22 The Cavernous Sinus: Surgical Approaches—Endoscopic and Open

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Abbreviations

ACP Anterior clinoid process
CN Cranial nerve
DDR Distal dural ring
ICA Internal carotid artery
PCP Posterior clinoid process
SOF Superior orbital fissure
V2 2 segment of trigeminal nerve

Introduction

The cavernous sinus, once termed the "anatomical jewel box" by Parkinson [1], remains one of the most complex intracranial spaces. The development of the expanded endonasal endoscopic approaches to the skull base added more direct access options to the medial and anteroinferior cavernous sinus. Surgical approaches to the cavernous sinus should be tailored to the need of each patient while taking into consideration the precise pathology and its location in relation to neurovascular structures.

In this chapter, the surgical anatomy of the sinus, as well as its open and endoscopic approaches, are outlined.

Surgical Anatomy

The cavernous sinus is a paired structure consisting of a plexus of variously sized veins located on either side of the body of the sphenoid bone and interconnected by venous channels. The cavernous sinus extends approximately 2 cm along the lateral aspect of the body of the sphenoid bone from the superior orbital fissure (SOF) anteriorly to the petrous apex posteriorly [2].

Osseous Relationships

The cavernous sinus is partially surrounded by bone. Bony landmarks relevant to the cavernous sinus include the body of the sphenoid, the greater wing, the lesser wing, the anterior clinoid process (ACP), the posterior clinoid process (PCP), the carotid-clinoid foramen, and the interclinoid osseous bridge (these are if the ligaments

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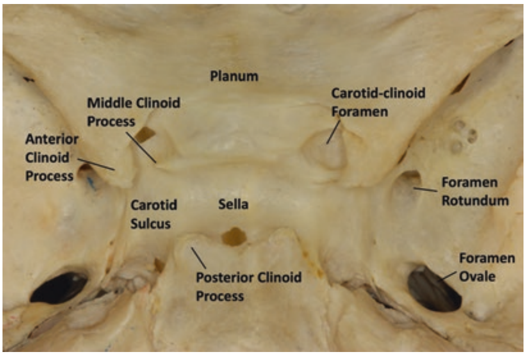

Fig. 22.1 Axial cut of a dry skull showing important anatomical landmarks. The body of the sphenoid, the greater wing, the lesser wing, and the anterior and posterior clinoid processes. The ossified carotid-clinoid foramen and interclinoid osseous bridge are present in this specimen and must be addressed before removing the anterior clinoid process to avoid injury to the ICA

are ossified). Occasionally, a prominent middle clinoid process is seen on the lateral surface of the sphenoid body (Fig. 22.1) [2, 3].

The lesser wings of the sphenoid bone extend medially, forming the optic canal roof, and fuse in the midline, forming the jugum sphenoidale.

The ACP, a triangular projection superior and lateral to the optic foramen, is a medial and posterior extension of the lesser wing. On its inferomedial aspect, the ACP is connected to the sphenoid body via the optic strut, which forms the inferolateral boundary of the optic foramen [2].

The PCP(s) are the cephalad projections of the dorsum sellae and may be pneumatized with the sphenoid sinus. The posterior fossa dura bridging the gap between the PCP and the petrous apex forms the posterior limit of the cavernous sinus.

Clinical Significance

In surgically approaching the cavernous sinus, an initial step is to "unlock" the contents of the sinus from their bony confines. This step includes anterior clinoidectomy, unroofing, and mobilizing the optic nerve (CN II) after dividing the falciform ligament. Anterior clinoidectomy can be performed in an extradural or intradural fashion. During an extradural anterior clinoidectomy (Fig. 22.2), the lesser wing of the sphenoid is drilled flat. On the lateral side of the SOF, a dural-periosteal fold, the temporo-periorbital ligament (aka meningo-orbital fold) attaches the temporal dura to the periorbita in the SFO. This ligament should be sharply divided to mobilize the dura from the lateral aspect of the ACP and fully expose it.

Dural Relationships

Rhoton described the sinus as a boat-like structure with a narrow keel centered at the SOF anteriorly and a wider bow extending between the dorsum sella superomedially and the petrous apex inferolaterally [2]. The sinus has a roof, a floor, and three walls: medial, lateral, posterosuperior. The floor is formed by the periosteum of the sphenoid and petrous bone inferior to the sinus and is demarcated by the maxillary nerve (V2 of the trigeminal nerve) anteriorly and Meckel's cave posteriorly. The tentorium cerebelli contributes significantly to the cavernous sinus roof, and the dura propria of the middle cranial fossa contributes to the lateral wall of the cavernous sinus.

The cavernous sinus roof is formed by the anterior extension of the tentorium cerebelli and the lateral extension of the diaphragma sellae. As the tentorium curves anteromedially, it gives rise to two dural folds: first, the anterior petroclinoid fold extending anteriorly to the ACP; and second, the posterior petroclinoid fold extending to the PCP. An interclinoid fold connects the ACP and PCP. These three folds form the boundaries of the oculomotor trigone, which constitutes the posterior two-thirds of the roof of the cavernous sinus, and in essence, the lateral extension of the diaphragma sellae. The oculomotor nerve (CN III) penetrates the oculomotor trigone. Although this portion of the roof is accessible by direct intradural surgery, the anterior one-third is hidden below the ACP, which must be removed to gain access to this region.

The anterior petroclinoid fold splits into two layers that enclose the ACP. A superficial layer extends on its superior surface and onto the tuberculum sellae. It encircles the internal carotid artery (ICA) proximal to the origin of the ophthalmic artery to form the distal dural ring.

