dorello’s canal to reach the cavernous sinus. The superior limit of the posterior wall of the cavernous sinus is the posterior petroclinoid dural fold, and the lateral limit is the dura lining the medial edge of the trigeminal porus. The medial edge of the posterior wall of the cavernous sinus is located at the lateral edge of the dorsum sellae.

**Neural Relationships**

The nerves related to the cavernous sinus are the oculomotor, trochlear, ophthalmic, and abducens nerves and sympathetic plexus around the intracavernous carotid artery (Figs. 2, 3, and 4).
The trochlear nerve enters the roof of the cavernous sinus in the posterolateral apex of the oculomotor triangle, 8.12 ± 2.32 mm (range, 4.52–13.1 mm) behind the entrance of the oculomotor nerve and 13.82 ± 2.39 mm (range, 10.14–20.1 mm) posterolateral to the posterior clinoid process (Figs. 2, 3, and 5). After penetrating the roof of the cavernous sinus at the juncture of the anterior and posterior petroclinoid dural folds, the trochlear nerve courses in the lateral wall of the cavernous sinus below the oculomotor nerve. At the level of the anterior clinoid process, the trochlear nerve crosses, laterally to medially, between the upper surface of the oculomotor nerve and the dura lining the lower margin of the anterior clinoid and optic strut. After passing through the superior orbital fissure, the trochlear nerve crosses the origin of the levator muscle to reach the medial side of the orbit, where it innervates the superior oblique muscle.

The ophthalmic nerve (first trigeminal division) is embedded within the inner layer of the lateral wall of the cavernous sinus together with the oculomotor and trochlear nerves (Figs. 2, 3, and 5). The ophthalmic nerve courses below the trochlear nerve en route to the superior orbital fissure, where it divides into three branches: lacrimal, frontal, and nasociliary. Only the upper part of the medial wall of Meckel’s cave and the upper one-third of the gasserian ganglion are located immediately lateral to the cavernous sinus. The maxillary nerve (the second trigeminal division) courses below and does not belong to the lateral wall of the cavernous sinus. The cavernous sinus ends just above the superior margin of the maxillary nerve, where
the medial and lateral walls of the cavernous sinus join in a keel-like formation.

The abducens nerve and the sympathetic plexus around the intracavernous carotid artery are the only nerves that have a purely intracavernous course. The abducens nerve pierces the dura of the clivus, has a short course upward, and penetrates the cavernous sinus by passing through Dorello’s canal, located below the petrosphenoidal ligament (Gruber’s ligament). It passes lateral to the posterior vertical segment of the intracavernous carotid artery and courses inside the lateral venous space of the cavernous sinus lateral and inferior to the horizontal segment of the intracavernous carotid and medial to the ophthalmic nerve to reach the superior orbital fissure. In cases in which the intracavernous carotid is tortuous, the abducens nerve sometimes courses inside the anteroinferior venous space. The abducens nerve usually pierces the dura of the clivus as a single bundle, although it may be separated into two bundles in the prepontine cistern; however, it may split into as many as five bundles inside the cavernous sinus. The sympathetic plexus (Fig. 3G) around the intracavernous carotid sends branches to the abducens nerve; from the abducens nerve, these sympathetic fibers reach the ophthalmic division en route to the long ciliary nerves that innervate the pupillodilator fibers of the iris.

Arterial Relationships

The cavernous sinus contains the intracavernous segment of the internal carotid artery and its branches. The intracavernous sinus joins between the paired intracavernous carotids and the cavernous sinuses. The medial venous space extends between the pituitary gland and the artery. The anterior intercavernous sinus crosses the anteroinferior surface of the pituitary gland. The ophthalmic artery courses inferolateral to the optic nerve inside the optic canal. The intracavernous carotid artery is the only artery that has a purely intracavernous course. The abducens nerve pierces the dura of the clivus, has a short course upward, and penetrates the cavernous sinus by passing through Dorello’s canal, located below the petrosphenoidal ligament (Gruber’s ligament). It passes lateral to the posterior vertical segment of the intracavernous carotid artery and courses inside the lateral venous space of the cavernous sinus lateral and inferior to the horizontal segment of the intracavernous carotid and medial to the ophthalmic nerve to reach the superior orbital fissure. In cases in which the intracavernous carotid is tortuous, the abducens nerve sometimes courses inside the anteroinferior venous space. The abducens nerve usually pierces the dura of the clivus as a single bundle, although it may be separated into two bundles in the prepontine cistern; however, it may split into as many as five bundles inside the cavernous sinus. The sympathetic plexus (Fig. 3G) around the intracavernous carotid sends branches to the abducens nerve; from the abducens nerve, these sympathetic fibers reach the ophthalmic division en route to the long ciliary nerves that innervate the pupillodilator fibers of the iris.
Photographs illustrating the stepwise dissection of the posterior wall of the cavernous sinus.

