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The cavernous sinus: An anatomic study with clinical implication

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Abstract

Objective: The management of lesions involving the cavernous sinus remains a formidable challenge. To optimize care for patients with tumors extending into this skull base region a detailed understanding of the surrounding osteology as well as neural and vascular relationships is requisite. This thesis examines the gross anatomy of the region and highlights important surgical implications drawn from these as well as previously published studies.

Methods: A review of the historical scientific, anatomic, clinical, and surgical literature extending to the present (1992) relating to the cavernous sinus has been performed and discussed. Additionally, the author has performed and described cadaveric dissections revealing novel details about the macroscopic (dural and neurovascular anatomic relationships) and microscopic structure of the cavernous sinus. A series of cases of cavernous sinus pathologies that were addressed in an interdisciplinary surgical approach at the author's institution is also reported.

Results: Included in this report is a comprehensive review of the embryology of the cavernous sinus and its associated neurovascular structures. Cadaveric dissections have also revealed novel details about dural/meningeal compartments of the cavernous sinus as well as well as associated arterial, venous, and neural relationships. Microscopic observations also reveal novel fundamental insights into the components and structure of the cavernous sinus. Clinical examples from 20 patients illustrate the critical importance for clinical application of cavernous sinus anatomic knowledge to the surgical treatment of pathologies in this region.

Conclusion: The cavernous sinus is a tripartite venous osteomeningeal compartment intimately neighboring vital structures including the optic tracts, pituitary gland, cranial nerves III, IV, V, V, VI, and the internal carotid artery. Surgical management of cavernous sinus lesions has and continues to evolve with increasing anatomic and clinical study as well as advancements in diagnostic and surgical methodologies.

Level of Evidence: NA.

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KEYWORDS
anatomy, carotid artery, cavernous sinus, cranial nerves, dura, skull base, skull base surgery, surgical anatomy, surgical approach

1 | INTRODUCTION

"The parasellar compartment commonly known as the 'cavernous sinus' contains a more compact complexity of gross anatomy than any other structure, a veritable anatomic jewel box."[1] This observation, expressed by Parkinson, a researcher and surgeon responsible for significant surgical contributions to the management of carotid cavernous fistulae,[2–4] broadly reflects not only the structures and intimate relationships among neural, vascular, and bone elements but the relative inaccessibility of this region.

For the otolaryngologist, interest in this anatomic region has been historically peripheral.[5] Involvement of the cavernous sinus by the extension of infectious or malignant processes have long been recognized and acknowledged in the differential diagnosis of these pathologies. However, increasingly interdisciplinary management schemes have recently required intensified study of the cavernous sinus, incorporation of corresponding anatomic nomenclature into the otolaryngologic lexicon, and development of procedures associated with the management of cavernous sinus pathology.

Because the past quarter century has witnessed an increasing number of patients being diagnosed with lesions involving the skull base (Figure 1)—a direct result of advances in diagnostic radiographic technique—the otolaryngologist-head and neck surgeon has been forced to redefine the interdisciplinary boundaries that tangentially cross in serving this unique patient population.

The genesis for this thesis takes origin from several sources. Shortly after completing his training, the author was asked by a neurosurgical colleague to participate in the extirpation of a large skull base lesion invading the intracavernous carotid artery. Review of the existing anatomic and surgical text literature was not adequate to allow full understanding of the relevant surgical anatomy of the cavernous sinus, which identified the need for further study. The second source of stimulus for this text came from the author's departmental colleagues who demanded not just a regional descriptive anatomic explanation of this area of skull base surgery but a detailed understanding of this region to optimize the choice of procedure to be employed in conjunction with traditional otolaryngologic or neurosurgical procedures. Cadaveric investigation needed to be the educational cornerstone for the surgical exercises advocated.

Finally, this study was also motivated by educational needs for otolaryngology residents. Articles in the literature found inconsistencies and clinical paradigms without satisfactory explanation. A well-defined description of cavernous sinus anatomy is requisite for optimal surgical education regarding pathobiology of regional invasion—and ultimately an organized approach to the overall management—of lesions that involved the cavernous sinus.

2 | DEVELOPMENTAL ANATOMY AND EMBRYOLOGY

Several authors have made monumental contributions to our understanding of the development of the cranial venous system in man: Markowski,[6,7] Streeter,[8,9] Padget,[10] and Butler.[11] These authors independently observed that numerous problems arose in the study of the developing venous vasculature in humans. In particular, it was noted that: (1) a degree of common variation normally occurs, (2) variances in pattern were observed in contradistinction to comparative

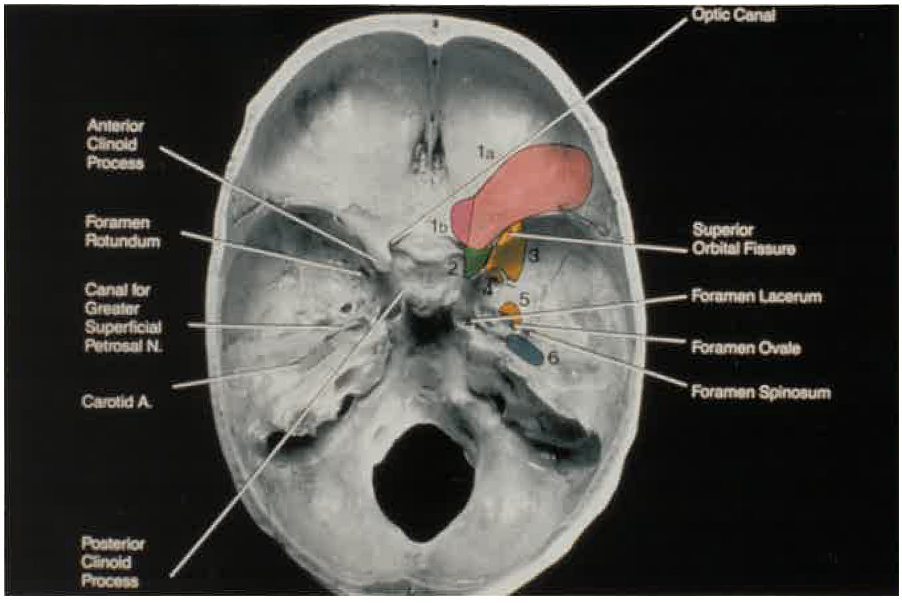


FIGURE 1 The irregular and complex osteology of the skull base is shown. Extradural and intradural structures are labeled. Extradural: la. Orbital roof. lb. Optic canal. 2. Anterior clinoid process. 3. Superior orbital fissure. 4. Foramen rotundum. 5. Foramen ovale. 6. Glasscock's triangle. Intradural. 1. Dural opening. 2. Carotid ring. 3. IIIrd cranial nerve. 4. IVth cranial nerve. 5. Vth cranial nerve. 6. VIth cranial nerve.

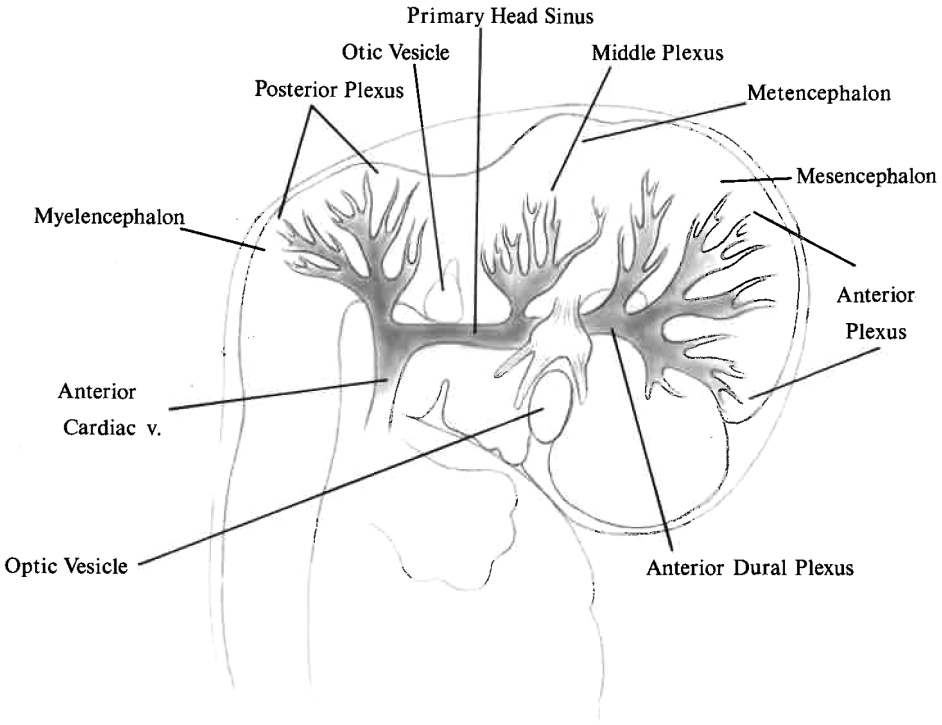


FIGURE 2 The dural plexus drains through three recognized tributaries: an anterior middle and posterior plexus which pool into a ventrally located primary head sinus.

anatomic studies, and (3) specimens often tore in preparation of the regional tissue and associated vessels. Further, because of differences in technical skills and methodologies employed, injected tissue specimens frequently did not optimally fill giving false patterns to study. Finally, fixation and tissue preparation often resulted in a variable degree of tissue alteration and venous specimen distortion.

Walker in 1933 first reported the difficulty in dissection of the veins at the skull base and alerted scientists to the fact that anatomic and pathologic studies may be flawed by technical difficulties.[12] Clearly, as laboratory techniques have become more sophisticated this has been mollified; however, tissue analysis remains demanding and time consuming. For purposes of discussion, the staging system described by Padget[13,14] will be employed, and all descriptions are based upon the detailed analysis of the photomicrographic record of embryologic dissections belonging to the Carnegie Collection and reproduced by Gasser[15]:

Stages I and II: Embryos are 4–6 mm in crown–rump length, Stage III: 7–12 mm, Stage IV 12–14 mm, Stage V 16–18 mm, Stage VI: 20–24 mm, and Stage VII 40 mm.

Developmental stages I and II reflect a specific correlation among vertebrates.[14] The aortic arches noted in the first three pharyngeal bars form the basis of the common and internal carotid arteries. A capillary plexus in the developing pial layer is supplied by these vessels. Associated capillaries drain into a superficial venous plexus that eventually is noted to subserve the dural layer dorsolateral to the developing neural tube. The aforementioned dural plexus drains thru three recognized tributaries: an anterior, middle, and posterior plexus which pool into a ventrally located primary head sinus (Figure 2). The primary head sinus is in continuity with the anterior cardinal vein which will eventually give rise to the internal jugular vein. At this stage, a linguofacial vein (future common facial vein) is noted to feed into the plexus that will eventually become the internal jugular vein. These vessels lie next to the developing ventral pharyngeal artery (future external carotid). Concomitant to this, prominent vascularization is noted about the optic vesicle in the developing maxillary process.

The head in stage II shows the three pharyngeal bars (branchial or visceral) which give rise to the mandibular, hyoid, and glossopharyngeal elements with respective nerves, while the arterial system can be identified with the internal carotid supplying the anterior and cephalic parts of the brain.[13] In contrast, named veins are uncommon with most venous vasculature remaining quite immature. The anterior cardinal vein (from the head) joins the posterior cardinal vein (from the trunk) to form the common cardinal vein (duct of Cuvier) entering the primitive heart. In stage II, the anterior, middle and posterior cerebral veins described by Mall in 1904 are not the same as those named by contemporary convention that will be later identified in the adult.[16] During Stage II, a primitive maxillary vein is noted to drain the ventrocaudal aspect of the optic vessel as well as the olfactory region above and Rathke's pouch below. While this vessel is significant and is appreciated to be a morphological constant, other vessels assume much of its drainage function. The stem of the primitive maxillary vein ultimately becomes the drainage port for all the ophthalmic and orbital veins in the adult. As the embryonic brain matures, dural venous channels begin to lie more laterally. Exemplary of this are the internal jugular vein and primitive head sinus which migrate laterally to several neural ganglion while still noted to lie medial to the developing Gasserian ganglion and trigeminal nerve. The head sinus remains attendant to a significant maxillary tributary. Furthermore, as

the dural and pial layers separate, many small venous channels are resorbed and only a few transversely located vessels remain.

During stage III, expansion of the frontal and maxillary regions is significant while the mandibular and hyoid bars development slows. Other changes occur concomitant to the growth of the maxillary process including: elevation of the auricular hillocks, overgrowth of the glossopharyngeal bar by the cervical sinus, and maturation of the basilar artery and vertebral artery. Interestingly, the venous system remains limited in development although changes are taking place. At the junction of the posterior dural plexus and the head sinus, the primitive internal jugular vein (anterior cardinal vein) is noted. The head sinus then migrates laterally to the Xth nerve and dorsocranially to the fibers of the XIth nerve. A prominent venous ring is noted juxtaposing those developing neural structures. The lateral migration of the head sinus is paralleled by simultaneous caudal migration of the posterior dural root which will join with the primitive jugular vein and ultimately become the caudal end of the adult sigmoid sinus. The proximal portion of the pial-arachnoid vein, lying between the roots of the IXth and Xth nerves will give origin to the inferior petrosal sinus. The positioning of this venous vascular-neural interface outside of the skull is unusual and is explained by Padget as reflective of the extensive positioning of the pial-dural venous vasculature.[14] The anterior cardinal vein forms the primitive internal jugular vein as the common cardinal vein descends to the level of the lower cervical nerves defining the neck region.

In stage IV, the caudal parts of the chondrocranium outlining the base of the future skull can be well recognize.[17] The basioccipital plate is situated to surround the notochord, while the sella position lies at the level of the bilateral otic capsules. Condensations of mesenchyme (membranous skull) radiate from separate cartilages helping to define contiguous dural tissue anlage containing the primary head-sinus with its three dorsal tributaries, draining the three dural plexuses. During stage IV, the internal jugular vein completes its migration to the lateral side of the XIIth nerve primordium. Fibers of the second and third cervical nerves now join the XIIth nerve to form the ansa hypoglossi. The lateral migration of the jugular and its linguofacial tributary, the adult common facial vein, results from its relative immobility in early stages, when it is compressed by the connections of the Xth and XIIth nerves and sometimes by the upper cervical nerves.

In stage V, the caudal end of the head-sinus which is becoming continuous with the internal jugular vein is noted to be related to the otic capsule more laterally than dorsally. At this stage, the head-sinus is being replaced by secondary anastomoses that drain commonly into the developing sigmoid sinus lying dorsal to the otic capsule. During this developmental phase, cephalically, a more primitive sinus (the future transverse sinus) is first noted. Inferiorly, the facial region is drained cranially by the prominent ophthalmic and maxillary tributaries of the head-sinus while caudally its drainage pathway is through the linguofacial tributary of the internal jugular vein. This is significant because it is at this point in embryogenesis that initial appreciation of a defined facial architecture is first observed with the development of the eye, nose, jaw and ear. Finally, of singular importance during Stage V is the emergence of a definitive extracranial venous system.