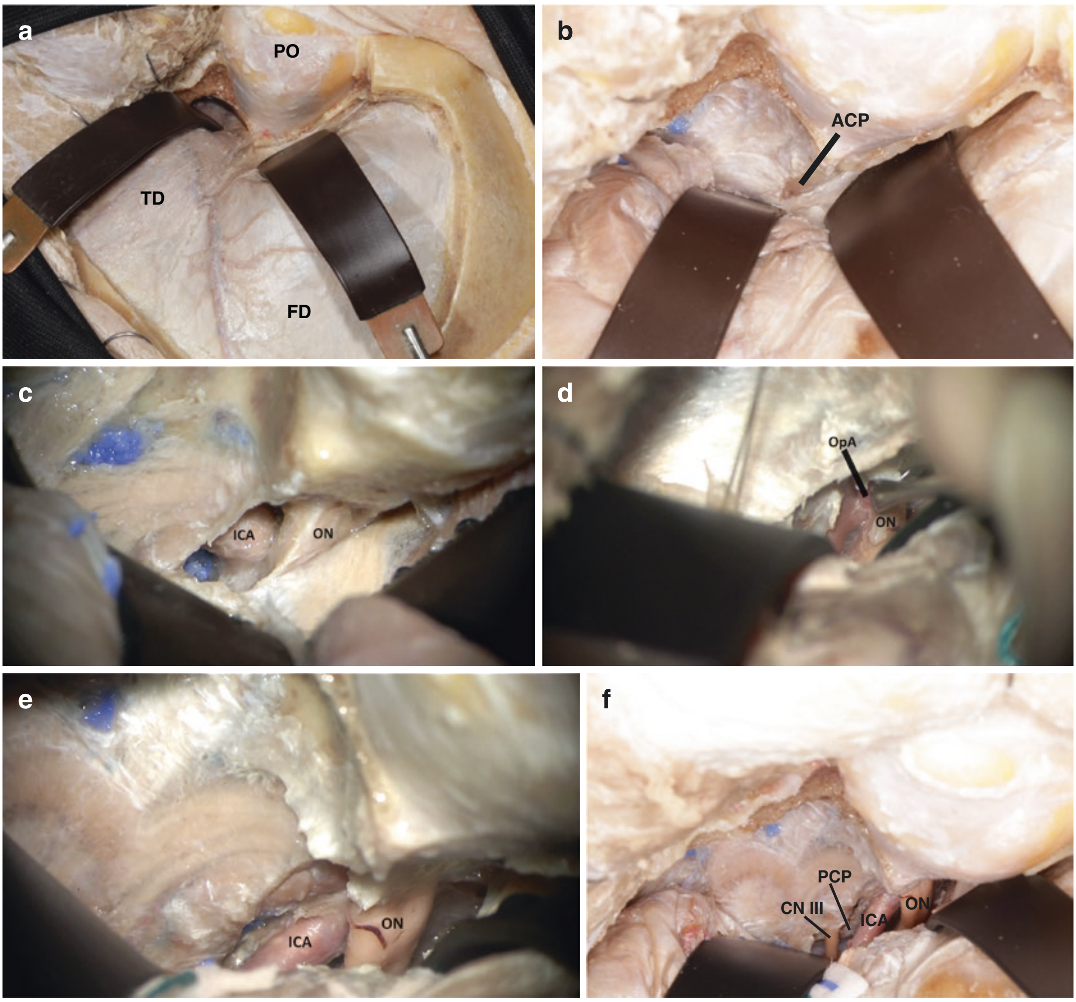

Fig. 22.2 Cadaveric dissection illustrating the steps of the anterolateral approach to the cavernous sinus. (**a**) An orbitopterional craniotomy is performed, and the greater wing of the sphenoid is drilled down to the level of the meningo-orbital fold. (**b**) Dividing the meningo-orbital fold allows further posterior dissection of the frontal and temporal dura to expose the optic nerve (CN II) medially, SOF laterally, and more of the ACP. (**c**) The ACP is drilled extradurally to expose the lateral wall and floor of the optic canal. The clinoid segment of the ICA, which is bordered proximally and distally by the proximal and distal dural rings, respectively, is identified. The falciform ligament overlying the optic nerve is also identified. (**d**) Under direct visualization of both the intradural and extradural ICA segments, the DDR is divided, and the origin of the ophthalmic artery is identified. (**e**) The carotid collar and proximal ring can be divided to mobilize the ICA. (**f**) The oculomotor trigone is opened, and the oculomotor nerve (CN III) is seen coursing through the lateral wall of the cavernous sinus toward the SOF. (**g**) CN III is sharply dissected off its attachment to the lateral wall of the cavernous sinus. (**h**) The PCP is drilled to expose the basilar artery, ipsilateral superior cerebellar artery, and upper pons. (**i**) The caudal extension of this approach exposes the abducens nerve (CN VI) as it passes under the petroclinoid ligament (Gruber ligament). ACP: anterior clinoid process; BA: basilar artery; ICA: internal carotid artery; CN: cranial nerve; FD: frontal dura; CN II: optic nerve; OpA: ophthalmic artery; PCP: posterior clinoid process; PCoA: posterior communicating artery; Ped.: peduncle; PO: periorbita; SCA: superior cerebellar artery; TD: temporal dura; V1: ophthalmic nerve; V2: maxillary nerve; V3: mandibular nerve. (Used with permission from Barrow Neurological Institute, Phoenix, Arizona)

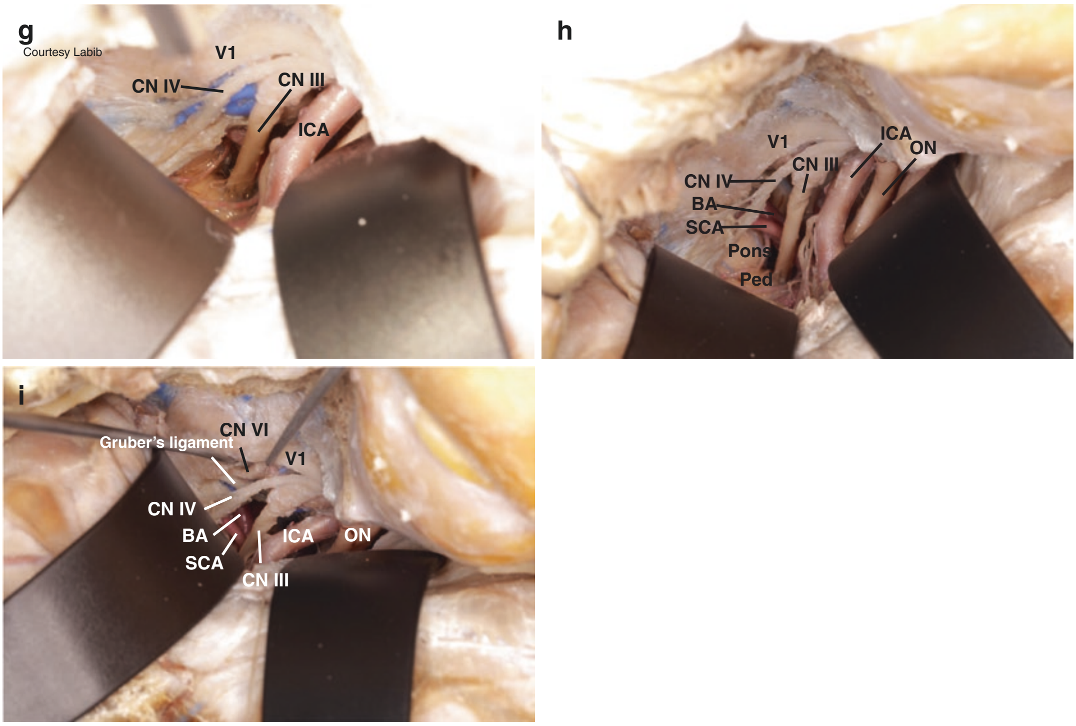

Fig. 22.2 (continued)

The deeper layer encircles the ICA as it emerges from the cavernous sinus to form the proximal dural ring and extends laterally to the oculomotor nerve as the carotid-oculomotor membrane. The clinoid, or C5 segment of the ICA, is located between these two rings (Fig. 22.3).