**FIGURE 6.** Photographs illustrating the stepwise dissection of the posterior wall of the cavernous sinus. A, posterior view showing the posterior wall of the cavernous sinus. The posterior wall of the cavernous sinus sits between three points: the posterior clinoid process, the site where the abducens nerve pierces the dura of the clivus, and the medial aspect of the trigeminal porus. The abducens nerve has an upward course after piercing the dura of the clivus and passing through Dorello’s canal. The oculomotor nerve penetrates the roof of the cavernous sinus through the oculomotor triangle located on the medial side of the anterior petrosphenoid dural fold. A microdissector placed below the diaphragma sellae and lateral to the pituitary gland can be observed through the thin medial wall of the cavernous sinus. B, view showing the clival dura opened to expose the cavernous sinus. C, view showing the clival dura opened to expose the basilar sinus, the largest communication between the cavernous sinuses. The petrosphenoid ligament (Gruner’s ligament), which roofs Dorello’s canal, extends from the petrous apex to the lateral wall of the sphenoid sinus. D, view showing the intracavernous carotid and nerves removed to expose the medial wall of the cavernous sinus. The microdissector, placed below the diaphragma sellae and lateral to the cavernous sinus, can be observed through the thin medial wall that separates the cavernous sinus from the pituitary gland. **FIGURE 5.** Continued. G, sagittal view directed through the sphenoid sinus to the medial wall of the cavernous sinus showing the pituitary gland sitting in the sella above the sphenoid sinus. The anterior intercavernous sinus crosses the anterior aspect of the gland. The basilar sinus, the largest communication between the cavernous sinuses, crosses the back of the dorsum sellae and opens into both cavernous sinuses. H, enlarged view showing the pituitary gland removed to expose the medial wall of the right cavernous sinus. The anterior intercavernous sinus courses between the meningeal layer of dura facing the gland and the dural fold. A microdissector placed below the diaphragma sellae and lateral to the pituitary gland can be observed through the thin medial wall of the cavernous sinus. I, view showing the roof and lateral wall of the cavernous sinus exposed. The clinoidal space has been exposed by removing the anterior intercavernous process. The carotidoculomotor membrane, which forms the anterior part of the roof of the cavernous sinus and the anterior collar, has been folded forward to expose the clinoidal segment of the carotid. The oculomotor nerve enters the roof of the cavernous sinus through the oculomotor triangle located on the medial side of the anterior petrosphenoid dural fold. A microdissector placed below the diaphragma sellae and lateral to the pituitary gland can be observed through the thin medial wall of the cavernous sinus. J, enlarged view showing the microdissector through the thin medial wall sinus that separates the cavernous sinus from the pituitary gland. K, view showing the intracavernous carotid and nerves removed to expose the medial wall of the cavernous sinus. The microdissector, placed below the diaphragma sellae and lateral to the cavernous sinus, can be observed through the thin medial wall that separates the cavernous sinus from the pituitary gland. L, view showing the medial wall of the cavernous sinus opened, with the leaves of the sellar portion of the medial wall folded outward to expose the lateral surface of the gland. The sphenoidal portion of the medial wall is exposed along the anterior and lateral edges of the gland. A, artery; Ant., anterior; Car., carotid; Carotidoculom., carotidoculomotor; Cav., cavernous; Clin., clinoid; Clinoidal, CN, cranial nerve; Diaph., diaphragm; Gr., great; Hyp., hypophyseal; Inf., inferior; Intercav., intercavernous; Lig., ligament; Med., medial; Memb., membrane; Ophth., ophthalmic; PCoA, posterior communicating artery; Pet., petrosal; Petroclin., petroclinoid; Petroling., petrolingual; Petrosphen., petrosphenoid; Pit., pituitary; Port., portion; Post., posterior; Seg., segment; Sphen., sphenoid; Sphenoidal; Ven., venous; Vert., vertical.
CAVERNOUS SINUS