The evolution of changing venous drainage patterns in Stage V is dramatically demonstrated by the maxillary vein which early on serves as the sole drainage of the optic region and in succeeding stages becomes subservient to a primary ophthalmic vein and associated orbital tributaries. The maxillary vein, in addition to its optic connection maintains a relationship to the other maxillary tributaries, particularly the components of the adult pterygoid plexus. The maxillary vein which was once confined to the maxillary process with the maxillary division of the Vth nerve begins to receive distributions cranially and caudally encompassing the territory of the ophthalmic and mandibular divisions of the trigeminal nerve. At about this time, the formation of the anterior facial vein is becoming noticeable. In the 16–18 mm embryo, a plexiform anastomosis between lateral tributaries of the linguofacial and maxillary veins has already formed around the outer labial margin. Among the many plexiform and more medial tributaries of the maxillary vein, the adult pterygoid plexus is already represented. This is significant as it will be retained as a direct route of communication to the adult cavernous sinus which has yet to formally develop. In later stage V, the plexiform vertebral vein has formed draining a field supplied by its companion named artery. Concomitantly longitudinal anastomosis between the primary transverse intersegmental veins has produced a primitive vertebral vein, with most of the jugular ends of the intersegmental veins ablating. The vertebral vein remains plexiform around its companion artery and empties into the internal jugular or primitive subclavian vein before the formation of the left innominate vein in later stages of embryological development.

Stage VI sees the emergence of the external jugular system. The newly formed external jugular will replace those vessels of the internal jugular system concerned with the developing face and neck. By this stage, all of the brain can be seen to drain into the junction between the sigmoid sinus and the primitive transverse sinus. A venous asymmetry may develop at this point as a result of an alteration in cardiac development. Here, the sinus venosus contributes to a detour of blood flow from the left side of the heart while the sagittal and straight sinuses in the embryo therefore drain more to the right. To offset this maldistribution; the innominate—a transverse anastomosis between the bilateral anterior cardinal veins (internal jugular) develops. If there is symmetrical development from right to left a symmetrical pattern will develop at the torcula. However, if asymmetry remains it will be reflected at the torcula.

During stage VI with a well-defined facial region, arterial development is highlighted by the establishment of the external carotid system. The head sinus which the three dural stems originally joined has almost disappeared by this developmental period with the exception of a short segment—the lateral portion of the future cavernous sinus medial to the Vth nerve. The only other remnant of the primitive head sinus can be appreciated to accompany the VIIth nerve extracranially, ventral to the otic capsule. The developing vasculature of the ear region shows this head sinus remnant to be incorporated into the veins accompanying the superficial petrosal and stylomastoid arteries which anastomose with each other in accompanying the intraosseous course of the VIIth nerve. The caudodorsal (lateral) end of the pro-otic

sinus is in the position of the adult petrosal sinus (superior). This sinus is more cranial than dorsal to the crest of the otic capsule and is extracranial in reference to the chondrocranium. Despite their intimate anatomic relationship, the physiologic communication between the superior petrosal sinus and the cavernous sinus is a late secondary development which often does not occur until after birth.

The pro-otic sinus, unlike the resorbed middle dural stem, does not principally concern drainage of the brain. Instead it serves as a direct outlet for the supraorbital and maxillary veins; this fact will be significant once the cavernous sinus forms and participates in the efferent drainage of the paranasal sinus region. As the anterior dural plexus closes, blood that had been ventrally directed is now directed dorsally into the lateral segment of the primitive transverse sinus. The anterior and middle dural plexus become consolidated in the condensed mesenchyme representing the tentorium and together constitute a tentorial plexus. By stage VI, the chondrocranium is prominent at the base of the brain and as noted by Lewis surrounds the cranial roots especially in the basioccipital and temporo-occipital regions.[18] At this point, the anterior and posterior facial veins are visualized with the embryonic linguofacial tributary of the internal jugular vein now be referred to as the common facial vein. Concomitant to this, the lateral portion of the maxillary vein can be seen as the deep facial vein.

Padget uses the 40 mm size change to define the transition into Stage VII and denote an embryonic developmental stage distinct from a fetal developmental stage.[13,14] By the 40 mm stage, the circle of Willis has formed.[13] The development and maturation of the venous sinus system gets underway in stage VII.[19] The process of anastomotic progression or spontaneous migration, as Streeter noted in 1918, initiates the formation of the superior sagittal sinus.[9] Another differentiation of the midline sagittal plexus includes the first stages in the establishment of the Galenic system of intracerebral drainage. Macklin, in 1921, observed that as the chondrocranium matures and portions of the membranous skull become prominent, permanent derivatives of the pro-otic sinus become manifest.[20] Emergent vessels include both the inferior petrosal sinus and the cavernous sinus. It will be recalled that there exists no specific vessel that would serve as an embryologic template for the inferior petrosal sinus. Nevertheless, a venous developmental pathway may be suggested as follows. An extracranial segment of the primary head sinus which originally passed from the lateral aspect of the otocyst and IXth nerve to the medial side of the Xth nerve is recognized and is resultant from position shifts due to the enlarging brain. This retained sinus receives flow from the neural tube between the Xth and XIth nerves as well as the hypoglossal emissary vein and the vein of the cochlear aqueduct. Further just distally, the myelencephalic vein receives a collateral circulation from dural veins that extend between the otic capsule and basioccipital cartilages. This confluence of venous structures ultimately defines the forming inferior petrosal sinus.[9,10,14,15]

At this point at the level of the XIth nerve root, which is surrounded by the inferior petrosal sinus, a new plexus is noted to join with a channel medial to the trigeminal ganglion. Taking origin from the medial surface of the pro-otic sinus, this plexus surrounds the carotid artery at the level of the hypophysis. While Streeter has referred to the remnant of the head sinus that lies medial to the trigeminal nerve as the cavernous sinus,[9] it is generally felt that the presence of a venous sinus about the internal carotid that is in continuity with the vertical remnant of the primitive head sinus is representative of the early cavernous sinus (Figure 3).[14] The newly formed inferior petrosal sinus and cavernous sinus will allow for direct caudal blood flow to the internal jugular vein from the orbital venous blood syphon replacing the pro-otic sinus.

The circular sinus (intercavernous sinuses) and the basilar sinus of the adult are extensions of the midline plexiform sinus and

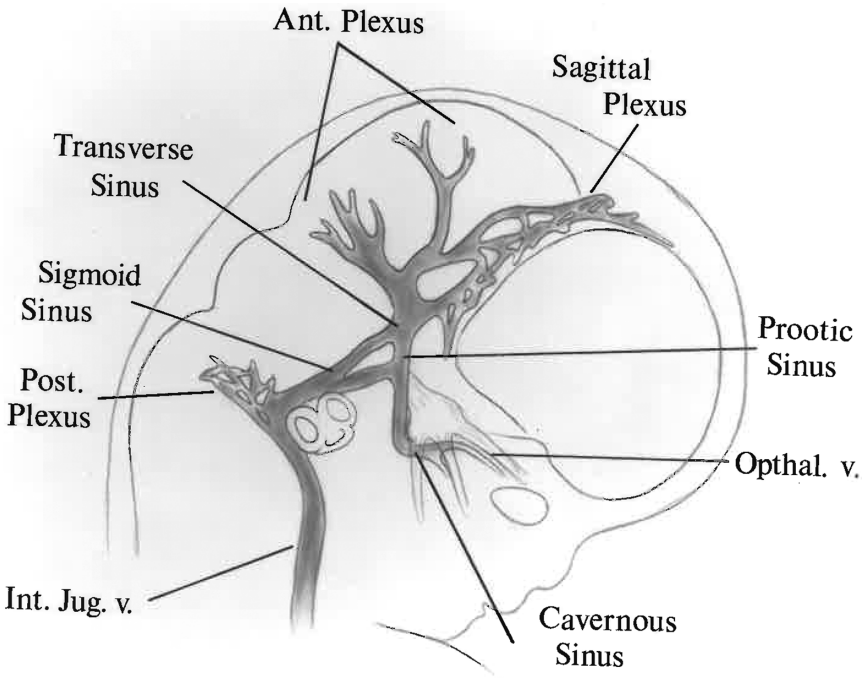
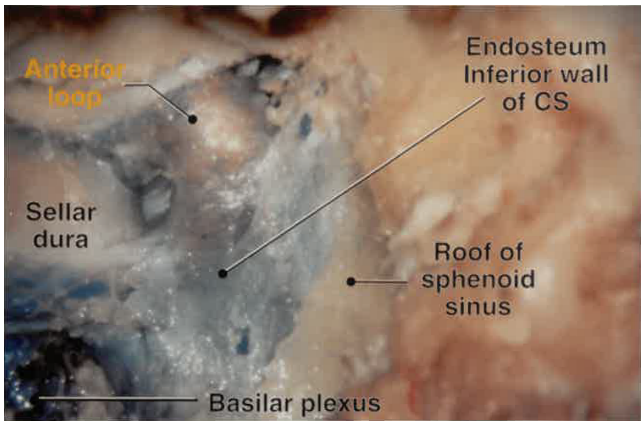
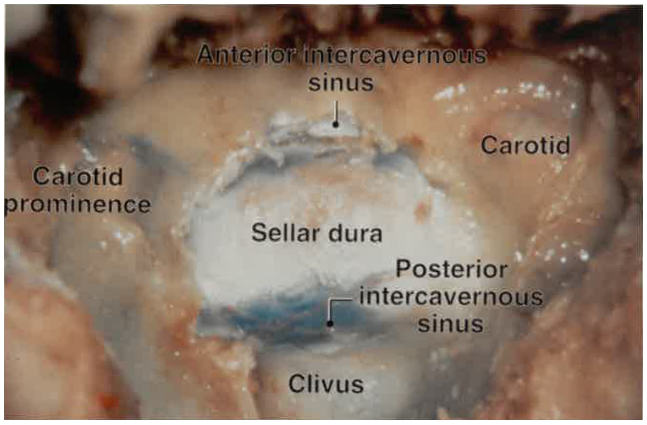


FIGURE 3 Taking origin from the medial surface of the pro-otic sinus, a plexus surrounds the carotid artery at the level of the hypophysis. This venous sinus plexus that is in continuity with the vertical remnant of the primitive head sinus is representative of the early cavernous sinus.



PHOTOILLUSTRATION 1 Inferior exposure showing the relationship of the anterior loop of the internal carotid artery to the sphenoid sinus and sellar region. Note continuity of contrast from the cavernous sinus into the basilar plexus.



PHOTOILLUSTRATION 2 The close medial relationship of the internal carotid artery to the midline sellar region is shown. Intercavernous venous channels are shown in this specimen to be present in both anterior and posterior locations. Tumors that expand from the clivus will collapse these channels and displace the internal carotid artery laterally and upward while tumors expanding from the pituitary if not enveloping the internal carotid artery will direct it laterally.

communicate via a series of plexiform tributaries with the cavernous sinus (Photoillustrations 1 and 2). Initially, the cavernous sinus plays no part in cerebral drainage, representing only a secondary caudal outlet for venous flow from the orbit by way of the inferior petrosal sinus. Emissary veins are noted to appear in stage VII. Included among this newly formed group are: the angular (nasofrontal) vein, frontal, and the supraorbital veins. The modifications of the primary pro-otic sinus between the 40 and 80 mm embryo depends more on the growth of the skull rather than the brain. The dural channel that becomes quite conspicuous by stage VII is the superior petrosal sinus, the last of the major adult sinuses to become definitive in human development. This vessel has been historically confused with the pro-otic sinus because it is smaller than the inferior petrosal sinus and its communication with the cavernous sinus is both secondary and inconsistent. The superior petrosal sinus is the major metencephalic vein of the posterior fossa, the proximate end of which becomes surrounded to a variable extent by an anatomically distinct fold of dura—the tentorium. Application to the petrous ridge ultimately results from otic and cerebral expansion.

Based upon the work of Lasjaunias and Moret et al.,[21–23] four arteries are identified as participating in the embryologic blood supply of this region. They are respectively the dorsal ophthalmic artery, the stapedial artery, the trigeminal artery and the primitive maxillary artery. The dorsal ophthalmic artery is responsible for supplying the optic nerve and globe itself after entering the orbit through the superior orbital fissure, initially noted in primitive mesenchymal tissue. While regressing by the time of birth, its proximal remnant is often described as the resultant adult inferior lateral trunk of the second most prominent branch of the intracavernous internal carotid artery.

The stapedial artery, which otolaryngologists are most familiar with, juxtaposing the stapes may be followed in a cephalic direction entering the floor of the temporal fossa through a small unnamed foramen on the upper surface of the petrous bone. Ultimately, it will contribute to the middle meningeal artery[24] and maxillomandibular artery (which eventually leaves the cranial cavity through the foramen spinosum as the future maxillary artery). The latter becomes involved with the external carotid system as the internal maxillary artery and the former will remain part of the internal carotid system manifesting as the caroticotympanic artery.

The adult trigeminal artery, which is noted to persist with an incidence of 0.1–0.5%, takes origin from the basilar system and will run medial to the trigeminal nerve following the ophthalmic division (V_1) as it enters the cavernous sinus where it anastomosis with the internal carotid, near the carotid syphon. Variances in the anatomy of the trigeminal artery are numerous with common patterns being described.[25] Finally, the primitive maxillary artery taking origin from the carotid syphon supplies the posterior portion of the pituitary anastomosis with its counterpart from the contralateral side.[13]

Ultimately, as the gestation period progresses to term, the arteries directly related to the cavernous sinus in the mature fetus are limited. The arteries that are commonly identified include: the posterior inferior hypophyseal artery, the lateral artery of the clivus also referred to as the dorsal meningeal artery, the recurrent artery of foramen lacerum, the lateral artery of the trigeminal ganglion, and the artery of the free margin of the tentorium cerebelli. Other named vessels include the basilar tentorial artery, capsular arteries, and inferior lateral trunk, all being reported with variability regarding frequency and area of supply.[13,26–29]

According to Rhoton, the meningohypophyseal trunk (MHT) is present in all cases and its caliber appears to be similar to that of the ophthalmic artery.[29] Further, the meningohypophyseal artery divides into its three respective branches, the tentorial artery, the dorsal meningeal artery, and the inferior hypophyseal artery. Parkinson also noted a consistent mature trifurcation of the MHT in 100% of his specimens and further describes the development and presence of an arterial circle around the sellar area.[1] Brassier et al. further make an

important note of the role played by the internal maxillary artery and the ascending pharyngeal artery interconnected with the carotid syphon and suggest that there are several areas of the skull base which are dependent upon them that classically have been described as receiving a blood supply only from the carotid artery.[30] This latter observation is potentially important as these vessels may act as conduits for the passage of both infection and tumor in seeding of the skull base. Moreover, these authors do note the duality between the internal and external carotid system and the importance of the various branches of the carotid at the level of the syphon in supplying the region of the forming cavernous sinus and neighboring skull base neural elements.