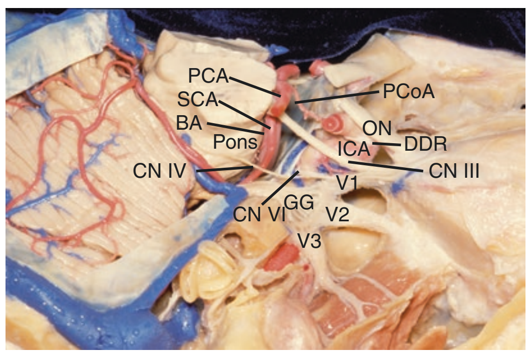

Fig. 22.3 Lateral view of the cavernous sinus. The right anterior clinoid process is removed, the clinoidal segment of the internal carotid artery (ICA) bounded by the distal dural ring (DDR), and the proximal dural ring is identified. The oculomotor nerve (CN III) is seen coursing from the interpeduncular cistern to the superior orbital fissure. The trochlear nerve (CN IV) is also observed entering the lateral wall of the cavernous sinus posterolateral to the oculomotor nerve. The abducens nerve (CN VI) is seen before it enters the superior orbital fissure medial to the ophthalmic nerve (V1). The ventral surface of the midbrain, pons, and basilar artery (BA) and its branches are identified. CN: cranial nerve; GG: Gasserian ganglion; PCA: posterior cerebral artery; PCoA: posterior communicating artery; SCA: superior cerebellar artery; V1: ophthalmic nerve; V2: maxillary nerve; V3: mandibular nerve. (Used with permission from Barrow Neurological Institute, Phoenix, Arizona)

The Lateral Wall

A thorough understanding of the anatomy of the lateral wall has been critical to the evolution of cavernous sinus surgery. The lateral wall is formed of two layers, the superficial dura propria of the middle fossa and a deeper reticular layer (or inner membranous layer) [4]. This deep layer is formed by the epineurium of the nerves traversing the lateral wall of the cavernous sinus (Fig. 22.3).

In the anterior half of the cavernous sinus, on the lateral side of the SOF, the periosteum of the orbital wall (periorbita) bridges to the periosteal dura of the middle fossa and is continuous with the medial wall of the cavernous sinus. The meningeal dura forms the lateral wall of the cavernous sinus (superficial layer). Posterior to the

SOF, the two layers begin to separate, and splitting of the periosteal bridge (meningo-orbital fold) leads to the initial point of dissection of the superficial layer. Close to the SOF, cranial nerves are wrapped with a common meningeal sheath, which is continuous to the periosteum of the orbit anteriorly and to the inner layer posteriorly. The upper rim of the cavernous sinus is exposed by incision of the tentorial fold subdurally from the oculomotor trigone, where the superficial layer is not attached, which forms a meningeal pocket to the SFO anteriorly. The bottom of the meningeal pocket is covered only by a thin meningeal layer, which blends with the inner layer. Posterior to this point, the trochlear nerve (CN IV) is hard to separate from the tentorial fold. In the posterior half of the cavernous sinus, the posterolateral wall is formed by Meckel's cave and the trigeminal nerve (CN V). Meckel's cave is covered with a thinner dural layer, and it is occasionally opened by dissection of the superficial layer. The abducens nerve (CN VI) in the course of the Dorello's canal is located behind the cave and can be exposed only by mobilization of the trigeminal nerve (V1) laterally.

The Medial and Anterior Walls

The anterior wall of the pituitary gland is enveloped by two layers, an inner meningeal and an outer periosteal layer. The two layers separate at the lateral edge of the sella turcica. The inner meningeal layer travels medially to invest the medial aspect of the pituitary gland and forms the medial wall of the cavernous sinus. The outer layer courses laterally to form the anterior wall of the cavernous sinus. Because the medial wall of the sinus is single-layered, lesions like pituitary adenomas often invade this wall and enter the sinus [5].

Clinical Significance

The anterior loop of the ICA can be mobilized after anterior clinoidectomy and circumferential division of the distal dural ring. This mobilization allows the surgeon to manage aneurysms of the anterior loop and clinoidal segment of the ICA. Sectioning the proximal ring allows mobilization of the entire anterior loop and entry into the anterior cavernous sinus.

Because it is widely known that venous sinuses are situated between the periosteal and meningeal dura (dura propria) [6], the cavernous sinus is considered to be a venous plexus in an interdural space [7, 8].

On the lateral side of the SOF, the two periosteo-dural layers form the periosteal bridge to the middle fossa. The detachment of the periosteal bridge parallel to the SOF introduces the interdural space where the anterior cavernous sinus is exposed without opening the meningeal dura. The semitransparent inner layer protects the cranial nerves and venous channels. However, surgeons must know the three venous bleeding points where the deep layer is absent posterolateral to the SOF, posterior to the proximal dural ring and the posterior part of the Parkinson's triangle. Overpacking this space with hemostatic material in the venous channels may cause cranial nerve palsies. Because there is a distinct cleavage plane between the dura propria and the inner membranous layer, tumors of the lateral wall can be exposed without entering the cavernous sinus proper [9]. Tumors within the cavernous sinus are generally approached by mobilizing the dura propria and are followed by exploring the sinus through variously defined triangles bordered by the cranial nerves that traverse them. Three surgical points are described where sharp dissection is required to avoid cranial nerve injury during lateral wall mobilization, (1) around the foramina rotundum and ovale because the superficial dural layer is adherent to the nerves near the foramina, (2) the cavernous sinus apex because the cranial nerves are wrapped in a common meningeal sheath, and (3) the posterior part of the trochlear nerve as it courses under the tentorial fold firmly adherent to it [10].

Vascular Relationship

Arterial

The ICA enters the cavernous sinus distal to the petrolingual ligament. The cavernous segment (C4) usually has a vertical portion, a posterior bend or medial loop of the ICA, a horizontal portion, and an anterior bend or anterior loop of the ICA. This C4 segment ends at the proximal dural ring. The anterior loop, oriented 30° to the horizontal plane, is firmly fixed to the skull base by the distal dural ring. The clinoid segment (C5), that segment of the artery between the proximal and the distal rings, is extracavernous, infraclinoid, and extradural [11]. The distal dural ring is the only complete ring that surrounds the ICA. This ring is continuous with the adjacent dura of the falciform ligament, ACP, and the roof of the cavernous sinus.