FIGURE 7. Photographs illustrating the intradural approach to the left cavernous sinus. A, view of completed fronto-orbitozygomatic craniotomy and pretemporal approach to the cavernous sinus showing wide dissection of the sylvian fissure. The carotid artery is located medial to the anterior clinoid, and the optic nerve is located superomedial to the internal carotid artery. The approach to the cavernous sinus starts with removing the anterior clinoid process to expose the anterior portion of the roof. The dura above the anterior clinoid has been opened. The oculomotor nerve penetrates the roof of the cavernous sinus by passing through the oculomotor triangle, which forms the posterior part of the roof. B, view showing the anterior clinoid removed. Continuous irrigation is necessary to avoid heat damage to the optic nerve and the clinoidal segment when a drill is used to remove the clinoid. Removing the anterior clinoid process exposes the clinoidal space. The dura extending medially from the upper surface of the anterior clinoid forms the upper ring. The carotidoculosellar membrane lines the lower surface of the anterior clinoid and extends medially to form the lower dural ring and carotid collar. C, view showing the carotid artery elevated to expose the posterior communicating and anterior choroidal arteries. The oculomotor nerve passes lateral to the posterior clinoid process and penetrates the roof of the cavernous sinus by passing through the oculomotor triangle. D, view showing the opening of the posterior portion of the roof, which begins by opening the oculomotor cistern. The incision follows the third nerve forward to the posterior edge of the clinoidal space. The posterior clinoid is exposed medial to the oculomotor nerve. E, view showing the roof of the cavernous sinus opened on the medial side of the oculomotor cistern. Gentle packing with Surgicel controls the bleeding. The posterior clinoid and adjacent part of the dorsum and upper clivus have been removed. The basilar trunk has been exposed behind the dorsum sellae. The suprachiasmatic carotid artery bifurcates below the anterior perforate substance in the A1 segment of the anterior cerebral artery and M1 segment of the middle cerebral artery. F, view showing a small segment of the suprachiasmatic carotid removed to expose the pituitary stalk. The pituitary gland can be reached between the initial suprachiasmatic segment of the carotid and the horizontal segment of the intracavernous carotid. A., artery; A1, A1 segment of the anterior cerebral artery; Ant., anterior; Car., carotid; Carotidoculosellar; Ch., choroid; Clin., clinoid, clinoidal; Cist., cistern; CN, cranial nerve; Hyp., hypophyseal; M1, M1 segment of the middle cerebral artery; Memb., membrane; Oculom., oculomotor; Olfact., olfactory; Ophth., ophthalmic; PCoA, posterior communicating artery; Pit., pituitary; Post., posterior; Seg., segment; Sup., superior; Triang., triangle.
rotid artery and has three branches: 1) the dorsal meningeal artery, 2) the inferior hypophyseal artery and 3) the tentorial artery (artery of Bernasconi-Cassinari) (Fig. 3). The dorsal meningeal artery passes posteriorly in the direction of Dorello’s canal and supplies the dura of the upper clivus. The inferior hypophyseal artery courses medially to supply the posterior pituitary capsule and lobe. The tentorial artery at first passes forward along the lateral wall of the sinus before turning backward in the tentorium. The tentorial artery sends branches to the oculomotor nerve and the trochlear nerve.

There are two types of meningohypophyseal trunk: complete and incomplete. The complete type gives rise to all three of the usual meningohypophyseal branches. The incomplete type gives rise to one or two of the usual branches, and the other ones arise directly from the intracavernous carotid. Inoue et al. (18) reported 70% of the complete type and 30% of the incomplete type. All three of the usual branches of the meningohypophyseal trunk may infrequently originate directly from the intracavernous carotid artery.

The inferolateral trunk, also called the artery of the inferior cavernous sinus, usually arises from the middle one-third of the inferior or lateral surface of the horizontal segment approximately 5 to 8 mm distal to the origin of the meningohypophyseal trunk. It nearly always passes above the abducens nerve and then downward between the abducens and ophthalmic nerves to supply the dura of the inferolateral wall of the cavernous sinus and adjacent area around the foramen rotundum and ovale (Fig. 3) (17, 18, 30). It rarely originates from the meningohypophyseal trunk. A marginal tentorial artery usually originates from the inferolateral trunk if no tentorial artery arises from the meningohypophyseal trunk.

Other arteries that can originate from the intracavernous carotid artery but are much less common than the meningohypophyseal and inferolateral trunks are: 1) McConnell’s capsular artery (8% of carotid arteries), which arises from the medial aspect of the intracavernous carotid and supplies the pituitary capsule; 2) the ophthalmic artery (8% of carotid arteries); and 3) the persistent trigeminal artery, which rarely arises from the central one-third of the posterior bend of the intracavernous carotid, courses posteriorly to pierce the posterior wall of the cavernous sinus lateral to Dorello’s canal, and anastomoses with the basilar artery between the superior and anterior inferior cerebellar arteries (18).

**Venous Relationships**

The cavernous sinus is shaped like a boat, being narrowest anteriorly near the superior orbital fissure and widest posteriorly at the junction of the sinus with the basilar, superior, and inferior petrosal sinuses. The cavernous sinus has four venous spaces (medial, anteroinferior, posteroinferior, and laterolateral), which are defined according to their position in relation to the intracavernous carotid (Fig. 3). The medial venous space is located between the intracavernous carotid and supplies the pituitary capsule.
the medial wall of the cavernous sinus (Fig. 5). The anteroinferior venous space is located anteroinferior to the posterior bend of the intracavernous carotid. The superior and inferior ophthalmic veins or their common trunk usually opens into the anteroinferior venous space. The posterosuperior venous space is located between the intracavernous carotid artery and the posterior part of the roof of the cavernous sinus and is the site where the cavernous sinus joins the basilar sinus. The lateral venous space, located between the intracavernous carotid and the ophthalmic nerve, is narrow. The abducens nerve courses medial to the ophthalmic nerve in this space, but it can also course in the anteroinferior venous space if the intracavernous carotid has a tortuous course.

The main venous channels that communicate with the cavernous sinus are from the orbit, cerebral hemisphere, posterior fossa, and contralateral cavernous sinus. The communications between the two cavernous sinuses are through the anterior, inferior, and posterior intercavernous sinuses and the basilar sinus (Figs. 5 and 6). The anterior intercavernous sinus courses anterosuperior, the posterior intercavernous sinus courses posterosuperior, and the inferior intercavernous sinus courses below the pituitary gland. These sinuses can occur together or separately. Sometimes, the anterior and posterior intercavernous sinuses along with both cavernous sinuses communicate around the diaphragm sellae to form a venous circle in the periphery of the diaphragma, called the circular sinus. The anterior intercavernous sinus empties into the posterosuperior venous space of the cavernous sinus near the tip of the anterior clinoid process. The posterior intercavernous sinus empties into the posterior portion of the posterosuperior venous space of the cavernous sinus. The basilar sinus is located behind the dorsum sellae and upper clivus and communicates at the lateral edge of the dorsum sellae with both cavernous sinuses (Figs. 5 and 6).