3 | MACROSCOPIC ANATOMY: A CADAVERIC STUDY

Early anatomic studies cited by Bedford[31] and credited to Winslow[32] defined the cavernous sinus because of its interior filamentous structure which suggested a cavernous appearance not unlike the penile corpora cavernosa. Clearly, no physiologic association was intended or even implied by this author. Nevertheless, the name entered the medical literature and has been employed over time. Subsequently, anatomic texts[33–37] defined the cavernous sinus borders as extending to the superior orbital fissure anteriorly, the sella and pituitary fossa medially, and the apex of the petrous pyramid in the posterior lateral direction. Neural elements are described as traversing the lateral wall while the internal carotid artery along with sympathetic nerve fibers and the VIth nerve are enveloped by the central sinus venous space. A variable amount of adipose tissue is confined to the sinus proper,[38] while a double sheath of dura circumscribes the margins of the sinus cavity, within its osteologic framework.[12,39] The macroscopic evaluation of this space constitutes the initial series of dissections undertaken in this study.

3.1 | Materials and methods

A total of 30 cadaveric heads were prepared for study. Fresh specimens were employed in 15 preparations with gel injection while 15 specimens were studied in formalin fixed heads. For macroscopic investigation, following injection of the fresh head preparations, initial exposure employing a frontolateral transzygomatic intracranial-extradural exposure was employed.[40] Subsequently, the brain tissue from the middle and anterior fossae was selectively removed; with careful preservation of the underlying attendant neural and vascular elements. The vessels at the base of the skull and the neck, the vertebral arteries first, followed by the common carotid artery or by the external and internal carotid arteries independently were dissected for a distance of approximately 2 cm, and cannulated with an appropriate diameter catheter (Tigren^{R} or Dow-Corning^{R}). Mechanical flushing to wash the clots from the system is accomplished with tap water.

Arterial injection is performed with a preparation of 40 cc of 3110 RTV silicone rubber from Dow-Corning^{R} mixed with a double volume (80 cc) of 5% Dow-Corning^{R} fluid thinner. In the venous system injection, the ratio is 1:1 employing 80 cc of both liquid silicone and fluid thinner. Water-soluble crayola powder paint (Artista$^{®}$) is mixed with the silicone liquid and rubber until the desired color is obtained. Slow catalyst from Dow-Corning^{R} is added at a ratio of 1:10 to the silicone rubber just prior to injection, leading to the slow solidification of the silicone in a time period of 3–4 h when the head is refrigerated after the completion of the injection. Clamping of the injection sites is done immediately after preparation and left in place for 12–16 h to prevent spillage.

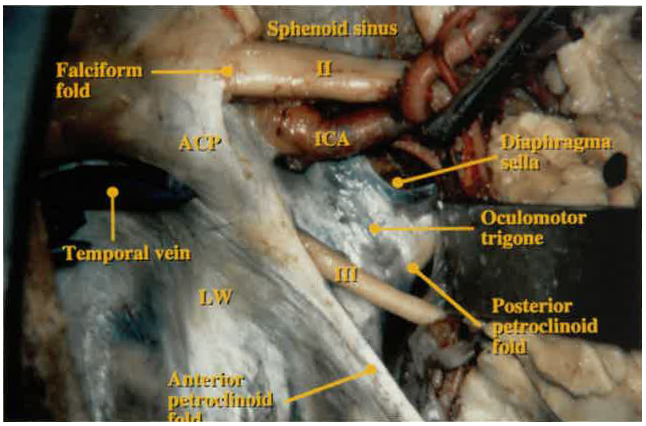
Photographs taken employ a Halogen light system with a Contax 35 mm camera on the Zeiss neurocontravas microscope. Tungston ISO 160 film at an exposure time of 12 s with the aperture set at 1/12 was used. A 2× magnifier was placed between the microscope and the camera to increase the field of exposure.

3.2 | Meningeal compartments

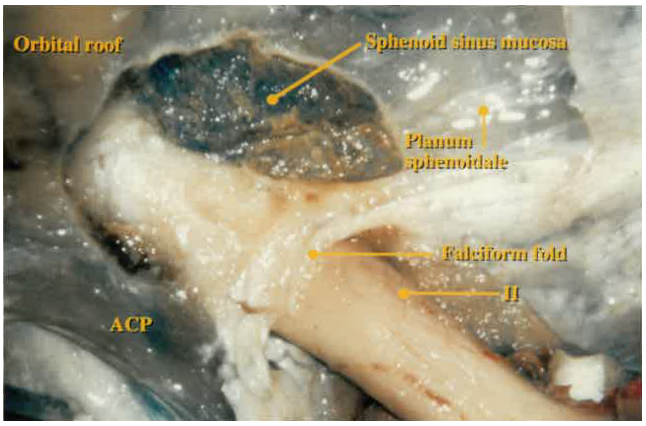
Before encountering the contents of the cavernous sinus space, the basal region osteologically bounded by the sphenopetrosal relationship supports a meningeal envelope that courses the midline, ringing the pituitary and reflecting itself on the contralateral basal region. The meningeal nuances are noted by the foldings and interdigitations of the tentorium and the tissue slips about the cranial nerves, ganglion, veins and the pituitary gland. Because of its intimate relationship with the periosteum of the sphenoid bone anteriorly, the petrous bone and temporal–parietal area posterior and lateral to this interface was examined first.

The bifurcation of the meningeal dural fold at the level of the petrous temporal bone was well defined in 93% of dissections. In 7% of dissected preparations, the dural folds could not be maintained in anatomic position. This may have resulted from specimen age or natural thinning of the tissue in preparation. The Gasserian ganglion is clearly adhered to in those dissections with preserved meningeal dural folds. Projecting in an anterior fashion the lesser circumferential tentorial border firmly inserts into the anterior clinoid process. The dura passes above the posterior clinoid as it forms part of the free edge posterior border (Photoillustrations 3 and 4). The posterior dural bifurcation passes its ventral fold along the middle cranial fossa floor creating a sheath from the posterior petrous bone to the sphenoid floor.

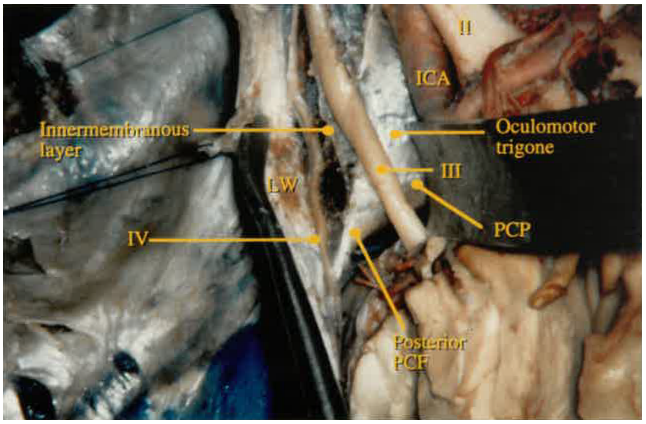
The superior border (greater circumference) of the tentorium inserts into the upper border of the petrous ridge up to the level of the posterior clinoid process. It is now seen to continue as the dural lining of the clivus which is in apposition to the dural sheaths of the internal carotid artery. Consea et al. described three osteomeatal dural rings: (1) on the superior edge of the petrous bone for the passage of the trigeminal nerve, (2) at the level of the clivus for the medial oculomotor nerves, and (3) covering at Dorello's canal for VI (Photoillustrations 3 and 4).[33] At the level of the posterior clinoid process, a thickening is noted in the dural foldings. Variable thickness and



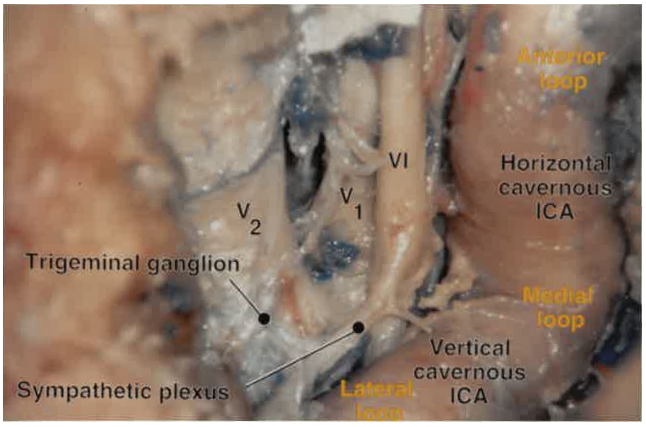
PHOTOILLUSTRATION 3 The tentorial fold (dura) contributes to the anterior petroclinoid fold (APF) and the posterior petroclinoid fold (PCF). Anteriorly it is in continuity with the falciform fold attached to the optic nerve (II). The oculomotor nerve (III) is seen running into the lateral wall (LW) of the cavernous sinus as it passes toward the superior orbital fissure. Note the dural edge at the level of the diaphragm sella medially which is demonstrated by retraction of the internal carotid artery (ICA) and branches. With mobilization, the oculomotor nerve is shown.



PHOTOILLUSTRATION 5 The optic nerve (II) is firmly fixed by the falciform fold, a thick dural band that lies in continuity with the dura over the anterior clinoid process (ACP). Access to the cavernous sinus requires removal of the ACP and of the falciform fold. The sphenoid sinus mucosa is seen (after drilling) in close proximity to the optic nerve. Traumatic injury to the sphenoethmoid complex may result in cerebrospinal fluid leakage if the dura is violated here. More importantly, fracture into the cavernous sinus may create a carotid cavernous fistula or dural shunt.



PHOTOILLUSTRATION 4 The lateral wall of the cavernous sinus is exposed demonstrating the lateral and medial dural folds. The smaller trochlear nerve (IV) and larger oculomotor nerve (III) are appreciated to run in the lateral wall dural layer (medial) toward the superior orbital fissure. Anteriorly, the trochlear nerve (IV) will cross the oculomotor nerve (III). Tumors expanding from the lateral wall, such as schwannomas, meningiomas, and neuromas will often displace the internal carotid artery (ICA) medially.



PHOTOILLUSTRATION 6 The trigeminal (Gasserian) ganglion is dural covered with a fine reticular membrane attendant to the branches. The intracavernous internal carotid artery (ICA) is exposed showing the lateral, medial and anterior loops created by the vertical to horizontal orientation of the artery. Sympathetic plexus fibers are seen to pass from the ICA margin to the abducens nerve (VI).

crossed interdigitation are noted just cephalic to this region with a of prominent bony elevation identified and noted to be the middle clinoid process. This process was identified in 90% of the dissections. A meningeal fold lying between the sphenoidal wings is in continuity with the superior orbital fissure allowing for the intracavernous passage of nerves and ophthalmologic veins. This fold has variable thickness and was tissue paper thin in 30% of the dissections. The medial reflection of this dura is in continuity with the thick falciform fold (Photoillustration 5). At the opposite end, the dural covering seen to Intimately envelope the nerves can be traced from the posterior perspective demonstrating the Gasserian ganglion to be suspended by Pricentau's ligamentary system which maintains a separate hold from the actual dural covering. This suspending system makes mobilization of the Gasserian ganglion difficult in both cadaver dissection and surgery (Photoillustration 6).

The model set forth by Taptas helps to explain some of the controversy related to the defining of the cavernous sinus boundaries.[37,41] It is imperative to understand the relationship between the dura propria (internal layer of the pericerebral dura) and the intracranial

periosteum (external layer of the dura) (Photolllustration 4). Phylogenetically, dura propria intimately surrounds the brain and its neural and vascular structures. The ultimate morphologic disposition of the dura is then the result of developmental alterations as the brain grows and the bony skull base positions itself. This is discussed in Section 2 wherein the development of the venous vascular pattern was shown to reflect the expanding temporal and frontal lobes as the middle and anterior cranial fossa develop to accommodate the expanding brain. Taptas takes exception to the concept that the free border of the tentorium attaches at the anterior clinoid after crossing the peripheral border attached to the posterior clinoid process. This is described as the roof of the cavernous sinus with the posterior and lateral walls being formed by dural folds (Photoillustration 3). He feels that in the parasellar region because of neural and vascular structures the two parts of the dural envelop diverge and form an extradural space. Despite fresh cadaver material, we were unable to identify a formal extradural parasellar space independent of the cavernous sinus. Superomedially, the dura is in continuity with the dura of the parasellar periosteum (Photoillustration 5) while laterally the dura propria of the temporal lobe forms the lateral boundary between the petrous apex and the superior orbital fissure (Photoillustration 3).

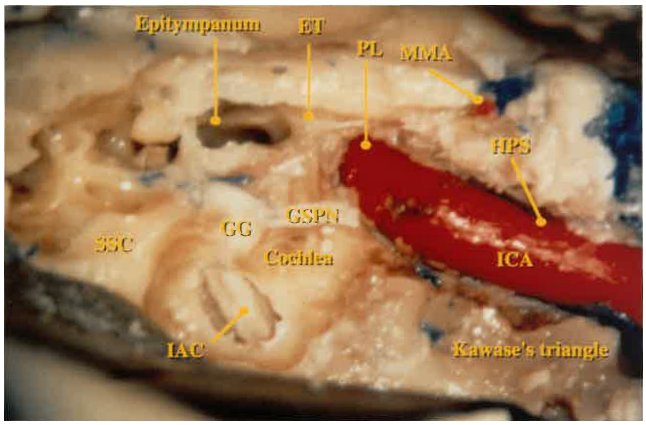
3.3 | Arterial relationships

The position and relationship of the carotid artery to the venous vasculature, neural elements and osteomeningeal interfaces is central to the interest and trepidation with which surgeons have approached lesions of the cavernous sinus. For purposes of our dissection profile, the internal carotid artery was followed from the cervical region (done initially to prepare the injected preparation) to where it entered and traversed the carotid canal ultimately passing over the foramen lacerum before it entered the cavernous sinus. Once defined as intracavernous, it was followed until it became intradural in its course. The artery is oriented from an inferior, posterior and lateral vantage (proximal) to one that is superior, anterior, and medial (distal) in disposition.[42–46] The proximal intracranial portion of the carotid artery is relatively fixed, lying within the carotid canal and ensheathed by a variable thickened fibrous membrane at the level of the Gasserian ganglion. By contrast, the intracavernous carotid artery is free and unencumbered by either a fibrocartilaginous or osseous sheath (Photoillustration 6).

Intrapetrous (subtemporal or middle fossa) dissection with an intact cochleovestibular end organ via either Glasscock's triangle (posterolateral) or Kawases' triangle (posterior medial) demonstrates variability to the thickness of the intrapetrous carotid canal roof. These surgical triangles are detailed in Section 4. The triangles (Photoillustrations 6 and 7) as defined by Dolenc are as follows[40]:

3.3.1 | Glassock's triangle (posterolateral)

This space is bounded by the greater superficial petrosal nerve medially, the Gasserian ganglion and root of V_3 anteriorly, and the posterior border drawn by a line from the facial hiatus to the petrous apex.