The intracavernous ICA has three major branches: (1) the meningohypophyseal trunk, the largest intracavernous branch, present in 100% of the specimens examined [1, 12, 13], (2) the artery of the inferior cavernous sinus, present in 84% of specimens, and (3) McConnel's capsular arteries, present in 28% of specimens. Less frequent branches of the intracavernous carotid were the ophthalmic artery (8%) and the dorsal meningeal artery (6%). The meningohypophyseal trunk arises from the medial loop and divides into three branches: (1) the tentorial artery, also called the artery of Bernasconi–Cassinari [14], which courses posterolaterally to the roof of the cavernous sinus and along the free edge of the tentorium, giving branches to the oculomotor and trochlear nerves and anastomoses with the meningeal branch of the ophthalmic artery and its mate of the opposite side; (2) the inferior hypophyseal artery, which travels medially to supply the posterior pituitary capsule; and (3) the dorsal meningeal artery, which perforates the cavernous sinus wall to supply the clival area and the abducens nerve. The inferolateral trunk, also known as the inferior cavernous sinus branch, arises from the lateral surface of the horizontal segment and also supplies the abducens nerve.

Venous

Three main venous spaces are found within the sinus and are identified according to their relation to the carotid artery [13]: medial, anteroinferior, and posterosuperior compartments. These three venous spaces are larger than the space between the carotid artery and the lateral sinus wall. The lateral space is so narrow that the abducens nerve, which passes through it, is adherent to the carotid on its medial side and to the sinus wall on its lateral side.

Intercavernous venous sinuses may be found in the margins of the diaphragma and around the gland. They are named on the basis of their relationship to the pituitary gland and may occur at any site along the anterior, inferior, and posterior surfaces of the gland. The anterior sinus is usually larger than the posterior sinus, but either or both may be absent. If the anterior and posterior connections coexist, the whole structure constitutes the circular sinus [15].

Clinical Significance

Aneurysms arising from the anterior loop of the ICA can project into the subarachnoid space and, therefore, can present with subarachnoid hemorrhage if they rupture. Mobilization of the anterior loop after sectioning the distal dural ring allows clipping of the aneurysm neck, which is often hidden by the ACP.

Surgical approaches to the cavernous sinus are decided based on arterial (ICA) and venous (space) relationships of pathology. Holocavernous lesions are approached through an anterolateral approach, whereas posterolateral lesions are approached through a subtemporal/middle fossa approach. Medial lesions are approached through an endonasal midline approach, and anteroinferior lesions are approached through an endonasal transpterygoid approach.

The inferolateral trunk of the cavernous sinus plays a major role in the blood supply of the cranial nerves. All the branches from the inferolateral trunk are located on the inferomedial aspects of the intracavernous cranial nerves and should be factored in the selection of the surgical approach in order to be preserved during cavernous sinus surgery [11]. Disregarding the vascularization of cranial nerves can lead to loss of neurological function.

Neural Relationships

CN III through CN VI are closely associated with the cavernous sinus. The oculomotor nerve courses above the posterior petroclinoid fold lateral to the PCP and enters the cavernous sinus via the oculomotor foramen in the oculomotor trigone. It travels along the superior lateral wall of the cavernous sinus where its epineurium interweaves with the epineurium of the trochlear nerve and V1, which forms the inner layer of the lateral wall of the cavernous sinus. It courses anteriorly along the inferolateral surface of the ACP and enters the SOF. The carotid-oculomotor membrane stretches between the anterior loop of the ICA and the oculomotor nerve as it crosses the artery, giving rise to the proximal dural ring. The trochlear nerve penetrates the margin of the tentorium posterolateral to the PCP between its diverging anterior and posterior petroclinoid folds. The nerve travels along the tentorium over a few millimeters before entering the lateral wall of the cavernous sinus. In the lateral wall, it travels anteriorly below and lateral to the oculomotor nerve, deep to the dura propria and suspended within the inner membranous layer. The trochlear nerve crosses over the oculomotor nerve before entering the SFO. The ophthalmic division (V1) of the trigeminal nerve enters the lateral wall of the cavernous sinus at its most posterior end. V1 courses below and lateral to the trochlear nerve in the lateral wall and lateral to it in the SOF. V1 divides into three branches: (1) the large frontal branch courses with the trochlear nerve, and (2) the small lacrimal branch travels in the lateral-most part of the fissure; both these branches are outside the annulus of Zinn. (3) The intermediate nasociliary branch enters the orbit through the annulus between the two heads of the lateral rectus muscle. The dura of the cavernous sinus is innervated by the ophthalmic and maxillary branches of the trigeminal nerve.

The abducens nerve penetrates the clival dura and ascends toward Dorello’s canal. This small triangular space is a passage formed beneath the posterior petroclinoid ligament from the petrous apex to the PCP and contains the abducens nerve, inferior petrosal sinus, and dorsal meningeal artery. Within Dorello’s canal, the abducens nerve is usually lateral to the inferior petrosal sinus, although it may be below in some cases [16]. The abducens nerve enters the posterior cavernous sinus, passes laterally over the lateral surface of the ICA, and has the distinction as the only cranial nerve that is truly intracavernous in position.

Cervical sympathetic fiber bundles travel on the surface of the ICA as it emerges from the foramen lacerum. They cross over the abducens nerve before ultimately being distributed to the first division (ophthalmic, V1) of the trigeminal nerve. Within the cavernous sinus, the plexus sends filaments to the trigeminal nerve via the abducens nerve and from it to the ciliary ganglion [1]. The remainder of the plexus continues upward around the artery as it emerges from the cavernous sinus. No sympathetic fibers have been reported to travel through the oculomotor or trochlear nerves.

Clinical Significance

Cranial nerve palsy is the most common manifestation of pathological processes involving the cavernous sinus. Diplopia is often the presenting symptom. In one study, multiple cranial neuropathies occurred in 82% of patients [17]. An abducens nerve palsy with postganglionic Horner’s syndrome suggests a cavernous sinus lesion [18]. Sensory symptoms in the distribution of V1, and occasionally V2, are also common presenting symptoms of cavernous sinus lesions. Impaired visual acuity is less often a presenting symptom than double vision [17].

Most cavernous sinus explorations are for benign disease with the goal of preserving and improving cranial nerve function. Exploration of the cavernous sinus usually follows mobilization of the lateral wall and entry through one or more of the various triangles formed by these cranial nerves and the dural folds. To reduce the incidence of cranial neuropathy, the surgeon must minimize mechanical trauma to the nerves, avoid heat injury, and preserve the blood supply to the cranial nerves.