Another small venous component of the cavernous sinus is the clinoid venous space located between the clinoid segment of the internal carotid artery and the carotid collar. The narrow venous channels in this space communicate with the anterior portion of the roof of the cavernous sinus and have connections through small foramina in the surface of the anterior clinoid process and optic strut with the diploic veins of the orbital roof.

Illustrative Cases

We have selected some clinical cases to illustrate successful surgical strategies for approaching cavernous sinus pathological findings and for using transcavernous approaches to pathological findings around the cavernous sinus. The approaches were performed by one of the senior authors (EdO) and are accompanied in the figures by cadaveric dissections to illustrate important anatomic considerations when performing the approaches. The cavernous sinus can be approached through its roof or lateral wall. The approach through the roof in-
The clinoidal segment of the internal carotid artery, optic strut, and anterior part of the roof of the cavernous sinus are exposed in the clinoidal space. This space is defined distally by the upper (or distal) dural ring and proximally by the lower (or proximal) dural ring. The oculomotor nerve pierces the posterior portion of the roof of the cavernous sinus by passing through oculomotor triangle on the lateral side of the posterior clinoid process. The supraclinoid carotid artery bifurcates below the anterior perforate substance in the A1 segment of the anterior cerebral artery and M1 segment of the middle cerebral artery. A small aneurysm can be observed at the origin of an early temporal branch of middle cerebral artery.

The oculomotor triangle, which forms the posterior portion of the roof of the cavernous sinus, is the site where the oculomotor and trochlear nerves enter the roof of the cavernous sinus (Figs. 2 and 7). The posterior portion of the roof of the cavernous sinus is usually entered only after the anterior portion has been exposed by removing the anterior clinoid process. The dura over the oculomotor nerve and its cistern is opened using a 90-degree microdissector to elevate the dura over the oculomotor nerve and a sharp blade to cut the dura against the tip of the microdissector. The incision extends along the oculomotor nerve to the anterior portion of the roof of the cavernous sinus. The incision is then carried posteriorly through the anterior and posterior parts of the roof of the cavernous sinus to the posterior clinoid process. After opening the roof, the posterior clinoid process and the upper clivus can be removed to provide additional access to the basilar artery (Figs. 7 and 9).

The approach through the lateral wall of the cavernous sinus involves separating the outer dural layer from the inner dural layer of the lateral wall of the cavernous sinus (Figs. 10–12). Separating these layers allows visualization of the neural structures within the inner layer of the lateral wall. The lesion is accessed at the point where it is nearest or invades and bulges into and deforms the lateral wall (Fig. 11). In Figure 11, a large trigeminal neuroma with a cystic portion extending to the posterior fossa has been completely removed by an extradural approach. The site of the incision in the lateral wall was over the most prominent part of the tumor, which was between the...
first and second divisions of the trigeminal nerve, taking care to not damage the trigeminal divisions. The tumor had created its own route to the posterior fossa, and this route through the enlarged porus of Meckel’s cave was used to remove the tumor extending to the posterior fossa. Knowledge of the anatomy of this region aids in avoiding damage to the trigeminal divisions. The tumor had created its own route to the posterior fossa, and this route through the enlarged porus of Meckel’s cave was used to remove the tumor extending to the posterior fossa. Knowledge of the anatomy of this region aids in avoiding damage to the trigeminal divisions.