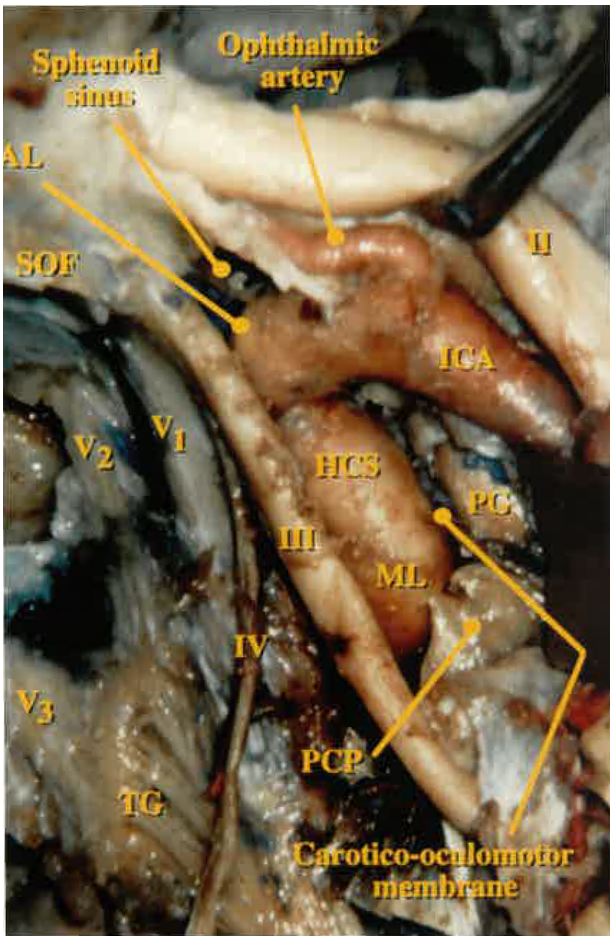
PHOTOILLUSTRATION 7 Subtemporal exposure of the petrous internal carotid artery (ICA) is shown. Glasscock's triangle lies laterally with Kawase's triangle shown medially. The facial nerve is defined at the level of the geniculate ganglion (GG) with the greater superficial petrosal nerve (GSPN) divided anteriorly. The internal auditory canal (IAC) has been opened between the labyrinth (superior semicircular canal [SSC]) and the basal turn of the cochlea. The posterior loop and horizontal petrous carotid are shown lying anterior to the cochlea and just medial to the eustachian tube (ET). At the foramen spinosum the middle meningeal artery (MMA) is noted with a venous plexus intimately close by.

3.3.2 | Kawases' triangle

Lies medial to this space and is bounded medially by the posterior petrous ridge bone. Access to the ICA shows fibers of the sympathetic plexus in this region before branches join the VIth nerve. This portion of the ICA is referred to as the posterior loop. The tensor tympani and the eustachian tube lie lateral to the ICA.

As the carotid passes above foramen lacerum toward the posterior clinoid process, it then turns anteriorly in its horizontal component and passes upward at the level of the anterior clinoid process (Photoillustrations 6 and 8). Paullus et al. found that in 84% of cases the ICA was exposed under the trigeminal nerve and in 14% the bone was quite thin.[46] We found the ICA covered in a periosteal sheath in 85% of the specimens and completely dehiscent in only 15% of the cases. When exposed in the described fashion, the geniculate ganglion was naturally dehiscent in 20% of the specimens. The greater superficial petrosal nerve was identified to the facial hiatus and the internal auditory canal was opened as described by House.[47,48] No attempt was made to expose the vertical petrous carotid and measurement was taken from the horizontal petrous carotid only since the former is not routinely exposed in cavernous sinus surgery. In its course, the horizontal segment ranged from 12.2 to 26 mm in length and averaged 21.5 mm with an average width (superior surface) of 4.8 mm (range 4.2–6.4 mm) (Photoillustration 7).

No branches of the internal carotid artery were identified coming off the superior surface of the artery; however, in two specimens, lateral branches were noted. In one case, the internal carotid artery was looped and anastomosis made with the middle meningeal artery, in the second the arterial branch passed anteriorly to the Gasserian



PHOTOILLUSTRATION 8 The full exposure of the cavernous sinus is obtained through a superior-lateral extradural-intradural dissection. The cranial nerves III, IV, V1, and V2, are seen in the lateral wall of the cavernous sinus. The anterior clinoid process and the orbital roof have been removed allowing for exposure of the internal carotid artery (ICA) throughout the cavernous sinus to the paraclinoid level at which point it becomes intradural. The ICA is noted within the anteromedial triangle between cranial nerves II and III. This venous space is considerably larger than the paramedian triangle created between the IIIrd and IVth nerves. Parkinson's triangle, the oculomotor triangle, the anterior lateral triangle, and the lateral triangle can all be constructed in the venous spaces defined by neural and dural tissue. The inferior medial triangle with the VIth nerve is not exposed.

ganglion.[49] Before reaching the fibrocartilage of the foramen lacerum, a prominent intraperiosteal venous plexus is noted in 65% of the dissections. In a minority of cases (12%), there is continuity with the venous plexus about the middle meningeal artery at the foramen spinosum. Clearly, in the vast majority (84%), the pericarotid venous plexus represents an extension of the posterior lateral cavernous sinus plexus or connects to the superior petrosal sinus.

The carotid relationships with petrous pyramid structures are well known to otolaryngologists. The cochlea was found at variable depths from the transition zone between vertical and horizontal carotid canals (range 1–7 mm, average 2.5 mm) in the posterior or posterior superior direction. Variable pneumatization patterns as expected allowed for ease of identification of the otic capsule. The cochlea intimately effaced the lateral portion of the internal auditory canal and, as noted by Glasscock[43] and Paullus,[46] is quite close to the facial nerve averaging 0.7 mm (0.5–7.4 mm) from the geniculate ganglion (Photoillustration 7). The greater superficial petrosal nerve was identified parallel and above the internal carotid artery in 70% of the dissections. The eustachian tube was noted anterior and lateral lying parallel to the horizontal internal carotid artery. In 12% of the cases, a bony dehiscence in the internal carotid artery wall allowed for direct communication with the eustachian tube.

After passage through the region of the foramen lacerum, the intracavernous carotid is defined. Two named segments are noted after the carotid has passed between the petrous apex and sphenoid base, and is truly intracavernous—the medial and anterior loops—lying central in the cavernous sinus. The medial and anterior loops as noted are free whereas the posterior and lateral loops are not only confined by the carotid canal, but are fixed by the banding of the Gasserian ganglion (Photoillustration 8). Fibrous tissue is found separating the Gasserian ganglion and Meckel's cave from the internal carotid artery.[50] Sympathetic neural fibers also leave the internal carotid artery to join the VIth nerve at this level (Photoillustration 6). No recognized (constant) branches of the internal carotid artery were identified at the level proximal to the medial loop; except those cited at the level of the horizontal petrous internal carotid artery. Two major branches noted within the intracavernous portion of the internal carotid artery are the meningiohypophyseal trunk and the inferior lateral trunk or artery of the inferior cavernous sinus.[51] The former was identified in 28 of 30 complete dissections (92%) and then later in 21 of 30 specimens (70%).

3.4 | Venous relationships

The conceptualization of the venous space as defined by its relationship to the carotid artery serves as a useful tool in understanding the topography of the cavernous sinus. Three spaces are described as follows: (1) the medial venous compartment, (2) the anterior/inferior compartment, and (3) the posterosuperior compartment (Photoillustrations 1, 2, and 8).[26,52]

The medial space sits between the internal carotid and the pituitary. Arterial channels may indent on the sphenoid wall or collapse the venous space. In 28% of the dissections, a prominent bowing into the sphenoid sinus by the internal carotid artery was noted. Of these, in 38%, only a thin wall separated the artery from the sinus.

The anterior/inferior compartment sits below the intracavernous carotid, lateral to the clival region. The VIth nerve is noted to pass below the internal carotid artery into this venous space. The inferior lateral trunk takes origin from the internal carotid artery in this space and intimately contacts the VI nerve. The posterior/superior space lies between the internal carotid artery and the posterior roof of the sinus. The meningiohypophyseal artery lies in this space. Just lateral and bounded by the dura propria the IIIrd, IVth, and Vth nerves run in the

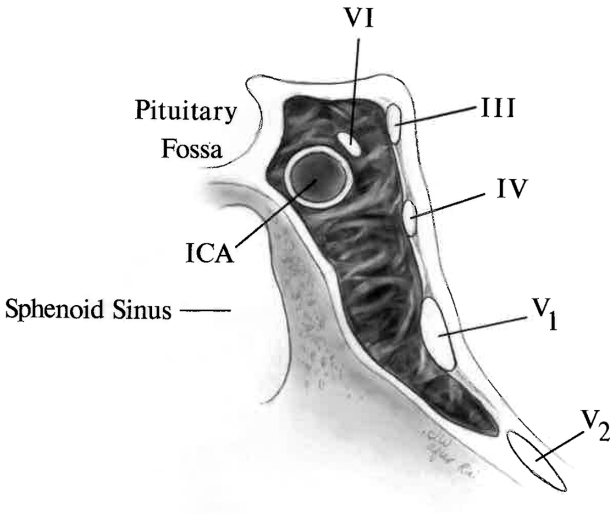
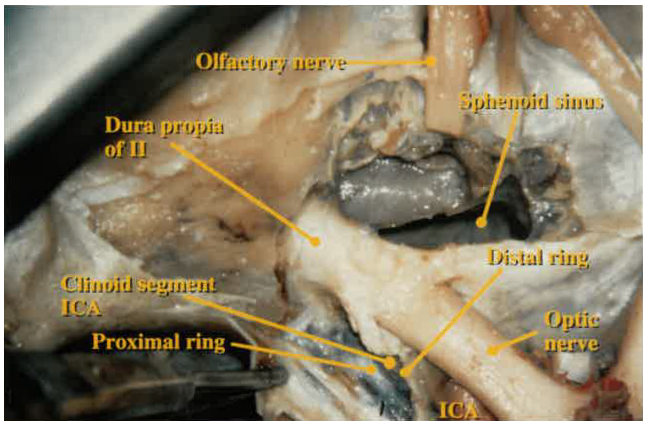


FIGURE 4 Traditional atlas representation of the cross-sectional anatomy of the cavernous sinus and regional anatomy.



PHOTOILLUSTRATION 9 The dural rings (proximal and distal) are shown before the optic nerve is mobilized to expose the internal carotid artery (ICA) in its paraclinoid segment. The floor of the anterior skull base is widely exposed showing the olfactory nerve and sphenoid sinus.

lateral wall of the cavernous sinus. Intracavernous connections exist and may both be present as anterior and posterior channels or exist as a single channel at any point around the sella (Photoillustration 2).[53]

Anterior intercavernous sinuses were present in 76% of the specimens, while posterior intracavernous sinuses were noted in 6%. Ten percent of the anterior intracavernous sinus extended in front of the pituitary gland. The intracavernous venous connection posterior to the clivus called the basilar sinus is the largest and most constant connection cross the midline between the cavernous sinuses. This cavity (multiloculated) lies within the dura on the posterior aspect of the dorsum. It receives blood from the superior and inferior petrosal sinus. The basilar sinus was present in 82% of cases. The VIth nerve enters the cavernous sinus by passing thru the basilar sinus (Photoillustration 1).

3.5 | Neural relationships

Classic anatomic texts illustrate the relationship from superior to inferior of the nerves of the cavernous sinus as the: IIIrd, IVth, VIth V_1, and V_2 (Figure 4). The IIIrd, and IVth, and first two divisions of the Vth nerves lie between two dural folds in the lateral sinus wall. The IIIrd and IVth nerves are intimately related and pass with each other along the dural roof of the cavernous sinus in their course to the superior orbital fissure (Photoillustration 4).

Bergland and associates have defined the relationship of the optic chiasm to the tuberculum sellae and the pituitary.[54] They describe the chiasm as fixed (normal), prefixed, and postfixed. In all specimens examined, the IInd nerve was separated from the anterior cavernous sinus roof by prominent dural folds and bone (Photoillustration 9). Rhoton found that on the average the optic nerves are covered by dura along their routes as they approach the optic canals with an "uncovered" window of approximately 3 mm (0.5–8.0 mm). Furthermore, in 4% of cases, *no* bone was found to cover the nerves in their relationship to the supralateral portion of the sphenoid sinus and the only cover was the nerve sheath and sinus mucosa.[55] We found no examples of an exposed optic nerve nor was the sphenoid sinus uncovered without dissection.

3.6 | Sphenoid sinuses

The paired sphenoid sinus cavities are rarely symmetrically paired with the majority of paired sinus cavities having irregular bony septa found within their confines. The major bony septae is directed in an anteroposterior plane. Rhoton finds that 68% have a single major bone septae, 46% were noted to cross the floor of the sella. A common cavity was found in 28% while no minor cavities were found in 18%.[29,55] Major septae, by tomographic evaluation, were noted to be found a maximum of 8 mm from the midline with no specific predilection for side.

Anatomic variation of sphenoid sinus pneumatization by Hamberger classifies the sinus into conchal; presellar and sellar pneumatization types.[56] The conchal type is found more commonly in childhood. In Rhoton's study, presellar types were noted in 20%, while sellar types were found in 80%. Hamberger noted 11% presellar, and 86% sellar types.[56,55] The lateral wall of the sphenoid sinus also shows the bulge of the internal carotid artery. This is noted by Rhoton in 71% of cases with 4% being uncovered of bone and 66% had less than 1 mm of bony covering. In many of the cases, the bone covering would not have been satisfactory to protect the artery with manipulation (Photoillustration 2).

4 | SURGICAL ANATOMY

The neurosurgical literature is in increasing fashion employing a nomenclature that allows surgeons to understand intracavernous dissections within a common framework. Having reviewed the surgical

boundaries with Dolenc on several occasions in laboratory dissection courses his descriptives will be employed in outlining the surgical subunits presently being employed.[40,57,58] The cavernous region is broken down into three areas of dissection. These include the (1) parasellar region, (2) petrous region, and (3) clival region.

4.1 | The parasellar region

The parasellar region includes four named anatomic spaces/triangles. The anteromedial triangle conforms to a region bounded by the optic nerve forming the medial border, the IIIrd nerve laterally within its dural sheath before entering the superior orbital fissure, and the border for the dural ring circumscribing the internal carotid artery in the pararachnoid region. It is important to realize that full exposure of this triangle requires the extradural removal of the anterior clinoid process. Opening of this space provides access to both the venous space of the cavernous sinus proper, as well as the anterior loop of the internal carotid artery. Furthermore, mobilization of the optic nerve will allow for access and manipulation of the ophthalmic artery (Photoillustrations 3 and 8).