Anatomic Triangles

The cranial nerves, in conjunction with dural folds and some osseous structures of the skull base, tend to form a pattern of triangles (Fig. 22.4). The organization of the cavernous sinus region into a series of anatomic triangles was first described by Dolenc [19] and was later refined and expanded by other authors [20]. The triangles of the cavernous sinus, as described by Dolenc, are categorized into three regions:

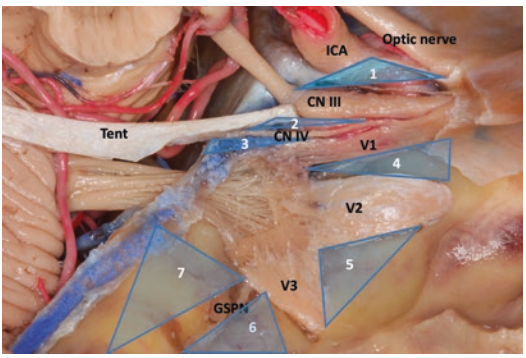

Fig. 22.4 Cavernous sinus triangles. The anatomical borders of the cavernous triangles are outlined below. (**1**) Anteromedial triangle: medial, optic nerve; lateral, oculomotor nerve (CN III); and base, dural edge. (**2**) Paramedian triangle: medial, oculomotor nerve; lateral, trochlear nerve (CN IV); and base, the dural edge of the tentorium (Tent). (**3**) Parkinson's triangle: medial, trochlear nerve; lateral, V1 of the trigeminal nerve; base, the dural edge of the tentorium. (**4**) Anterolateral (Mullan's) triangle: medial, V1 of the trigeminal nerve; lateral, V2 of the trigeminal nerve; and base, the line between V1 in the superior orbital fissure and the foramen rotundum. (**5**) Lateral triangle: medial, V2 of the trigeminal nerve; lateral, V3 of the trigeminal nerve; and base, the line between the foramen rotundum and the foramen ovale. (**6**) Posterolateral (Glasscock's) triangle: medial, greater superficial petrosal nerve (GSPN); lateral, the line between foramen spinosum and arcuate eminence; and base, V3 of the trigeminal nerve. (**7**) Posteromedial (Kawase) triangle: medial, superior petrosal sinus; lateral, GSPN; and base, V3 trigeminal nerve. (Used with permission from Barrow Neurological Institute, Phoenix, Arizona)

1. The parasellar region consists of the anteromedial triangle, paramedial triangle, and Parkinson's triangle.
2. The middle fossa region contains the anterolateral (Mullan) triangle, lateral triangle, posterolateral (Glasscock) triangle, and posteromedial (Kawase) triangle.
3. The paraclival region—inferomedial triangle and inferolateral (trigeminal) triangle.

The boundaries and contents of each triangle are described in Table 22.1 (Fig. 22.4).

The triangles that are involved in the initial approach to expose the cavernous sinus lateral wall are called "approach triangles." These are the paramedial triangle of Dolenc, the posterolateral triangle of Glasscock, and the posteromedial triangle of Kawase. There are four triangles through which the inner space of the cavernous sinus is usually exposed and explored, and we call these "entry triangles." These are the anteromedial triangle of Hakuba [20], paramedial triangle of Dolenc [19], Parkinson's triangle [1, 7], and the anterolateral triangle of Mullan.

The anteromedial triangle of Hakuba is only fully apparent after the complete removal of the ACP. The distal horizontal segment and anterior loop of the ICA can be exposed through this triangle after complete removal of bone anterior to the ICA, which unveils the mucosa of the sphenoid sinus.

Parkinson's triangle is commonly used to expose holocavernous tumors such as pituitary adenomas, chordomas, and chondrosarcomas.

The anterior cavernous sinus can be entered at the apex of the anterolateral triangle, where the lateral portion of the anterior loop of the ICA is found. The anterolateral triangle is often explored for tumors that enter the cavernous sinus from the middle fossa floor or infratemporal fossa (e.g., chordoma or chondrosarcoma).

Surgical Approaches to the Cavernous Sinus

Approaches to the cavernous sinus can be categorized into three groups on the basis of which

Table 22.1 Anatomic triangles of the cavernous sinus

	Boundaries			
Triangle	Medial	Lateral	Base	Contents
Anteromedial (Hakuba)	CN II	CN III	Anterior petroclinoid fold	Anterior clinoid process, carotid rings anterior loop, distal horizontal ICA
Paramedial (Dolenc)	CN III	CN IV	Anterior petroclinoid fold	Horizontal ICA, inferolateral trunk
Parkinson's	CN IV	V1	Anterior petroclinoid fold	Medial loop, horizontal ICA (distal), CN VI
Anterolateral (Mullan)	V1	V2	Superior orbital fissure to foramen rotundum	Horizontal ICA, CN VI
Lateral	V2	V3	Foramen rotundum to foramen ovale	Lateral loop of ICA
Posterolateral (Glasscock)	Greater superficial petrosal nerve	Arcuate eminence to foramen spinosum	V3 lateral margin	Posterior and lateral loops of ICA, tensor tympani, lateral loop of Eustachian tube
Posteromedial (Kawase)	V3, Gasserian ganglion	Greater superficial petrosal nerve	Petrous apex	Posterior surface of medial loop, petrous apex with Meckel's cave, posterior fossa dura
Inferomedial	Line between posterior clinoid and CN VI at Dorello's canal	Line between CN VI and CN IV at tentorial edge	Petrous apex	
Inferolateral	Line between Dorello's canal and CN IV tentorial edge	Line between Dorello's canal and petrosal vein at tentorial edge	Petrous apex	

sinus compartment must be addressed. These approaches are as follows:

1. Anterolateral: These approaches are frontotemporal, with or without orbital and zygomatic osteotomies. They allow access to the entire sinus but are preferably used for lesions in the superior posterior compartment as well as those involving the lateral wall of the sinus.
2. Lateral: These approaches provide access to the posterior cavernous and are essentially anterior extensions of the extended middle fossa approach (Kawase) to Meckel's cave lesions.
3. Anteromedial: These approaches include two endoscopic endonasal approaches, one to the medial compartment of the cavernous sinus and the other to the anterior inferior compartment of the sinus.

Transcranial Surgical Approaches

In this section, the anterolateral approaches (their modifications) as well as the lateral approaches to the cavernous sinus are described.