**DISCUSSION**

The cavernous sinus region is located at the cranial base, bordering the basal cisterns and surrounded by important neurovascular structures. Since the pioneering introduction of cavernous sinus surgery by Browder (4) and Parkinson (27), a number of different approaches have been used for dealing with pathological findings in and around this region. Vascular, neuroplastic, and inflammatory diseases affect the cavernous sinus region. Approaches to the cavernous sinus include the intra- or extradural transcranial and transbasal approaches (7–11, 14, 16, 18, 27, 28, 31–33, 35, 37, 44, 45) and the transsphenoidal approach (1, 37). Although the anatomy of this region has been extensively described (15, 17, 18, 20, 23, 26, 27, 29, 30, 34, 40, 43, 46, 48), controversy remains related to the best treatment and approaches for different kinds of lesions (2, 35, 38), such as cavernous sinus meningiomas (6, 38). There is a consensus that surgery for nonmeningeal tumors is safer than surgery for meningiomas and more often results in total removal (2, 5, 9, 13). Major risks of a direct approach to the cavernous sinus include excessive bleeding and damage to the intracavernous carotid and cranial nerves. Alternative methods for treating cavernous sinus lesions have appeared. In the past decade, radiosurgery has taken on a prominent role alone or as an adjuvant to partial resection (3, 12, 19, 24, 25, 39, 47). Some authors have suggested that radiosurgery is the treatment of choice for cavernous sinus meningiomas because of the low morbidity and mortality and the high rate of growth control (12, 19, 25, 42). However, radiosurgery is not completely absent of complications. Spiegelmann et al. (43) reported an incidence of 4.7% of new trigeminal neuropathy, a 2.8% incidence of new visual field defects, shunt-dependent hydrocephalus in 2 of 42 patients, and 1 patient with temporal lobe edema requiring surgical intervention. Cavernous sinus surgery can offer the possibility of tissue diagnosis and optic nerve decompression and can be used as a route to basilar artery aneurysms and extension of pituitary tumors. Conversely, excellent results have been achieved with surgical excision of meningiomas in this region (6, 33, 35). Microneurosurgery and radiosurgery have also been used for other types of tumors, such as pituitary adenomas (22), as well as for vascular lesions, such as hemangiomas (24). Another factor to consider is that new methods of treatment, such as radiosurgery and endovascular neurosurgery, are not available in all parts of the world; thus, neurosurgeons working in these parts of the world must rely on microsurgical technique combined with anatomic knowledge to deal with cavernous sinus pathological findings.

When planning cavernous sinus surgery, preoperative evaluation is paramount (31, 33, 35) and the surgeon must be prepared to reconstruct the internal carotid artery and the nerves related to this area (32). Proximal and distal control of flow through the internal carotid artery should be achieved before proceeding to the cavernous sinus. Proximal control can be achieved by exposure of the internal carotid artery in the neck and at the level of the petrous carotid canal in the cranial base, in accordance with Glasscock’s instructions (15). Distal control is acquired in the supraclinoid portion of the internal carotid artery after clinoidectomy performed extradurally or intradurally (7, 10, 31). The main technique for...
reconstructing the intracavernous carotid artery is bypass between the cervical or petrous carotid artery and the supraclinoid carotid artery using a sphenous vein graft (32, 36, 41).

The decision to establish proximal control depends on the type and position of the cavernous sinus pathological findings.

In addition to approaching intrinsic disease, the cavernous sinus can serve as a route for accessing other lesions, such as basilar tip, carotid-opthalmic, and paracclinoideal aneurysms as well as sellar and clivus tumors (Figs. 8 and 9) (8, 9, 11, 21, 33, 37). Often, lesions are not located within the cavernous sinus but around it. Therefore, anatomic familiarity with the region is important in accessing and protecting the neurovascular structures in and around the cavernous sinus that may be hidden by the sinus walls or the bone of the middle fossa.

The cavernous sinus approaches are through the roof or the lateral wall (Figs. 7 and 10) (7–11, 14, 16, 18, 27, 28, 31, 33, 35,
37, 44, 45). Umansky and Nathan (46) described the two-layer composition of the lateral wall of the cavernous sinus, which allows peeling of the outer layer of the dura away from the inner layer floor in the extradural approach to the cavernous sinus. In this approach, the nerves coursing in the semitransparent inner layer of the lateral wall of the cavernous sinus can be exposed without opening directly into the cavernous sinus (7).

The approaches to the cavernous sinus through its roof use a combination of the extradural and intradural routes (Figs. 7–9). They require a pre-temporal fronto-orbitozygomatic craniotomy and removal of the anterior clinoid process intradurally or extradurally to expose the anterior part of the sinus roof, after which the oculomotor triangle in the posterior part of the roof may be opened (7, 8, 13, 30, 33, 35, 37). The anterior portion can be opened alone or in combination with the posterior portion.

The anterior portion of the roof of the cavernous sinus is used frequently for approaches to paraclinoid aneurysms or carotid-ophthalmic aneurysms (Fig. 8). It can be opened intradurally or through a combined intradural and extradural approach, as described by Dolenc (8). The anterior portion, the clinoidal space or clinoidal triangle, has a more complex arrangement than the posterior portion. The anterior clinoid process occupies the upper floor of the anterior portion of the roof of the cavernous sinus. Removing the anterior clinoid process with the use of a high-speed drill exposes the clinoidal space or clinoidal triangle that forms the lower floor of the anterior portion of the roof. Removing the anterior clinoid process exposes the clinoidal segment of the carotid artery, carotidoculomotor membrane, optic strut, superior orbital fissure, and optic canal but does not open the venous space of the cavernous sinus. Adequate exposure of the anterior portion of the roof of the cavernous sinus is fundamental to approach paraclinoid aneurysms. The aneurysm sometimes arises inside the clinoidal space (or clinoidal triangle) and involves the clinoidal segment of the internal carotid artery. Familiarity with the anterior portion of the roof of the cavernous sinus is critical when approaching these aneurysms (Fig. 8).