The paramedial triangle is a narrower, more elongated space defined by the IIIrd nerve medially, the IVth nerve laterally and the dural sleeve between the two forming a posterior border. Just proximal to the superior orbital fissure the IVth nerve crosses the IIIrd nerve forming an anterior apical boundary for the paramedial triangle. Within this region, exposure of the dural roof of the cavernous sinus may be approached. Medially, the internal carotid artery, venous contents of the cavernous sinus, and the proximal portion of the VIth nerve may be identified. If the dural wall is reflected laterally, the first and second divisions of the Vth nerve can be seen (Photoillustrations 4 and 8).

The oculomotor triangle or trigone as it is commonly referred to lies between the dural folds of the anterior and posterior clinoid processes medially and the IIIrd and IVth nerves laterally. Access to the anteromedial and paramedial triangles may be enhanced by exposure of this space (Photoillustration 4).

Parkinson's triangle is the oldest defined entry space to the cavernous sinus. The region is bounded by the ophthalmic division of the trigeminal nerve laterally, the IVth nerve medially and the dural fold posteriorly. Opening the dura in the superior wall of the cavernous sinus and widening will enhance access to the internal carotid artery and neural elements of the cavernous sinus (Photoillustration 8): the trigeminal nerve laterally, the IVth nerve medially, and the dural fold posteriorly. Opening the dura in the superior wall of the cavernous sinus and widening will enhance access to the internal carotid artery and neural elements of the cavernous sinus (Photoillustration 8).

4.2 | The petrosal region

The four defined spaces/triangles of the petrosal region were initially described by Dolenc collectively as the middle cranial fossa subregion. In general, since safe access to this region is based upon definition of anatomic structures at the level of the petrous ridge we have focused on the temporal bone relationship to this area. It is important to understand that this is a function of specialty and nomenclature and not anatomic variance.

The anterolateral triangle sits medial to the anterolateral bony wall of the middle fossa floor (anterior), the maxillary division of V as the lateral border, with the medial border being defined by the ophthalmic division of V. The distal portion of the ICA may be exposed, as well as, the lateral region of the cavernous sinus when increased exposure is made by mobilizing or sectioning V2. When wide exposure is obtained, visualization of the VIth nerve is made as it passes out of Dorello's canal at the petrous apex. At the level of the petrous apex, a fibrodural tissue band can be seen extending from the foramen lacerum about the ICA, forming in part the proximal dural ring that intimately secures the internal carotid artery (Photoillustration 6).

A small triangular space referred to as the lateral triangle juxtaposes the anterolateral triangle. The lateral wall of the middle fossa bony floor lies laterally while the posterior and anterior borders are the third and second divisions of the trigeminal nerves respectfully. Increased exposure may be obtained by retraction on V, and V; or by extended bony dissection laterally. This space which is a rich venous pool intimately lies next to the Gasserian ganglion. Lying deep to the Gasserian ganglion in the depths of the lateral triangle is the lateral loop of the ICA (Photoillustration 6).

Glasscock's triangle or the posterolateral triangle lies lateral to the greater superficial petrosal nerve medially, the Gasserian ganglion anteriorly and the arcuate eminence posteriorly. Access to this space allows for proximal control of the petrous carotid in its posterior loop segment. Additional exposure may be gained by opening air cells along the petrous ridge and across the level of the eustachian tube (Photoillustration 7).

Kawase's triangle or the posteromedial triangle lies immediately medial to Glasscock's triangle. Here, the greater superficial petrosal nerve lies laterally, the medial border being the petrous bone edge, and the Gasserian ganglion lying at the apex anteriorly. This triangle, which includes the posterior venous drainage of the cavernous sinus via the superior petrosal sinus provides direct access into the posterior cranial fossa. Enlargement anterior to the internal auditory canal can be made with hearing preservation as long as the cochlea is not violated. Exposure can be extended forward to the level of the clivus.

The two noted eponymous petrous triangles are circumscribed by well defined otologic anatomic sites. Laterally, the eustachian tube and tensor tympani muscle and semicanal lie in apposition to the internal carotid artery. Above, the lesser and greater superficial petrosal nerves lie across the internal carotid artery. The ICA is noted to be directed anteriorly toward the foramen lacerum passing beneath V; and the Gasserian ganglion, forming the lateral loop.

4.3 | The paraclival region

The inferomedial triangle lies anterior to the Vth nerve in the clival region. At its inferior point the VIth nerve enters into Dorello's canal. Superior and lateral the Vth nerve enters below the tentorium with the medial boundary being defined by the posterior clinoid process.

Opening of this space gives direct access to the posterior wall of the cavernous sinus. The petroclinoid ligament lies across this triangular space (Photoillustrations 3 and 4).

5 | MICROSURGICAL ANATOMY: A CADAVERIC STUDY

Macroscopic studies of the cavernous sinus have revealed a yellow soft tissue color covering the infrastructure of the intrasinus structures. Neuroradiographic studies have demonstrated and microscopic histologic evaluation have confirmed the identity of this material to be fat. While not generally reported, the incidence of positive findings in the report by Hosoya et al. concludes that adipose material is found in over 90% of specimens—most commonly located in a juxtaposition to the anterolateral orbital fat tissue and in the posterior recess near to the petrous interface.[38] Islands of fat may be observed between neural and vascular structures. Fat appears most pronounced in the anterior compartment where it is in contact with the extrasinusal compartment fat pad. The fat tracks along neural elements as well as the carotid, tapering and decreasing in amount as it effaces the posterior borders of the cavernous sinus. The fat sits against the arachnoid tissue at the level of the cavernous sinus roof.

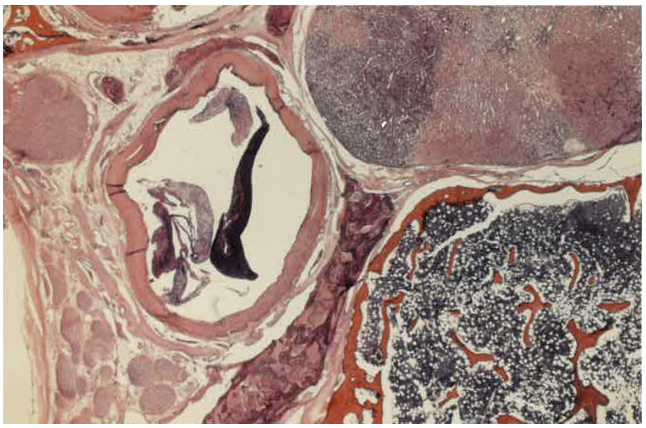
The normal trabeculae pattern of arachnoid separates the cavernous sinus from the CSF, with the normal villous cytoarchitecture sitting into the cavernous sinus. Entering from an anterior direction (retroorbital) the vascular walls are noted to be a thin layer of fibrous tissue covered by a vascular endothelium with fat surrounding the area. Within the sinus proper, the lateral walls of the venous cytoarchitecture are noted to be thicker as they efface the dural sheaths along the lateral wall and about the nerves. It is the presence of thinning veins, arachnoid and adipose elements that account for the reticular tissue noted. Further, the venous compartment is defined by a delicate fibrous wall about the internal carotid artery, hypophysis and floor as well as roof of the sinus. The objective of this next study was to view the cavernous microscopic anatomy. Specifically, the anterior segments of the cavernous sinus and human sphenoid bones were reviewed after decalcification.

5.1 | Materials and methods

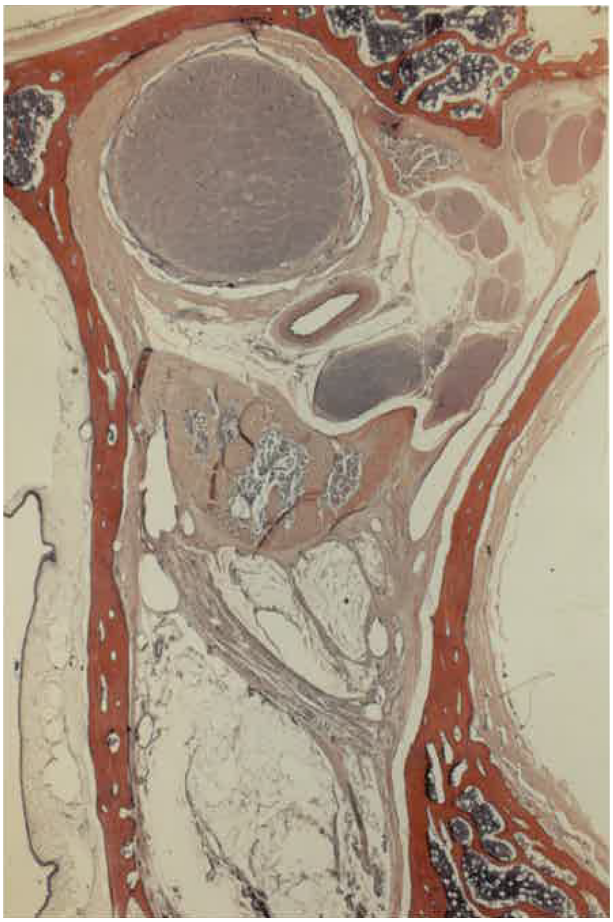
Human sphenoid bones and surrounding tissue were removed *en block* and placed in 10% neutral buffered formalin for 2 weeks. The specimen was decalcified in 5% nitric acid. The sphenoid block was then trimmed and prepared for paraffin imbedding. Sections were cut at 50 μm and stained histologically with hematoxylin and eosin stain. The sections were examined and photographs taken using a Zeiss photo microscope.

5.2 | Results: Histology

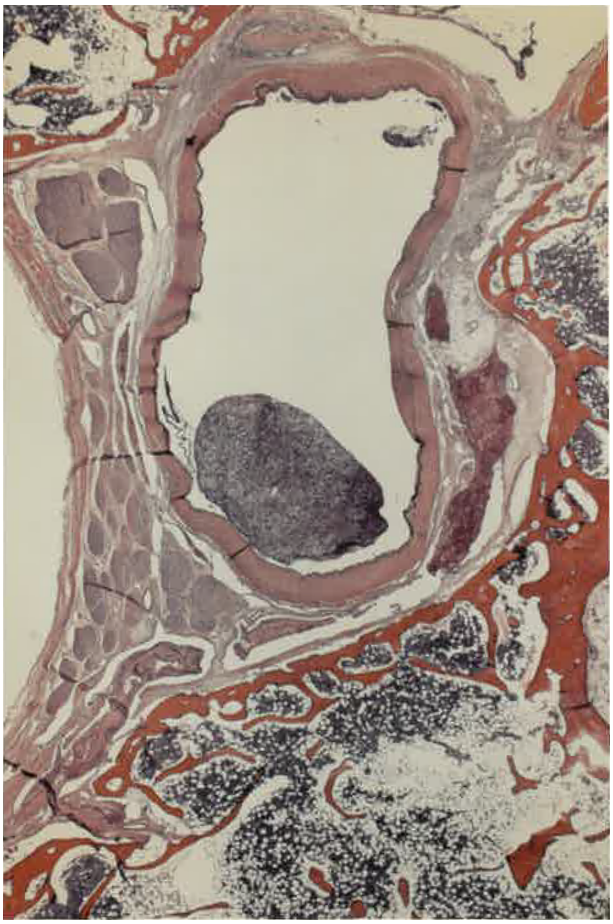
1. Photomicrograph 1—The internal carotid artery is seen in cross section in the region of the parasellar cavernous sinus. The pituitary gland is noted in close apposition to both the internal carotid artery as well as persistent intramembranous bone with a significant metapoietic marrow. Neural fiber bundles are seen to the opposite side of the internal carotid artery.



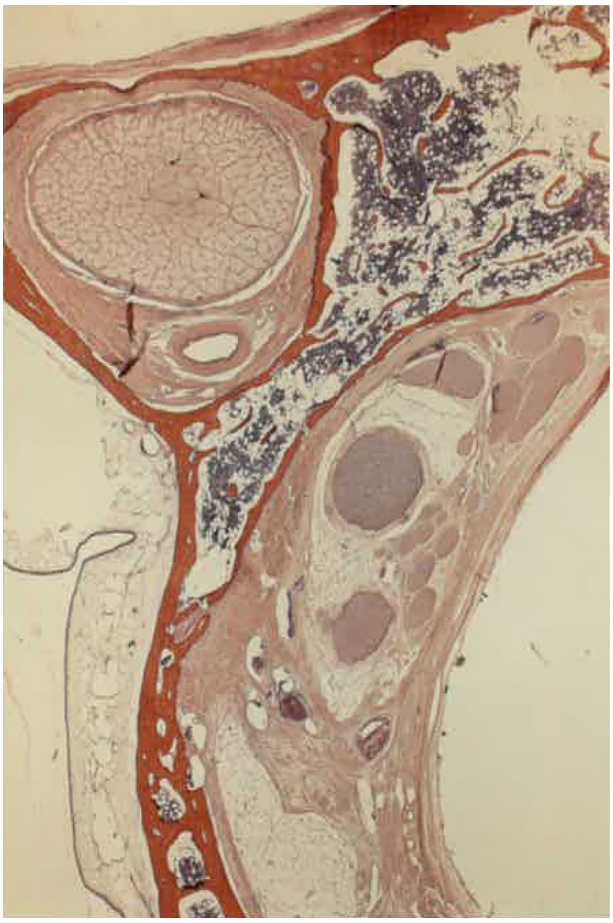
PHOTOMICROGRAPH 1 Cross section of the internal carotid artery is in the region of the parasellar cavernous sinus.



PHOTOMICROGRAPH 2 Relationship of the microscopic components in cavernous sinus. For orientation, a single large optic nerve is in the upper field while the sphenoid sinus is on the far-left side.



PHOTOMICROGRAPH 3 Microscopic relationships of the intracavernous internal carotid artery.



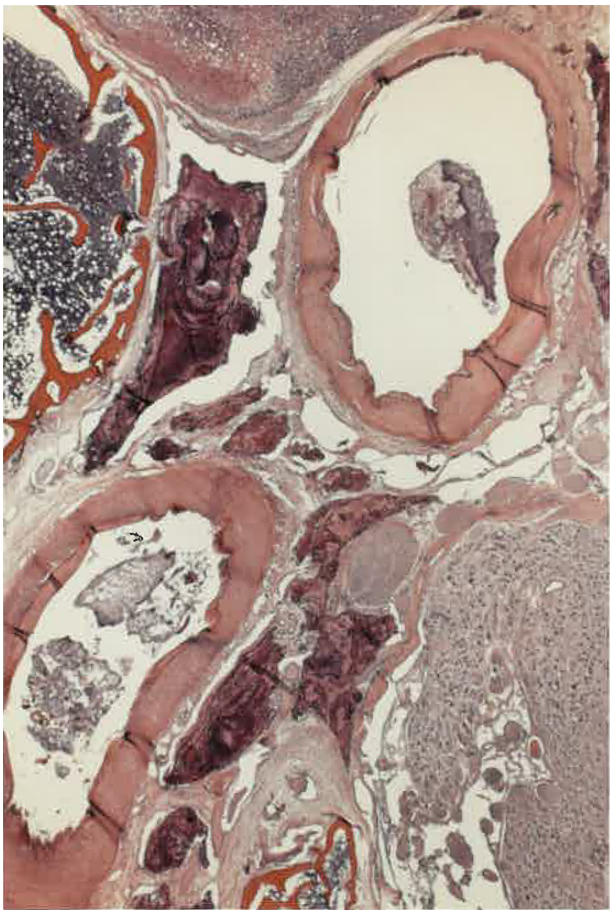
PHOTOMICROGRAPH 4 Microscopic relationships of the optic nerve in the cavernous sinus.