Anterolateral Transcavernous Approach (Dolenc's Approach)

Operative Procedure (Fig. 22.2)

Step 1: Frontotemporal Craniotomy with or Without an Orbitozygomatic Osteotomy

A frontotemporal craniotomy is essential. It can be supplemented with orbital and zygomatic osteotomies as required by the size and extension of the pathology. The removal of the orbital rim and roof expands the operative corridor, improves light delivery to the field, minimizes brain retraction while drilling the optic canal, maximizes surgical maneuverability, and optimizes the angle of attack toward a rostral midline lesion. Division of the zygomatic arch maximizes the extent of inferior reflection of the temporalis muscle and thus optimizes the upward angle of attack in subtemporal approaches. However, this step is reserved for high-riding lesions and is not necessary most of the time.

In order to maximize the pretemporal trajectory further, the greater wing of the sphenoid bone must be reduced to the level of foramina rotundum, ovale, and spinosum from anterior to posterior. Similarly, the lesser wing of the sphenoid bone is drilled medially toward the SOF.

Step 2: Exposure and Drilling of the ACP

The meningo-orbital fold and artery mark the lateral edge of the SOF and are the easiest point to start the dissection between the meningeal dura of the temporal lobe and the lateral wall of the cavernous sinus. Remaining in the plane between the two layers is important to avoid injuring the cranial nerves in the SOF and lateral wall of the cavernous sinus. The sphenoparietal sinus should be maintained on the dura propria side. The peeling of the dura from anterior to posterior is continued until the ACP is completely exposed.

The underside of the ACP overlies the SOF laterally and the roof of the cavernous sinus medially. Hence, the ACP should be completely freed off the underlying periosteal dura to avoid injury to the oculomotor nerve by using semi sharp dissectors. Under continuous irrigation, a 3-mm diamond drill bit is used to drill the ACP, starting at the superolateral aspect of the optic canal and proceeding medially. The core of the ACP is drilled up to the periosteal layer encasing the optic nerve. The optic strut is then carefully drilled with a 2-mm bit while realizing that the paraclinoid ICA lies against the posterior surface of the strut. The paraclinoid ICA is often engulfed in the venous blood that manages to escape from the cavernous sinus through the incompetent proximal dural ring. Such bleeding is easily controlled with Floseal. It is important to realize that to drill the ACP completely extradurally may not be safe or feasible if it is connected medially to a middle clinoid process (i.e., in the presence of a carotid-clinoid foramen) or posteriorly to the PCP (i.e., in the presence of an interosseous clinoid bridge). These osseous variants are usually visible on preoperative thin-cut computed tomography scans and must be inspected. In these situations, the residual ACP is disconnected from the middle or posterior clinoids intradurally. Failing to recognize these variants and forcefully pulling the tip of the ACP may result in injury to the ICA.

Step 3: Combined Intradural–Extradural Mobilization of Neurovascular Structures

The dura is then opened in a T-shaped fashion with the vertical limb along the proximal Sylvian fissure. The vertical limb does not need to be lengthy unless a distal fissure split is required. The horizontal limbs are fashioned as low as possible toward the frontal and temporal lobes at the cranial base to avoid exposing the brain unnecessarily. It is important to identify the cisternal segments of the optic and oculomotor nerves as well as the intradural ICA.

Under simultaneous visualization of both the intracranial and intracanalicular segments of the optic nerve, the falciform ligament is divided with a right-angled, micro-diamond knife, and the dura overlying the superior and lateral aspects of the nerve is opened. These maneuvers untether the optic nerve and lower the risk of injury during surgical manipulations. The origin of the ophthalmic artery is identified as it branches off the supraclinoid ICA immediately distal to the distal dural ring (DDR). Similarly, while visualizing both the ophthalmic and paraclinoid segments of the ICA intradurally and extradurally, respectively, the DDR is divided, thus untethering the ICA for further mobilization when needed. Finally, the oculomotor trigone is opened by dividing the anterior petroclinoid as well as the intercolonial folds. The nerve is completely freed and mobilized to its entrance to the SOF by dividing any arachnoid and dural attachments around it. Care must be taken to avoid injuring the trochlear nerve in the very narrow apex of the supratrochlear triangle while mobilizing the oculomotor nerve. The trochlear nerve enters the roof of the sinus posterolateral to the oculomotor nerve and then ascends to the apex of the triangle where it crosses medial to it en route to the SOF.

Step 4: Cavernous Sinus Exploration

Depending on the location of the lesion and its pathology, the sinus can be explored systematically using the approach triangles discussed above. The inner layer of the lateral wall can be incised along the long axis of each triangle using an arachnoid knife, and resection of the pathology can be performed.

Modifications of the Anterolateral Approach to the Cavernous Sinus

The general approach described above can be tailored to the lesion at hand. For example, the removal of the roof of the orbit and its rim is not essential for every approach to the cavernous sinus. For lesions with minimal rostral extension to the suprachiasmatic region, an orbitotomy may not be necessary. Similarly, removing or inferiorly displacing the zygoma may not be necessary in cases with minimal extension to the upper ambient cistern.

It is also important to realize that some of the steps in the general extradural approach described above can be done intradurally according to the description by Hakuba et al. [20] After performing a standard frontotemporal craniotomy (with or without an orbitotomy), the dura is opened in a T-shaped fashion and then the dura over the ACP, lesser wing of the sphenoid, and limbus sphenoidale is incised. The ACP and optic strut are then drilled intradurally. The falciform ligament is incised, and the dural opening is extended along the optic canal. This technique exposes what Hakuba et al. [20] called the medial triangle of the cavernous sinus, which has three apices: the dural entrance of the oculomotor nerve, the anterolateral margin of the PCP, and the anterior margin of the supraclinoid ICA. The triangle is then opened, and both the distal and proximal dural rings are incised. The dura of the temporal lobe can then be mobilized off the cavernous sinus and middle fossa floor, as described above.

Lateral: The Middle Fossa–Kawase Approach

For select lesions occupying Meckel's cave and the posterior fossa, with some anterior extension into the posterior cavernous sinus, a tailored Kawase (Chap. 31) approach may be used. A frontotemporal craniotomy with or without a zygomatic osteotomy is done. The floor of the middle fossa is drilled as far medial as the foramen rotundum anteriorly and the spinosum posteriorly. The middle meningeal artery is divided. The dura propria of the temporal lobe is then followed to its junction with the dural sleeves of the maxillary and mandibular (V3 of the trigeminal nerve) nerves. After incising the sleeves, the dissection is carried further anteriorly to expose as much of the lateral wall of the cavernous sinus as needed. An anterior petrosectomy is completed (Chap. 31).

Combined Anterolateral and Middle Fossa Approach

The hybrid Kawase–Dolenc approach is ideal for lesions originating in the middle clivus or Meckel's cave and extending anteriorly to the posterior cavernous sinus as in petroclival meningiomas. In such cases, a large frontotemporal craniotomy similar to the "Half and Half" approach will expose both anterior and middle fossa, and an anterior petrosectomy can be added to the Dolenc's approach. This approach is detailed in Chap. 37.