The anterior clinoid process is removed extradurally or intradurally with the aid of a high-speed drill and a diamond bit. Care has to be taken to unroof the optic canal when the anterior clinoid process is being removed. Continuous irrigation is necessary to avoid damage to the optic nerve by heating. A thin layer of bone may be left over the optic nerve and carotid artery to protect them from drilling, after which the final thin layer is removed using a microdissector. Drilling across the base of the anterior clinoid and removing it in one piece may prove dangerous, especially if there is an osseous bridge between the anterior and middle clinoid processes that forms a carotico-clinoidal foramen around the

FIGURE 11. Computed tomographic scans and photographs illustrating the extradural removal of a right trigeminal schwannoma. A, preoperative computed tomographic scan with contrast showing a large trigeminal schwannoma with a cystic portion extending into the posterior fossa. B, postoperative computed tomographic scan with contrast showing total resection of the trigeminal schwannoma by an extradural “peeling” approach to the lateral wall of the cavernous sinus. C, photograph showing completed orbitozygomatic craniotomy and pretemporal approach. The dura has been elevated from the middle fossa floor, and the anterior clinoid process has been removed to expose the clinoidal space in the anterior part of the roof of the cavernous sinus without opening into the venous spaces. The trigeminal schwannoma bulges laterally between the first and second divisions of the trigeminal nerve (broken line). D, photograph of anatomic dissection showing the same structures demonstrated in C. E, photograph showing completed incision between the first and second divisions of the trigeminal nerve over the most prominent bulge of the schwannoma. The tumor, including its extension into the posterior fossa, has been removed. The tumor had expanded the porus of Meckel’s cave and created a route to the posterior fossa. F, photograph of the operation showing preservation of the trigeminal divisions and total resection of the lesion. The enlarged Meckel’s cave is exposed. Clin., clinoidal; CN, cranial nerve; Fr., frontal; Op., operative; Seg., segment; Temp., temporal.
The clinoidal region of the sphenoid bone lies at the junction of the cranial base at three sites: first, to the lesser sphenoid wing; second, through its anterior root, which forms the roof of optic canal; and third, through its posterior root or optic strut, which forms the floor of the optic canal (Fig. 1). Drilling the lesser sphenoid wing extradurally detaches the clinoid from the lesser wing, and the other attachments are released by opening the optic canal roof and drilling the optic strut. Care has to be taken during this step to avoid damage to the clinoid segment of the carotid, which courses along the inferomedial surface of the anterior clinoid process and sits against the posterior surface of the optic strut. Only the thin carotidoculomotor membrane, which lines and extends medially from the lower surface of the clinoid, separates the venous plexus of the cavernous sinus from the anterior clinoid process. The anterior clinoidectomy exposes the anterior part of the roof of the cavernous sinus and the clinoidal triangle, without opening its venous plexus. The exposure of the anterior portion of the roof of the cavernous sinus continues by opening the optic sheath lateral to the optic nerve and the distal dural ring around the internal carotid artery. Bleeding from the sinus is common when exposing the anterior part of the cavernous sinus roof but is easily controlled by gentle packing with hemostatic products. After opening the distal ring, the clinoidal and supraclinoidal segments of the internal carotid artery can be mobilized. It is important to realize that the distal dural ring is tightly adherent to the internal carotid artery. The opening of this ring has to be performed carefully, leaving a cuff of dural ring that is not detached from the artery. Exposing the anterior portion of the roof of the cavernous sinus usually provides adequate exposure for approaching paraclinoid and some ophthalmic aneurysms (Fig. 8) (8). The posterior portion of the roof can be opened along with the anterior portion to access basilar tip aneurysms and intrinsic cavernous sinus tumors.
The posterior part of the roof of the cavernous sinus is approached through the oculomotor triangle, through which the oculomotor nerve pierces the roof of the cavernous sinus (Figs. 7 and 9). The nerve does not penetrate into the venous space but traverses a short cistern, the oculomotor cistern, after descending below the level of the oculomotor triangle. This cistern ends at the tip or below the anterior clinoid, where the nerve becomes incorporated into the inner layer of the lateral wall of the sinus. The opening in the posterior part of the roof of the cavernous sinus is begun by opening the superior wall of the oculomotor cistern by inserting a 90-degree microdissector in the cistern above the nerve and carefully elevating and incising the dura down to the dissection.

The incision is extended anteriorly over the third cranial nerve to where the nerve becomes incorporated in the lateral wall of the cavernous sinus. The next step in the dissection involves opening the carotidoculomotor membrane in the clinoidal triangle medial to the third cranial nerve. The space between the oculomotor nerve and the horizontal segment of the intracavernous carotid artery is devoid of any important neurovascular structures. When the carotidoculomotor membrane is opened, significant bleeding from the underlying sinus ensues. However, gentle packing with absorbable hemostat (e.g., Surgicel; Ethicon, Inc., Somerville, NJ) is effective in controlling the bleeding. The membrane was partially opened when the upper ring was opened. The posterior edge of the upper ring at the tip of the anterior clinoid process fuses with the carotidoculomotor membrane (Fig. 2, C, J, and K). The last step in opening the posterior part of the roof of the cavernous sinus is an incision directed posteriorly through the oculomotor triangle toward the posterior clinoid process. Both parts of the roof of the cavernous sinus have now been opened, and the lateral, posterolateral, and medial venous spaces have been exposed. The posterior bend, the horizontal segment, the anterior bend of the intracavernous carotid artery, and the pituitary gland between the horizontal intracavernous and suprACLinoidal segments of the internal carotid artery may be exposed. The posterior clinoid and upper clivus can be removed to access the interpeduncular and preopticine cisterns for basilar tip aneurysms (11, 37) or the upper clivus area for tumors (Fig. 9) (33).