2. Photomicrograph 2—A single large optic nerve is noted in the upper field. Inferiorly, smaller nerves are noted probably the abducens and the oculomotor. Stretching between plates of intramembranous bone are striated muscle fibers and below that are mature fat cells which lie in a network of venous passages. On the far left side, the sphenoid sinus is noted.
3. Photomicrograph 3—The internal carotid artery containing postmortem thrombus lies immediately above intramembranous bone with hematopoietic and fatty marrow. To the left of the artery numerous bundles of nerve fibers including sympathetic fibers are appreciated.
4. Photomicrograph 4—The optic nerve containing numerous bundles of fiber elements is seen in intimate relationship with the ophthalmic artery contained within a thin septum of intramembranous bone. Neural elements in the anterior/superior portion of the cavernous sinus are noted suspended within adipose tissue and fibrous connective tissue. To the left, the sphenoid sinus and retained epithelium is noted.
5. Photomicrograph 5—The intracavernous internal carotid artery transition zone is noted in this bisection view. Juxtaposing the artery is the sympathetic neural plexus that passes through the cavernous sinus in part still related to the artery at this point.
6. Photomicrograph 6—Venous passages are present within the bed of adipose tissue below the fibrous connective tissue coming from the septum of the intramembranous bone cutting obliquely across the field. To the left of the slide the sphenoid sinus with pseudostratified ciliated columnar epithelium is seen.

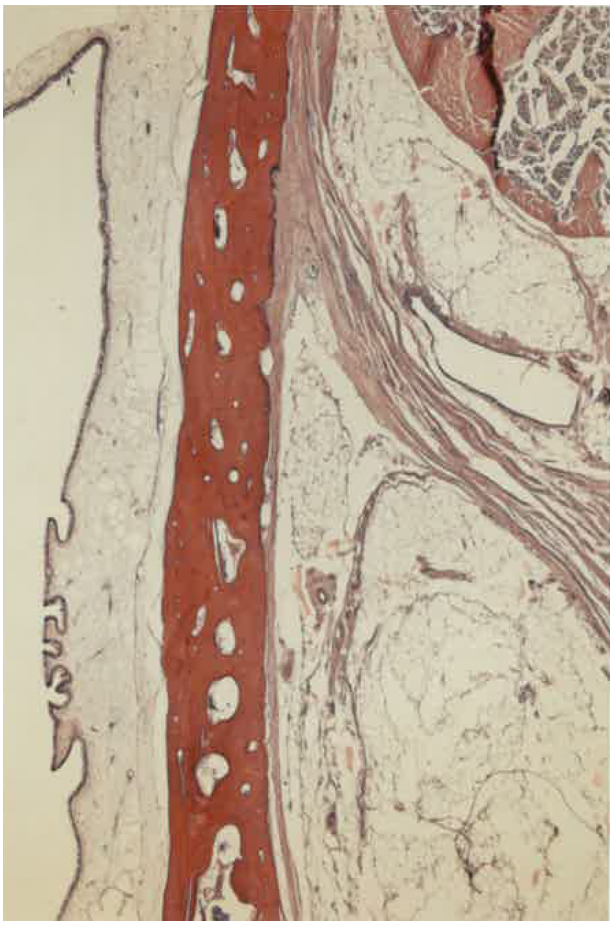
6 | SURGICAL APPROACHES

The surgical technique employed in the removal of cavernous sinus tumors reflect modifications of several classic procedures adapted from the experiences of Parkinson,[59,60] Dolenc,[40,61] House,[48,62] Fisch,[63,64] Glasscock,[43,47] and others.[65–69] Sekhar et al. have written extensively about the advantages and limitations of various skull base exposures which have been modified to allow for access to and extirpation of lesions involving the cavernous sinus.[70–73]

A survey of the various methodologies that have been employed in exposure and access to the cavernous sinus, in particular for tumorous lesions can be distilled down to four principle approaches. These are referred to as the (1) Fisch approach,[63] (2) Cocke[74] approach, (3) Kawase approach,[44] and (4) Dolenc approach. Each will be described as it pertains to access to the cavernous sinus. The fifth



PHOTOMICROGRAPH 5 Intracavernous internal carotid artery transition zone.



PHOTOMICROGRAPH 6 Microscopic relationship of adipose tissue and venous channels in the cavernous sinus.

approach which has classically been employed as a transnasal/transeptal/transsphenoidal approach to the pituitary provides such limited access to the lateral walls of the pituitary fossa, constituting only minimal safe exposure to the most medial portion of the cavernous sinus and is, therefore, not included.

6.1 | The Fisch approach

In a series of surgical exercises termed the Type A, Type B, and Type C infratemporal fossa approaches Fisch has delineated his transtemporal access to the bony skull base and involved neural and vascular elements. The Type C infratemporal fossa approach provides access into the cavernous sinus, from a posterior and lateral perspective. With the patient in the supine position and the head rotated an extended postauricular incision is made. A wide-field radical mastoidectomy is performed with the facial nerve exposed from the stylomastoid foramen and parotid bed to the level of the geniculate ganglion. The greater superficial petrosal nerve is sectioned and the internal auditory canal is opened with the facial nerve transposed posteriorly. Anteriorly, access into the infratemporal fossa incorporates removal of the zygomatic arch and lateral orbital wall. The internal carotid artery is skeletonized to the level of the foramen lacerun with the middle meningeal artery being coagulated at the foramen spinosum.

To gain full exposure to the cavernous sinus the maxillary division of the Vth cranial nerve must be sacrificed prior to its passage through the pterygopalatine fissure. Further extension anteriorly beyond the medial pterygoid lamina gives exposure to the lateral pharyngeal wall and the nasopharynx. When lesions are noted in the nasopharynx which extend into the peritubal region, tissue in the infratemporal fossa must be fully extirpated along with the pharyngeal basilar fascia and constrictor musculature that is attendant. In performing a Type C approach, the bone of the middle cranial fossa floor is removed extensively. Incorporated into this dissection is increased exposure through a fronto-orbital zygomatic bone flap with attendant muscular attachments. The eustachian tube, pterygoid musculature and levator as well as tensor veli palatini muscle may all be removed in full.

6.2 | Commentary

The infratemporal fossa Type C approach has been employed for the extirpation of angiofibromas, malignant tumors which have failed radiation therapy, nasopharyngeal tumors as well as lesions extending into

the cavernous sinus. The major drawback associated with this procedure lies in inevitable paralysis of the facial nerve due to the mobilization and posterior displacement. Furthermore, with otic capsule preservation, posterior lateral visualization toward the cavernous sinus may be compromised.

6.3 | The Cocke procedure

The extended maxillotomy and subtotal maxillectomy for excision of lesions at the bony skull base primarily taking root from the clivus with extension to the cavernous sinus was reported by Robertson and Cocke in 1990.[74] Based upon their experience with cadaver dissection and subsequently three surgical cases, these authors proposed the following procedure. A modified Weber–Ferguson incision is made and a widely based oral cavity facial flap is elevated exposing the maxilla. Incisions are then made through the subcutaneous tissue, periosteum, and mucoperiosteum of the maxilla which are elevated exposing the anterior and lateral walls of the maxillary sinus as well as nasal architecture to the inferior orbital rim. The bone of the posterior maxillary sinus is then removed, and the lateral pterygoid plate as well as the internal maxillary artery are defined.

Within the oral cavity, the hard palate mucoperiosteum is incised and subsequently an incision is made between the tonsil and the mandible elevating soft tissue to give exposure into the retropharyngeal space. The soft palate is then detached and the posterior margin of the hard palate exposed with the division of the greater palatine vessels and nerves. Leaving mucoperiosteum attached to the prevertebral fascia, the soft tissue covering of the lateral oropharyngeal wall including the anterior tonsillar pillar, tonsil, and pharyngeal mucosa are elevated and reflected medially. Exposure of the nasal cavity is then obtained by sectioning the soft tissue along the lateral margin of the base of the nasal piriform aperture. The coronoid process of the mandible is sectioned and pterygoid muscles are identified and divided. The hard palate is subsequently divided and the upper portion of the maxilla is split after muscular attachments to the bone are severed.

The sinuses may be variably opened to include a wider field of exposure to the ethmoid and sphenoid sinus respectively. Moreover, the lateral wall of the nasal chamber itself may be exposed with the removal of the middle and superior turbinates to the level of the inferior orbital rim. Exposure and removal of tumor invading the pituitary fossa and sphenoid bone may be accomplished by removing the posterior and inferior walls of the sphenoid sinus with the internal carotid arteries limiting dissection along the upper half of the surgical field. Laterally the dissection is limited by the presence of the inferior petrosal sinus and the petro-occipital fissure medial to the jugular tubercle. Extension of clival tumors into the infratemporal fossa may also be removed.

6.4 | Commentary

The major limiting factor of this operation is that it does not provide satisfactory access to the lateral compartments of the cavernous sinus.

6.5 | The Kawase approach

Anterior petrosal transtentorial approach primarily aimed at sphenopetroclival meningiomas with extension into the cavernous sinus. The patient is placed in the supine position with the head fixed in the lateral position. The middle cranial fossa or subtemporal craniotomy incision is outlined and the tomporal fossa exposed. The craniotomy is centered in a more anterior fashion than that of a classic middle cranial fossa approach for acoustic neuromas in that it lies just above the mandibular joint.

The dura is elevated from posterior to anterior along the floor of the middle cranial fossa identifying the arcuate eminence with care taken to avoid an exposed geniculate ganglion. The greater superficial petrosal nerve exiting from the facial hiatus, and the middle meningeal artery at foramen spinosum are identified. The latter is coagulated. The greater superficial petrosal nerve is sectioned to avoid traction on the geniculate ganglion and subsequent paresis or paralysis of the facial nerve. The surgical field is defined by the trigeminal impression anteriorly, the arcuate eminence posteriorly, the greater superficial petrosal nerve and its groove laterally and the internal carotid artery medially and inferiorly. At the posterior/inferior margin of the surgical field, the internal auditory canal is identified along its anterior border. The anterior pyramidal bone of the petrous ridge is removed with care taken not to violate the basal turn of the cochlea. The superior petrosal vein is preserved if possible and in cases where this cannot be done the vein is taken close to the superior petrosal sinus. The tentorium is incised at the tentorial notch and the incision can be followed in the free edge extending from the apex of the petrous bone above Dorello's canal to the posterior clinoid process. The lateral wall of the cavernous sinus is now widely exposed as extension of the middle fossa dura is incised at the lateral margin of tumor where the Vth nerve is usually identified just prior to its entry into Meckel's cave. Meckel's cave may be opened giving posterior and lateral exposure to the cavernous sinus. The dural opening is extended to the level of the anterior clinoid process as needed for exposure.

6.6 | Commentary

The bone window is not wide and may limit exposure to the anteromedial portion of the cavernous sinus and posterior fossa.

6.7 | The Dolenc approach

The patient is placed in the supine position with the head fixed in the Mayfield three point fixation head holder. An incision is made from the pretragal region approximately 8 cm cephalically and following the hairline is directed forward in a wide “C” shape. An inferiorly based temporalis muscle-fascia flap is developed and rotated downward giving exposure to the frontozygomatic region and the lateral rim of the orbit. The zygomatic arch and lateral orbital wall are sectioned and reflected inferiorly hinged to the fascia to maintain a blood supply that

is viable. A frontoparietal temporal craniotomy is performed and the temporal lobe is elevated from posterior to anterior. Depending on the tumor location, dissection will commence either anteriorly or posteriorly. If the cavernous sinus is involved by a tumor that comes across the petroclival ligament, the petrous apex or Dorello's canal the posterior field is exposed.

The acute eminence is identified as is the greater superficial petrosal nerve. The greater superficial petrosal nerve is followed to the geniculate ganglion and the internal auditory canal is opened without violation of the neural compartment. Anteriorly, dissection is begun in both Glasscock's and Kawases' triangles as the horizontal petrous segment of the internal carotid artery is identified. Employing a diamond burr, the posterior recess of Kawases' triangle is enlarged, taking extreme care not to violate the cochlea. Anteriorly, the optic canal roof is opened and the dural sheath is incised. The dura is followed to the superior orbital fissure with the anterior clinoid process being drilled away. Here, the medial edge of the sphenoid wing is removed exposing the dural cuff about the ocular nerves. Thus far, the dissection has remained extradural and approaches into the cavernous sinus may be through several routes depending on the nature and site of the tumor lesion.

6.8 | Commentary

This approach provides the most complete exposure of the sinus contents. Limitation of exposure may be encountered due to preservation of V1 in the posterior lateral field.

7 | PATHOLOGY OF THE CAVERNOUS SINUS

Diseases involving the cavernous sinus may be divided into several broad categories. Included among these would be tumor, trauma, infection, and idiopathic lesions. For the otorhinolaryngologist, several of these entities are of interest more from a diagnostic perspective than a therapeutic or interventional point. Nevertheless, being familiar with the pathobiology and pathophysiologic mechanisms inherent in the development of certain processes is important when viewed in the broad perspective regarding skull base-cavernous sinus pathology.

7.1 | Trauma

Fractures across the skull base may result in significant neural and vascular deficiencies. Among the many potential severe injuries associated with basilar skull fractures, few portend the ominous prognosis of an unrecognized injury to the internal carotid artery, particularly deep within the recesses of the cavernous sinus. The paroxysmal onset of massive epistaxis associated variably with extraocular palsy, exophthalmus, chemosis, and Vth nerve dysfunction is strongly suggestive of a communicating carotid cavernous fistulae.

From a physiologic perspective, these lesions prior to bleed represent a high-pressure, high-volume, vascular shunt that may cause the alteration of cerebral blood flow depending on the rapidity of development. Furthermore, the triad described by Maurer of (1) a fracture in the vicinity of the skull base near the cavernous sinus, (2) loss of vision, and (3) arterial epistaxis, may not immediately occur at the time of a traumatic event, but may, in fact, present at a time distant from the inciting event.[75]

Traumatic injury to the intracavernous carotid artery may result in fistula formation, aneurysm formation, or the development of a false aneurysm.[76–79] A variety of methods have been employed by the neurosurgical community for dealing with the aneurysmal changes including entrapment, obliteration and resection.[60,80–84] All vascular lesions, however, associated with the cavernous sinus in cases of trauma may not require intervention. The latter is, in fact, predicated upon hemodynamic stability, neural deficiency and possible concomitant cosmetic defect resulting from pulsatile exophthalmos.[85] Van Dellen postulates that as a direct result of trauma, aneurysms have a higher propensity for formation than fistulae because the veins of the sinus that are not violated help to contain extravasated blood, tamponading the arterial flow, and allowing for an aneurysm to mature.[86]

Management then is dependent on location and symptomatic presentation. Obrador et al.[87] citing observations made by Jeanamart note that aneurysms of the internal carotid artery within the cavernous sinus represent approximately 3–11% of the total number of intracranial aneurysms. These authors go on to state that many larger aneurysms within the cavernous sinus structure, because of their obliterative nature, often times act as expanding extradural or paraclinoid masses. Importantly, it should be recognized that lesions of this nature are uncommon. Hahn et al. reported on the experience of a 16-year-old female who had massive epistaxis resulting from a traumatic intracavernous aneurysm.[77] Citing a large series by Locksley, traumatic aneurysms were identified in 2.8% of aneurysms. Further, they quote a study by Hammon, who reported an incidence of 0.1% aneurysms of traumatic etiology in a series of 2187 cases.