Endoscopic Surgical Approaches

The endoscopic endonasal approaches to the cavernous sinus are directed either to the medial or to the anterior inferior compartment of the sinus. Both approaches are described below.

The Endoscopic Endonasal Approach to the Medial Cavernous Sinus

This technique is an interdural approach in which the medial compartment is opened, and the pituitary gland with the dura comprising the medial wall of the cavernous sinus enveloping it is transposed toward the contralateral side. Also, this approach allows direct access to the dorsum sellae and the PCP on that side. The drilling of these structures and opening the dura posterior to them grant access to the upper retroclival region. The steps for performing this procedure are outlined below (Fig. 22.5).

Step 1: Extended Transsphenoidal Approach

The endonasal approach to exposing the sphenoid sinus is performed as described in Chap. 15. Midline drilling extends from the tuberculum sellae to the floor of the sphenoid sinus. Removal of the sellar floor is necessary as it provides access to the base of the PCP. The bone overlying the parasellar ICA, the medial compartment of the cavernous sinus, and the rostral aspect of the paraclival ICA are removed.

Step 2: Opening the Medial Compartment of the Cavernous Sinus

A carotid Doppler is used to identify the course of the parasellar ICA as it veers laterally away from the pituitary gland. The dura overlying the medial compartment of the sinus is then opened. Two structures are immediately

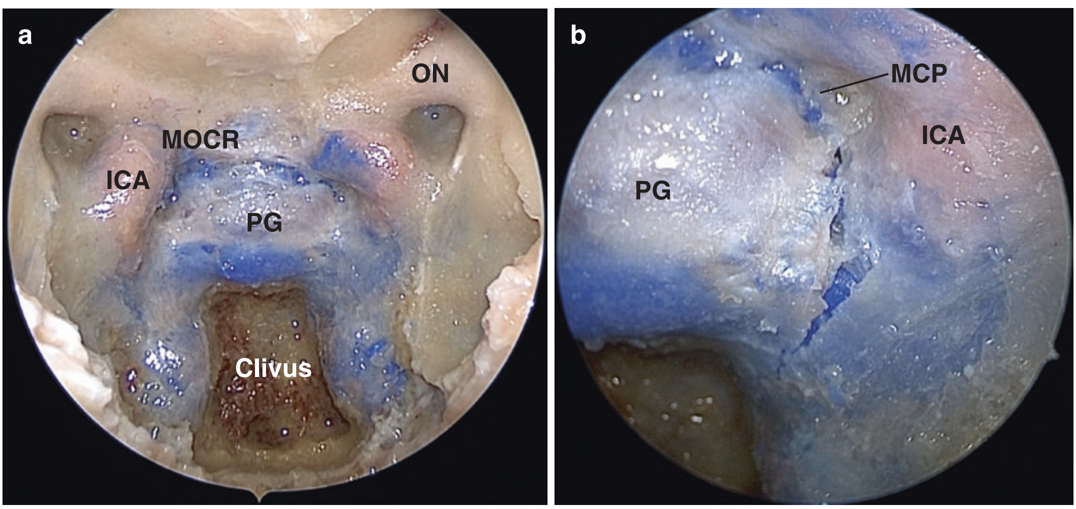

Fig. 22.5 Stepwise dissection illustrating the endoscopic endonasal approach to the medial cavernous sinus. (**a**) Zero-degree view after completion of a standard endoscopic endonasal approach. (**b**) An incision is made in the periosteal dural leaflet covering the anterior aspect of the medial compartment of the cavernous sinus. (**c**) The dura is elevated and retracted medially to expose the parasellar ligaments. (**d**) The inferior parasellar ligament is divided, and the inferior hypophyseal artery is identified and divided. (**e**) The medial wall of the cavernous sinus and pituitary gland is mobilized freely to the contralateral side to expose the dorsum sella and posterior clinoid process. (**f**) The dorsum sella and posterior clinoid have been drilled and the dura opened to expose the relevant neurovascular elements. Abbreviations: CN: cranial nerve; ICA: internal carotid artery; IHA: inferior hypophyseal artery; MCP: middle cerebellar peduncle; MOCR: medial opticocarotid recess; PG: pituitary gland. (Used with permission from Barrow Neurological Institute, Phoenix, Arizona)