The approach through the lateral wall of the cavernous sinus starts with peeling the dura away from the middle fossa floor (Figs. 10–12). The dissection begins at the greater sphenoid wing and proceeds toward the superior orbital fissure, where the intracranial periosteum is continuous with the periorbit. A shallow cut in the dura at the lateral edge of the superior orbital fissure allows the separation of the dura from the middle fossa floor to proceed medially along the wall of the sinus. The outer layer (meningeal dura) peels away from the inner layer (endosteal layer) exposing Cranial Nerves III, IV, V1, V2, and V3 and the gasserian ganglion. There are three points at which the peeling has to be done carefully. One is when separating the layers from V2, another is when separating the layers from V3, and the last one is when separating the layers at Parkinson’s triangle. The two layers are tightly adherent at the levels of V2 and V3, and the inner layer at Parkinson’s triangle is wider and easier to damage. Peeling the meningeal dura from the endosteal dura exposes the lateral wall of the cavernous sinus as well as the four triangles of the middle fossa floor (30): the
approach for intracavernous carotid artery aneurysms (10) and for pituitary tumors extending beyond the sella (9). One of the senior authors (EdO) has used this approach to pituitary adenomas extending beyond the sella with good results (Fig. 12). As Dolenc (9) reports, this last approach is complementary to the transsphenoidal approach, but if the tumor has a parasellar extension, it offers a great chance of total removal through a single operation (9).

The cavernous sinus region is anatomically complex, with a high density of neurovascular structures within its dural walls. Pathological findings of the cavernous sinus region are diverse and include intrinsic and extrinsic lesions. The appropriate treatment for cavernous sinus disease is controversial. All the patients on whom we have performed cavernous sinus surgery have experienced transient cranial nerve palsies but have recovered completely. Radiosurgery for some types of tumors (e.g., meningiomas) has provided excellent results (19, 25, 49). Unfortunately, this technological advance is not available in many countries and does not provide a tissue diagnosis in cases with unusual radiographic characteristics. In addition, radiosurgery can be limited by proximity to the optic nerve, requiring that the cavernous sinus be opened to debulk a tumor before radiosurgical treatment. The fact that technological advances like radiosurgery are not available in many countries and are not applicable in treating tumor close to the chiasm as well as the fact that surgeons with experience in this region have acceptable results means that cavernous sinus surgery continues to have a place in neurosurgery. A precise knowledge of the anatomy of this region can convert the cavernous sinus from an inaccessible surgical site (47) to an accessible surgical site. This knowledge, in addition to the surgeon’s experience, is the only way to perform satisfactory surgery in or through this “anatomic jewel box,” as Parkinson (29) described it.

FIGURE 14. Magnetic resonance imaging scans and photographs illustrating the surgical resection of a meningioma of the right cavernous sinus. A, preoperative magnetic resonance imaging scan showing a meningioma of the right cavernous sinus with the intracavernous carotid artery blocked by the tumor. B, postoperative magnetic resonance imaging scan showing resection of the part of the lesion inside the cavernous sinus. C, photograph showing completed orbitozygomatic craniotomy and pretemporal approach with middle fossa “peeling” and the anterior clinoid process removed, exposing the clinoidal space and anterior part of the roof of the cavernous sinus. The lesion can be observed bulging into and deforming the lateral wall and the roof of the cavernous sinus (broken lines). The petrous carotid has been exposed in the floor of the middle fossa just anterior and posterior to the third trigeminal division. D, photograph of anatomic dissection showing the structures exposed in C. E, photograph showing cavernous sinus with the lesion removed using a combined extradural and intradural approach. The petrous carotid artery was obliterated with a clip because it was observed to be occluded by the tumor on preoperative studies. Cav., cavernous; Clin., clinoidal; CN, cranial nerve; Fr., frontal; Gr., greater; N., nerve; Op., operative; Pet., petrosal; Seg., segment.

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COMMENTS

Yasuda et al. have put together in essence a comprehensive “primer” for microsurgery of lesions in and around the cavernous sinus. This should serve as an excellent starting point for any surgeon who wishes to effectively and safely treat these lesions via microsurgery and/or stereotactic radiosurgery. As I read the technique descriptions, it repeatedly became clear to me that there are many different techniques for operating in this region and also some differences in style.
However, the anatomy is always the same. An intimate knowledge of the relationships of bone to dura, to venous plexus, to arteries, and to cranial nerves is absolutely critical in the successful surgery of lesions in this region. Again, this article serves as an excellent starting point for anyone wishing to perform this type of surgery. It is critically important, in my opinion, that the intimate anatomic knowledge be translated from the pages of a book or journal or Internet web site to the three-dimensional arena of the cadaver laboratory before its translation into the operating room. A solid foundation of anatomic knowledge, both conceptually and in three dimensions, is the prelude to practicing dealing with living tissue and flowing blood. The very essential techniques in terms of technical microsurgery are not discussed in detail in this article. The best way that these technical aspects are learned is in the operating room with an accomplished cavernous sinus surgeon at the side of the student, either instructing or demonstrating how to handle cavernous sinus bleeding and manipulation of the tissues. All of these factors combine to result in a successful handling of cavernous sinus diseases.