The infrequency and severity of these aneurysms is acknowledged in the literature and, therefore, the occult presentation of epistaxis is even more concerning especially to the otorhinolaryngologist. Intracavernous carotid aneurysms are generally discovered because of compression of cranial nerves III, IV, V, or VI. Associated cavernous sinus syndrome with retro-orbital and ocular pain along with pulsatile exophthalmos may also occur. The pathophysiologic process as noted previously may be acute in onset or delayed. Citing work by Chambers, Hahn et al., note that epistaxis may be dramatic in presentation or associated with aneurysms that can have a delay in presenting of up to 30 years.[77] The provocative mechanism for the formation of an aneurysm may be from direct missile projectile injury or from blunt trauma with concussive effects, slight tears, or shifts of bridging veins or arteries effacing the dura.

There are four potential routes for blood from a ruptured intracavernous aneurysm to present in the nasal chamber and

nasopharynx.[88] These would include that (1) the aneurysm may rupture through the eroded or fractured sphenoid sinus wall,[89] (2) that blood may pass through the fractured wall of the ethmoid bone, (3) bleeding may manifest by rupturing through the eustachian tube wall,[90] or finally (4) through a basilar skull fracture itself with bleeding into the infratemporal fossa and pterygopalatine fossa. The authors conclude that it is conceivable "that the onset of epistaxis may occur sooner when the aneurysm is not buttressed by surrounding fibrous tissue or adhesions."[77]

Management by proximal ligation of the carotid artery would not be anticipated to be effective because of retrograde flow through the carotid syphon. Therefore, trapping techniques are required with intracranial clipping proximate to the ophthalmic artery. Alternatively, vascular balloon occlusion has been reported to be successful in unclipped aneurysms by several authors including Debrun[91] and Fox.[92] The vascular relationship between the high-volume, high-pressure arterial system and the low-pressure venous system within the cavernous sinus optimizes an anatomic environment for the manifestation of either carotid cavernous shunt or carotid cavernous fistulae.

Grove[93] in his detailed account of dural shunt syndrome, noted that carotid cavernous fistula represent communications wherein arterial blood is directed through the adventitial wall of the intracavernous segment of the internal carotid artery. This is to be distinguished from carotid cavernous shunts, in which communication exists between the arterial and venous pathways by means of small branches of the carotid feeding into the venous system. Because of the intimate relationship of these vascular structures with the dura, the term dural shut applied as opposed to the fistula which usually manifests with the paroxysmal onset of orbital vascular engorgement resulting in a diminution of ocular motility and exophthalmos accompanied by bruits. The presence of dural shunts results in a more insidious clinical course. In contradistinction to the normal venous pattern in which blood flows posteriorly from the orbit into the cavernous sinus and ultimately into either the inferior petrosal sinus or basilar plexus, blood now is directed in an anterior retrograde fashion toward the inflow tract of the ophthalmic vein. Historically, the pathophysiologic mechanism for the slow propagation of carotid cavernous shunts or dural propagation of carotid cavernous shunts or dural shunts has been viewed from the arterial side where a pressure head will cause the redirection of normal blood flow.[94] Grove takes the opposite perspective, suggesting that some venous out-flow obstructive phenomenon such as thrombosis may create a situation in which reversal of blood flow occurs in the efferent venous pathway of the cavernous sinus with the subsequent development of clinical orbital symptoms and signs compatible with that of dural cavernous shunt.

There are several physiologic parameters which need to be considered when examining the pathobiology of aneurysms or fistulae. In the case of aneurysms, especially those of traumatic etiology, a rapid and significant bleed may be associated with either resultant thrombosis or spasm of the artery. Clearly, an abrupt change in circulatory hemodynamics may result in untoward sequela from a neurologic perspective. Depending on the presence or absence of compensatory pathways, circulatory dynamics may be altered to such a degree that important cerebral function is threatened. In contrast, the carotid cavernous fistula more often results from a nonobstructive phenomenon and therefore slow shunting of blood away from its normal vascular channels occurs over time allowing for vascular hemodynamic compensation to occur. It is well recognized that congenital abnormalities have been associated with carotid cavernous fistula and cavernous dural shunts. It is suggested that in certain individuals there may be a greater susceptibility to vascular injury as a result of trauma.

Schoolman et al. have reported on bilateral spontaneous carotid cavernous fistula in a patient with Ehlers Danlos syndrome.[95] Rubenstein and Cohen[96] are credited with the first report of an intracranial aneurysm associated with this disease while Graf has reported several case studies of unilateral carotid cavernous fistulae in this population.[97] The presence of epistaxis and ophthalmologic symptoms in a patient with Ehlers Danlos syndrome, with its associated aberrant collagen and elastin membrane abnormalities, should alert the otorhinolaryngologist to the possibility and theoretical increase in the chance for cavernous sinus vascular pathology.

7.2 | Diabetes

Kosmorsky and Tomsack from the Cleveland clinic reported in 1986 on a 65-year-old patient with diabetic cavernous sinus syndrome. These authors quote a large series reported by Rucker of 1000 cases of cranial nerve palsies associated with diabetes. Concomitant dysfunction of the IIIrd and VIth nerve occurs with the approximate frequency of 7.6%.[98] Sergott suggests that diabetic patients with multiple spontaneous cranial nerve palsies should be evaluated for ischemic problems.[99] Since the IIIrd, IVth, and VIth nerve as well as the Gasserian ganglion are fed by the artery of the inferior cavernous sinus, a single acute lesion in this vessel could account for the neuropathies noted in patients with diabetes. Progressive changes associated with diabetic peripheral neuropathy and possible endarteritis manifesting with cavernous sinus syndrome or at least neuropathy related to such, has been postulated to be due to slow flow through the artery of the inferior cavernous sinus secondary to vascular changes resulting from increased deposition of collagen, perivascular lymphocytosis, and proliferation of endothelial cell intima.

7.3 | Granulomatous disease

Tolosa Hunt syndrome[100] which is characterized by (1) eye pain described as annoying or boring in nature, (2) cranial nerve involvement, (3) symptoms lasting for days to weeks, (4) spontaneous remission, (5) attacks occurring at intervals for months to years, and (6) no involvement in structures outside of the cavernous sinus, which may mimic a number of clinical entities. Included in the differential diagnosis of neuropathic changes noted in this patient group are: metastatic disease, temporal arteritis, aneurysm, carotid cavernous fistula, myasthenia gravis, and infection. Goto et al. recently reported on abnormal findings noted on MRI and CT scanning of the cavernous sinus in

three patient's with Tolosa Hunt syndrome.[101] In their series, while the CT scans are generally normal, Kwan has recently shown that high resolution fine density bone window CT imaging may demonstrate abnormal soft tissue both in the area of the cavernous sinus and the orbital apex.[102] The demonstration of abnormal tissue in the area of the cavernous sinus on MRI scanning is noted as an intermediate signal intensity on T1 and intermediate weighted images. This finding is consistent with that of a granulomatous inflammation. Smith et a described their findings and note that serial MRI in patients with Tolosa Hunt syndrome may, radiographically reflect the efficacy of steroid therapy, and can be employed as a monitoring modality to assess the responsiveness of patients being treated in such fashion.[103] Goto et al. conclude that MRI is a valuable adjunct technique to be employed while treating lesions in the cavernous sinus that are presumably responsible for and associated with Tolosa Hunt syndrome.[101]

Tolosa Hunt syndrome has been referred to as superior orbital fissuritis, or that of the syndrome of painful ophthalmoplegia. It is generally felt to be a nonspecific granulomatous inflammation in the cavernous sinus or superior orbital fissure. Recently, Spector and Fiandaca reported on this syndrome and reviewed the existing literature.[104] They observed that lesions of the orbital apex, superior orbital fissure, and cavernous sinus causing functional abnormalities of multiple cranial nerves are also associated with dysfunction of the oculosympathetic system. Furthermore the anatomic location of the involved nerves may assist, along with MRI scanning, in the compartmentalization and localization of the inflammatory process associated with Tolosa Hunt syndrome. Theoretically, it was noted that the efficacy of steroid therapy was not unique to this clinical entity but was quite successful (in part) in treating numerous ophthalmoplegias including those associated with meningiomas, chordomas, giant cell tumors, lymphoma, aneurysms, and extensive nasopharyngeal carcinoma. Inflammation is clearly just one manifestation of this disease process. The authors concluded that Tolosa Hunt syndrome is by definition an ambiguous entity without clear pathologic boundaries.[104]

While Tolosa Hunt syndrome represents a nonspecific granulomatous process, Gross et al. recently reported on a case of eosinophilic granuloma of the cavernous sinus in an HIV positive patient. The presence of histiocytosis X in an immunocompromised patient, while rare, is not altogether surprising. Manifestations within the cavernous sinus represent a unique clinical paradigm and it is stressed by the authors that parasellar syndromes need to rule out the possibility of nasopharyngeal carcinoma in this patient group. In contrast, unifocal eosinophilic granuloma of the orbit is generally a benign and self-limited disease presenting with proptosis, ptosis and a lytic defect on radiographic evaluation. Citing work by Mezelof, Gross et al. note that central nervous system involvement by histiocytosis X is uncommon and often reflects multisystem pathology. A wide spectrum of neurologic deficits has been reported in patients with central nervous system involvement including both diffuse motor and sensory deficits along with cognitive dysfunctions. Intracranial histiocytosis X readily infiltrates neural tissue with a predilection for the hypothalamic pituitary axis and surrounding structures. The aforementioned case report of a lesion with a parasellar epicenter and localized extension along the optic tract, orbital apex, and temporal fossa is consistent with the recognized pattern of spread. Bony destruction is often times not seen and it is postulated that cranial histiocytoses X takes origin from adventitial cells of blood vessels rather than bone and therefore, osteologic destruction becomes a secondary phenomenon due to compression rather than primary destruction. Recent work by Davis and Lieberman has suggested that disseminated multifocal histiocytosis may be responsive to chemotherapy and thymus extraction.[105] Clearly, surgical treatment plays a minor role. For the otorhinolaryngologist, cognizance of the presence of histiocytosis X in the head and neck region or involving the upper aerodigestive tract would be considered significant in a patient with cavernous sinus syndrome.

Kaplan[106] speculated that HIV positive individuals may have an altered cytogenetic predisposition to histiocytosis which heretofore was felt to be of spontaneous etiology. Patients with HIV positivity and those with non-HIV associated histiocytosis have several hematologic and cytologic profiles in common including morphologic changes in blood monocytes and lymph node histiocytes. Further, it is noted that there is a higher incidence of lymphoma in AIDS patients suggesting that the virus responsible may be able to affect susceptible histiocytes and change their cytogenetic architecture. Because the natural biology of histiocytosis X within the central nervous system is relatively unknown, it is felt that orbital eosinophilic granuloma is best managed conservatively while large lesions should be treated with curettage and low dose radiation and steroid injection.

7.4 | Infections

While granulomatous diseases are quite uncommon in manifestation and spread to the cavernous sinus, bacterial and fungal sinusitis with direct or hematogenous extension into the cavernous sinus has been recognized for many years. The sinuses with the greatest propensity toward infection with resultant cavernous sinus invasion would be the ethmoid and sphenoid sinuses respectively. The maxillary sinus is uncommonly involved, but may be indirectly inflamed as a result of oral cavity pathology. Pathologic processes that effect natural pathways for drainage including upper respiratory infection, tumor, trauma, acquired immunologic diseases, allergy, and iatrogenic processes including surgical alteration of the craniofacial anatomy or nasofrontal ethmoid sinus structure would all represent predispositions to the irregular and incomplete drainage through the natural ostia. McDonald,[107] Wyllie,[108] Abramovich,[109] and Lew[110] have independently reported on the nonspecific nature and often paucity of symptoms and physical findings associated with sphenoid sinusitis.

Vertex pain, diffuse headache, and paresthesias in the distribution of the trigeminal nerve as well as nasal and sinus drainage are often associated with complicated sphenoid sinusitis. Lew et al. reporting on the experience from the Massachusetts General Hospital on 30 patients with both acute and chronic sphenoid sinusitis noted that less than half of the patients on first arrival to the hospital were

diagnosed initially, and that six patients presented with intracranial complications, not recognized immediately. Direct spread of infection through venous channels or natural dehiscence in the sinus wall adjacent to the cavernous sinus, may predispose to thrombosis or thrombophlebitis. Bilateral presentation has been described in the reports of Karlin and Price.[107]

Cavernous sinus syndrome will manifest once infection or perivenous edema causes engorgement of the superior ophthalmic vein. Furthermore, spasm of the internal carotid artery may result from direct cavernous internal carotid artery invasion. Demonstrations of gross venous engorgement and invasion have been reported by Smith,[111] Lew,[110] and Caplan,[112] respectively, as draining dural and skull base veins become thrombosed. A case of the latter is reported by McDonald et al. of a patient with infarction of the dorsal lateral mid to lower pons and adjacent posterior fossa cerebellar structures due to venous thrombosis.[107] This patient presented with cochleovestibular as well as facial nerve dysfunction, ultimately developing a florid cavernous sinus syndrome as both the superior and inferior petrosal sinuses and bridging veins infarcted. Matsushima has theorized that the connecting venous vascular channels are responsible for the above noted phenomenon.[107] Extreme complications and their neurologic sequela have been described by Montgomery, Singer, and Hamaker in reports of subdural, intracerebral, and orbital abscesses resultant from direct bacterial transmission into venous channels.[113] Furthermore, meningitis or meningism may result from bacterial migration into the cerebrospinal fluid. Sphenoid sinusitis may cause fulminant or insidious superior orbital fissure syndrome which would include external ophthalmoplegia, exophthalmos, orbital cellulitis, ophthalmic and maxillary nerve hyperesthesia, and Horner's syndrome. In addition, formal orbital apex syndrome with evidence of impaired optic nerve function may manifest.[114] Since cavernous sinus thrombosis may result from any infected paranasal sinus, it is recognized that all must be evaluated by advanced imaging to identify the provocative sinus.