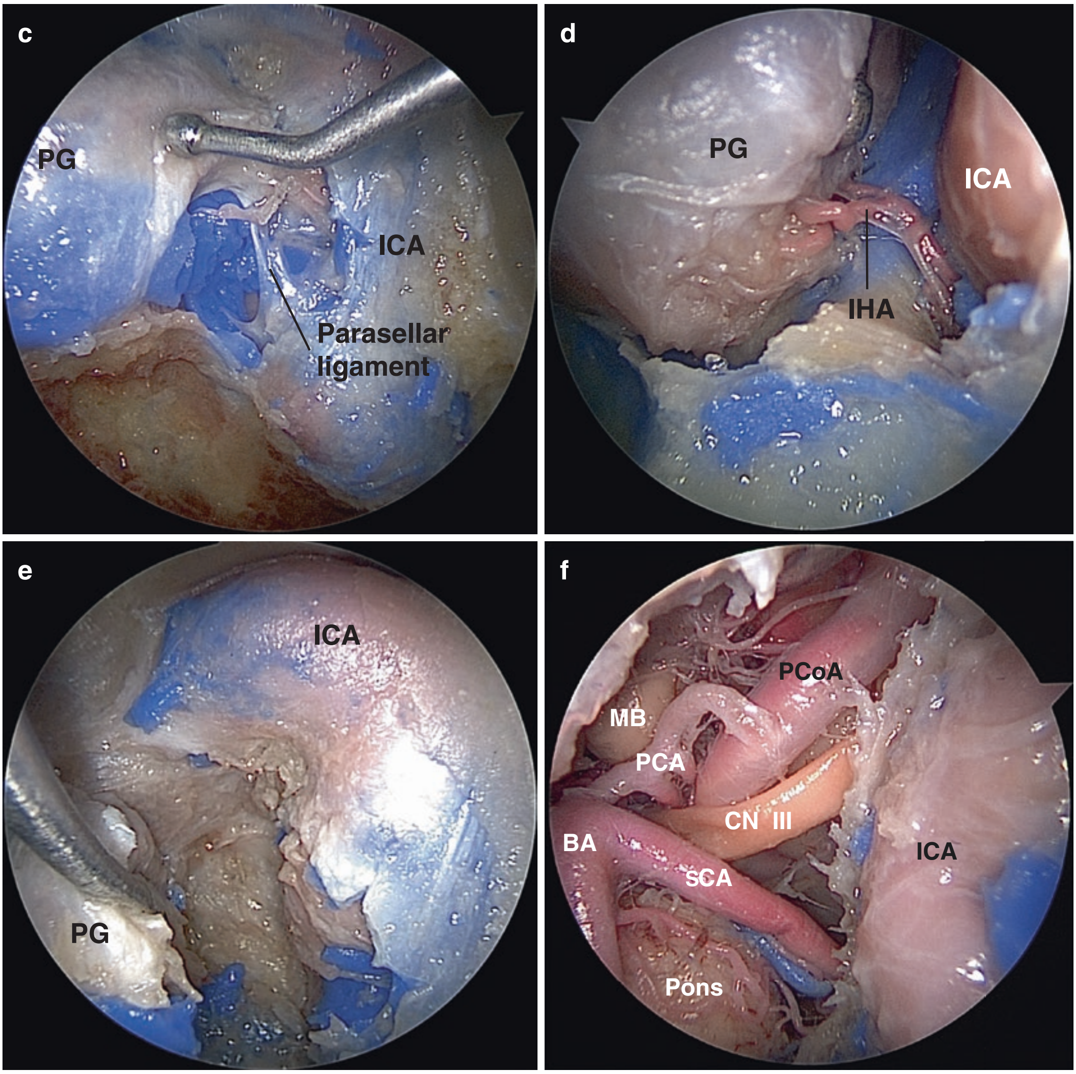

Fig. 22.5 (continued)

identified: the inferior hypophyseal artery and an inferior "pituitary ligament," connecting the ICA to the meningeal dura overlying the pituitary gland. The inferior hypophyseal artery is coagulated and divided to avoid its avulsion from the ICA. The inferior pituitary ligament is also divided to free the meningeal dura and enable further mobilization of the gland.

Step 3: Opening the Clinoidal Space

The PDR is divided and followed in a medial direction as it sends multiple fibers toward the meningeal dura of the medial wall of the cavernous sinus. If extensive access to the suprasellar cisterns is desired, the DDR is can also be divided.

The Endoscopic Endonasal Approach to the Anterior Inferior Cavernous Sinus

In addition to the general transsphenoidal approach described above (Step 1 of the approach to the medial compartment of the cavernous sinus), a transmaxillary transpterygoid approach is needed to achieve more lateral exposure to the anterior inferior compartment.

Step 1: Extended Transsphenoidal Approach (Discussed above)

Step 2: Transmaxillary/Transpterygoid Approach—Suprapetrous Module

The transmaxillary and transpterygoid approaches are detailed in Chap. 35. Briefly, the posterior wall of the maxillary sinus is exposed after performing a middle turbinectomy, uncinectomy, and removal of the medial wall of the maxilla. The sphenopalatine artery is identified, coagulated, and divided. A 2-mm Kerrison rongeur is used to remove the posterior wall of the maxillary sinus and expose the pterygopalatine fossa. The Vidian foramen is exposed and its neurovascular bundle is coagulated and divided to aid in the lateralization of the contents of the pterygopalatine fossa. The Vidian canal is drilled circumferentially, and the Vidian nerve is followed posteriorly until reaching the foramen lacerum, where the fibrocartilaginous tissue of the foramen fuses with the fibrocartilage of the roof of the Eustachian tube. This point demarcates the junction of the petrous and paraclival ICA. Similarly, the infraorbital nerve is followed from the pterygopalatine fossa posteriorly toward the maxillary nerve (V2) as it courses through foramen rotundum. The bone overlying the V2 is removed, and any bone between the V2 and the Vidian canal is also drilled.

Step 3: Exposure of the Paraclival and Parasellar ICA

The fibrocartilage overlying foramen lacerum and its junction with the Vidian nerve are excellent landmarks to identify the proximal aspect of the paraclival ICA. The paraclival and parasellar ICA segments do not need to be skeletonized or mobilized for anterior cavernous sinus lesions.

Step 4: Exposure of the Anterior Inferior Cavernous Sinus

The bone overlying the interval between the lateral optic carotid recess and V2 must be removed entirely to expose the lateral wall of the cavernous sinus.

Step 5: Dural Opening

Doppler ultrasound is used before opening the dura. It is safest first to open the dura over the sella and then proceed into the medial compartment of the sinus to identify the margins of the parasellar ICA before opening the dura laterally. Once the medial aspect of the parasellar ICA is identified, it can be protected, and the dural opening can be extended laterally. In most cases where this compartment of the sinus is approached, the tumor would have thrombosed the sinus already. The dura can be dissected downward inferiorly and laterally to the paraclival ICA, which has already been exposed.

Surgical Decision-Making Strategy

Management of cavernous sinus pathology is disease-specific, as detailed in the following chapters. In instances where the decision is made to pursue surgery, planning the surgical approach is governed by two important factors:

1. Tumor location: Lesions involving the medial or anterior inferior compartment of the sinus are approached through an endoscopic endonasal approach. Lesions occupying the space between the meningeal and periosteal layers of the lateral wall of the sinus (i.e., lateral to the oculomotor, trochlear, and ophthalmic nerves) can be safely removed using the anterolateral approach. If these lesions involve the cavernous sinus proper and are growing or causing compressive symptoms, the nature of pathology dictates the treatment strategy.
2. Pathology: Tumors involving the cavernous sinus may include pituitary adenomas, meningiomas, chondrosarcomas, chordomas, or schwannomas. All but meningiomas can be surgically removed through the previously mentioned approaches. Meningiomas (Chap. 23) tend to involve the cavernous sinus elements to varying degrees. When

meningiomas are involved in the interdural compartment between the meningeal and periosteal layers of the sinus, mobilization of the lateral wall allows gross total resection. Holocavernous meningiomas have been shown to histologically invade the cranial nerves and the tunica adventitia of the ICA [21–24]. In such cases, a cavernous sinus decompression strategy may be used by removing the ACP, mobilizing the lateral wall, and decompressing the optic nerve. The endoscopic endonasal approach can also be used to decompress the cavernous sinus medially and possibly debulk the tumor.

3. Extensive tumors on both sides of the neurovascular structures, in both medial and lateral cavernous sinus, may be best approached through combined/staged endonasal and open approaches.

Conclusion

In this chapter, the surgical anatomy of the sinus as it relates to open and endoscopic skull base approaches was reviewed with particular attention to the relevant clinical correlates. The skull base surgeon of the future must be able to perform open and endoscopic approaches and tailor them to the need of each patient while factoring into the decision making the precise location and pathology of the lesion. A 360° surgical approach to the cavernous sinus from the ventral and dorsal perspectives was described.

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