Yasuda et al. present an excellent and detailed study on the microsurgical anatomy of the cavernous sinus. They demonstrate the relevance of their studies in illustrative surgical cases, as a basilar tip aneurysm approached through the roof of the cavernous sinus. Trigeminal neuroma, pituitary macroadenoma, and meningiomas were approached through the lateral wall of the cavernous sinus.

As pointed out by the authors, the first neurosurgical goal in the latter lesions has to be debulking of tumor to achieve nerve decompression and histological diagnosis. It should be decided during surgery whether total tumor removal can be achieved, depending on the adhesion of involved neurovascular structures. Because tumor control can be achieved in the majority of cases after subtotal resection with additional therapy such as gamma knife treatment, total resection should not be performed at the cost of disabling permanent neurological deficits.

In pituitary lesions, the preferred and less invasive approaches are, in our opinion, the transsphenoidal or frontolateral route. In vascular lesions, as presented by the authors, interventional therapy should also be considered.

Yasuda et al. have provided an extensive anatomic study of the approaches to the cavernous sinus with illustrative cases. On the basis of my experience with nearly 500 neoplastic and vascular lesions involving the cavernous sinus, the following comments can be made.

In this age of radiosurgery and endovascular surgery, a knowledge of the anatomy and surgical approaches to the cavernous sinus is still important, especially for surgeons who will perform cerebrovascular or cranial base surgery. With respect to the anatomy of the cavernous sinus, although it is important to learn the various triangles, etc., in the pathological situation, they are of less importance, because many of these triangles are distorted by the disease. It is important for the surgeon to learn the approaches on the basis of the surfaces of the cavernous sinus: namely, the medial, lateral, superior, posterior, and inferior. There are particular approaches based on the pathological condition, as follows.

1. Pituitary tumors. The transsphenoidal medial approach, the transcranial medial and superior approaches, and very often, the actual approach used will be dependent on the nature of the lesion and the distortions caused by the lesion.

2. Meningiomas of the cavernous sinus. At present, our approach to these is multimodal treatment combining radiosurgery and microsurgery or radiosurgery alone. We are also seeing some tumors that have failed radiotherapy and that require a more aggressive microsurgical therapy.

3. Nonmeningiomatous benign lesions. Tumors such as schwannomas, pituitary tumors, and epidermoid and dermoid cysts are amenable to complete microsurgical removal, although for some of them, radiosurgery is also an option; the results of such treatments are under discussion.

4. Cavernous hemangiomas of the cavernous sinus. These are special types of vascular malformations involving the cavernous sinus. Microsurgical resection is the preferred approach, although there are some reports of treatment by radiosurgery.

5. Chordomas and chondrosarcomas. These are special tumors that are rare but frequently involve the cavernous sinus. My philosophy is to attempt total resection of these tumors and reserve radiation modalities for tumor residue, which may be difficult to remove from areas of the cranial base. The tumor from the cavernous sinus is generally easily removed, although in cases of recurrent tumors, the carotid artery wall may be involved, and a vascular bypass may be necessary.

6. Other malignant tumors involving the cavernous sinus. The approach to these lesions has to be individualized. If the patient is healthy and has no metastatic disease, and the removal of the cavernous sinus lesion may result in total tumor resection, then such an operation may be performed. Frequently, this will involve a carotid artery bypass and the placement of a vascularized flap for cranial base reconstruction. It has been my experience that such a treatment succeeds only when there is an adjuvant modality (such as radiotherapy or chemotherapy) that is also effective in eradicating microscopic tumor remnants.

7. Paraclinoid aneurysms. These lesions are being treated by microsurgery or endovascular surgery, depending on the
aneurysm anatomy and the patient’s circumstances. When microsurgical treatment is elected, unroofing the optic nerve and intradural removal of the clinoid process, combined with a superior approach, is frequently effective in exposing the aneurysm to be clipped. Aneurysms with no neck or a calcified neck may require a bypass and proximal occlusion or trapping.

8. *Intracavernous aneurysms.* On the basis of the natural history study, these are relatively benign lesions, and treatment is reserved for giant aneurysms and for enlarging aneurysms. Endovascular options are considered first and may include stenting and coiling. When endovascular options are not possible, a vascular bypass and trapping are recommended. I have also treated some aneurysms that have enlarged after endovascular coiling, with the appearance of trigeminal symptoms.

9. *Results of cavernous sinus surgery.* In general, because of the adoption of multimodality treatment and increased experience and expertise, the results of treatment of cavernous sinus lesions have improved dramatically with respect to cranial nerve function and overall patient function. However, updated microsurgical (or multimodality) treatment series need to be published to make neurosurgeons and neurologists aware of the current options.

Laligam N. Sekhar
Great Neck, New York