Staphylococcus aureus and *Streptococcus pneumonia* as well as other aerobic or anaerobic streptococci have been implicated as the most common organisms causing sphenoid sinusitis. Multiple organisms may include anaerobes which are found in 25% of cases. Parenteral antibiotics and emergent surgical drainage of the sphenoid sinus is the current treatment protocol. Systemic anticoagulation has been controversial in the past but at present is not recommended. With increasing surgical experience within the cavernous sinus, Dolenc recently suggested that surgical intervention and extirpation of the infected loculation within the cavernous sinus should be considered in similar fashion to the management of an infected and thrombosed sigmoid sinus.[57] Recently, Fujiwara reported a case of aspergillus causing cavernous sinus syndrome resultant from paranasal sinus infection.[115] The authors noted that a parasellar aspergillosis granuloma extending from the sphenoid sinus gave the neuroradiographic appearance of a neoplasm and could be readily confused with that of other inflammatory processes. The presence of a radiodense foreign body within an opaque antrum on plain sinus films is felt to be pathopneumonic of fungal disease according to Robb.[116] MRI in the case report demonstrated a hypointense area in the hyperintense mass on both TI and T2 weighted images. The above was verified by the surgical finding of a fungal granuloma within a mucinous fluid cavity. It was noted that in this case, paracavernous edema caused cranial neuropathy which resolved following satisfactory pansinus drainage. Galetta reported two cases of rhinocerebral mucormycosis resulting in cavernous sinus invasion with internal carotid artery thrombosis.[117] Prior to 1990, of the 37 cases reported in the literature of rhinocerebral mucormycosis with carotid artery occlusion, only six patients survived.[118–122] The authors felt that magnetic resonance imaging was highly specific and helped determine the extent of reasonable surgical intervention as well as efficacy and need for this treatment modality is not yet established.

Case reports of cavernous sinus thrombosis resultant from dental sources are rare. Ogundiya et al., reporting on their experience with this uncommon event at the Massachusetts General Hospital noted that the infection may spread directly through the pterygoid plexus veins and pterygomaxillary space extending into the cavernous sinus, or spread directly into the orbit from the pterygopalatine space. Blindness often times accompanies cavernous sinus thrombosis when infection involves the orbit.[123] Childs,[124] Gold,[125] and Grove[126] have independently reported on dental infections causing similar complications. Childs' series of cases of cavernous sinus thrombosis noted that maxillary teeth were involved in 22 cases whereas in 12 the site was undefined. In the latter series, oral infection and chronic sinusitis along with osteomyelitis appeared to be clinically correlated. Another source of potential spread for odontogenic infection resulting in cavernous sinus infection is through various fascial plains.[127] Here, infection may spread from the maxillary molar teeth into the buccal cortical plate via the maxillary sinus, pterygopalatine space or directly into the infratemporal fossa. From there, an infection may reach the orbit via the inferior orbital fissure. In most of the reported cases, beta hemolytic streptococci and an abundant mixed anaerobic flora have been cultured. In cases involving the facial and nasal areas as the common site of infection, staphylococcus is the most predominant organism.

In addition to abscess drainage, Geggel has noted the almost universal acceptance of steroids as an anti-inflammatory agent to lessen edema.[128] This along with surgical drainage and parenteral antibiotics is mandatory. Several cases of cavernous sinus thrombosis as a result of maxillary surgery have been reported both by Lanigan and Stern who commented independently upon the resultant complication from Leforte osteotomies.[129,130] In one case, resultant facial cellulitis and periorbital cellulitis developed with infection spreading to the orbit traveling anteriorly to exit via the infraorbital region on the skin surface as well as having a posterior extension to the orbital apex and into the cavernous sinus. Harbor reported on a case of mild odontogenic and gingival infection eventually causing a parapharyngeal space abscess which ultimately led to the retrograde passage of infection through the venous channels of the pterygoid plexus, seeding, and thrombosing the cavernous sinus.[131]

7.5 | Tumors: A case series

Tumors arising from the cavernous sinus or those that invade from regional epicenters remain uncommon. Moreover, metastatic

TABLE 1 Symptoms associated with tumors of the cavernous sinus.

- Headache
- Sight impairment (CN II)
- Exophthalmos
- Ptosis
- Cranial neuropathy (motor and/or sensory)
  III[a], IV[a], V[a], VI[a]
  VII (paresis or hemifacial spasm), VIII, IX, X, XI
- Otalgia
- Serous otitis
- Cerebellar dysfunction
- Hemiplegia
- Hydrocephalus
- Mental status changes

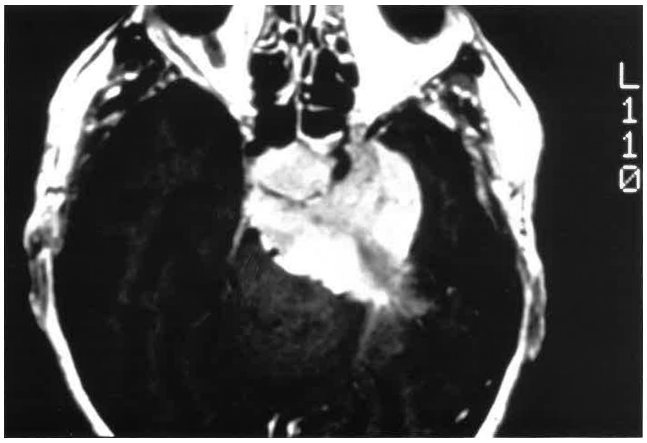
[a]Ophthalmoplegia is the most common neural problem associated with motor dysfunction, involving cranial nerves III, IV, and VI, while V_1/V_2 involvement is associated with sensory dysfunction.

neoplasms involving the cavernous sinus are rare.[132,133] However, because of the increased utilization of MRI scanning for a multiplicity of reasons, occult involvement of the cavernous sinus is being observed as well as the earlier identification of lesions that heretofore may not have been discovered until significant morbidity manifested. Locally invasive lesions constitute the majority of tumors found, including meningiomas[134,135] arising from the sphenopetrosal complex,[136] pituitary lesions advancing from the sella[137] and chordomas growing cephalically from the clivus. Regional neoplasms, in particular sinonasal tract and nasopharyngeal tumors may erode bone and destroy osteologic boundaries or violate preformed suture lines and foramina as they encroach upon and eventually destroy the protective dural margin. Symptoms associated with cavernous sinus tumor involvement while causing neural dysfunction and hemodynamic compromise within the cavernous sinus often specifically reflect the nature of the lesion, the site of origin and unique growth patterns followed by a given histpathology. Symptoms variably associated with tumorous invasion of the cavernous sinus are shown in Table 1.

Diagnostic imaging will demonstrate several changes commensurate with cavernous sinus involvement.[138] Both MRI and high resolution CT scanning are capable of showing gross tumor invasion of the cavernous sinus proper. A contrasted study will often show internal carotid artery displacement: tumors of the lateral wall; predominately neuromas and meningiomas, will direct the artery medially, while tumors from the clivus often displace the artery in a superior direction. Sellar lesions will likewise direct the internal carotid artery laterally and superiorly.[139] CT scanning will optimize visualization of bone erosion along the sphenoid wing, petrous ridge or clivus.[140,141] Furthermore, enlargement or distortion of the skull base foramen will be evident, in particular at the superior orbital fissure, f. ovale, f. rotundum, and f. lacerum.[142–145] T1- and T2-weighted images on MRI demonstrate variable findings depending on the signal characteristics of a known lesion.[146,147] Occasionally, calcification will be noted.

TABLE 2 Radiographic findings.

- –Sphenoid, sellae, clival, and petrous bone destruction
- –Foramen enlargement
- –Foramen distortion
- – Soft tissue mass
- –Variable enhancing lesion T_1/T_2 (NMR)
- –Carotid displacement



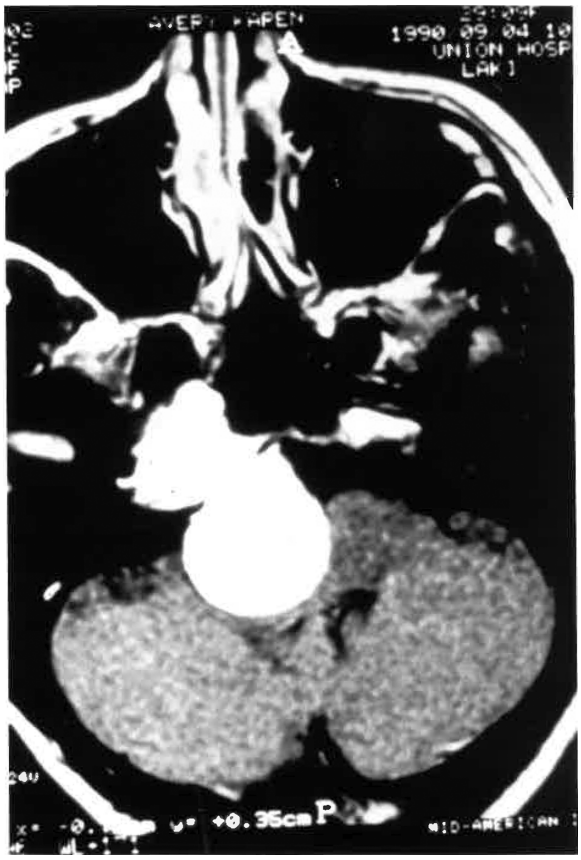
RADIOGRAPH IMAGE 1 Extensive intracavernous extension of a pituitary adenoma is noted on this T2 weighted image. The internal carotid artery is completely enveloped by the lesion.

Table 2 lists common radiographic findings associated with cavernous sinus tumors. Radiograph Images 1–15 show the representative diagnostic studies of cavernous sinus lesions. Arteriography will clearly evidence displacement, distortion or occlusion of the internal carotid artery within the cavernous sinus. Furthermore, collateral circulation and neovascular pathways may be observed.[148–151]

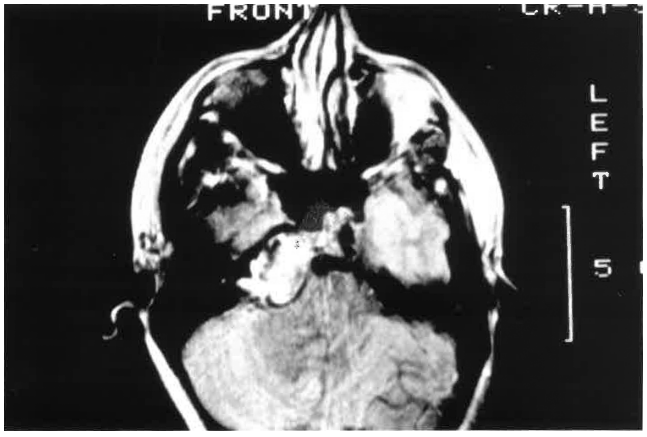
Classification of cavernous sinus lesions may be on an anatomic basis[152]—such as, clival or petrous bone tumors—or on a pathologic basis.[153–157] Table 3 enumerates the tumors of the cavernous sinus by identifying seven families of tumors that may involve the sinus: (1) peripheral nerve tumors,[158–161] (2) neuroectodermal neoplasms,[162,163] (3) soft tissue tumors,[71] (4) paragangliomas,[63] (5) vasoformative tumors, (6) teratomass, and (7) nasopharyngeal—sinonasal tract lesions.[164,165] The management strategies employed in caring for individuals with these lesions reflects both the tumor biology as well as the patients' overall condition and health. Each case assessment is unique and at most institutions, multidisciplinary skull base teams must define the optimal course of therapy based upon their own expertise and the standards set by the achievements of recognized successful colleagues.

8 | SURGICAL CASES

Between 1985 and 1991, 20 patients evaluated by our multidisciplinary skull base team were felt to be appropriate candidates for

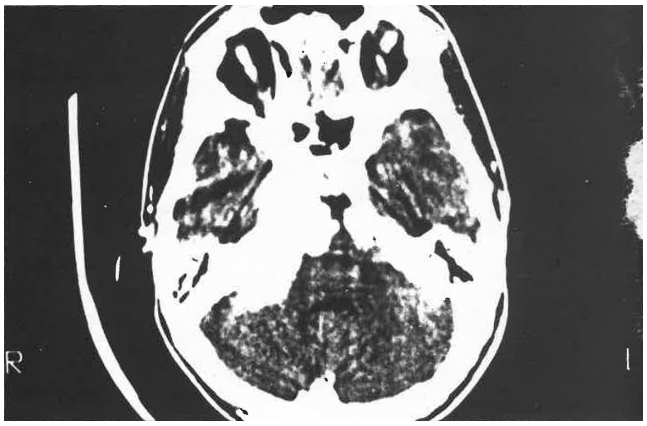


RADIOGRAPH IMAGE 2 Hyperintense petroclinoid chordoma is shown with extensive posterior fossa involvement (T1 image with gadolinium).



RADIOGRAPH IMAGE 3 Right-sided petrous apex epidermoid is demonstrated on T1 imaging with high signal intensity (without contrast enhancement).

extirpation of cavernous sinus lesions (Tables 4–9). No patient with a known malignant tumor, including individuals who were felt to be radiation failures, were considered candidates for cavernous sinus surgery. There were 8 male and 12 female patients ranging in age from 13 to 67 years with a mean age of 44 years (Table 4). Seventy-five



RADIOGRAPH IMAGE 4 Contrast enhanced CT shows extensive growth of a petroclival meningioma with intracavernous extension.

percent of the patients initially presented with cranial neuropathy, while 25% presented with progression of a known lesion producing changes including mental status alteration, tinnitus, and in one case significant nasal obstruction with the paroxysmal onset of severe epistaxis. Seventy percent of the patients demonstrated radiographically to have the epicenter of their tumor in the petroclival region while 10% presented with a primary sellar focus. The remaining tumors were related to thenasopharynx, sphenoid ridge and paraclival areas. Among these lesions (Tables 5 and 8), 55% were meningiomas, 10% were adenomas and epidermoids respectfully, with the remainder of the tumors including juvenile nasopharyngeal angiofibroma, chordoma, and neuroma.

At the time of surgery, two malignant tumors were discovered including a chondrosarcoma and an osteoblastoma (both patients also subsequently received postoperative full course radiation therapy). It was felt that in 11 of 20 cases or 55% total extirpation (Table 6) was accomplished while in 40% of the cases subtotal removal was obtained. In this latter group, tumor was left juxtaposed to the internal carotid artery, which was not sacrificed in any cases. In one case (5%) only partial removal of the tumor was attempted because of brainstem compressive signs and it was deemed unsafe for further tumor removal. of the four surgical approaches described previously, the Dolenc approach was employed in 50% of the cases while Fisch's infratemporal Type C dissection was used in 258 of the cases (Tables 7 and 9). Kawase's subtemporal approach was used in four cases (20%) and the transfacial approach described by Cocke was employed in one case (Tables 7 and 9). There were no intraoperative or perioperative deaths in this series; however, three patients did develop CSF leakage and one patient was required to return to the operating room for closure. Postoperative complications primarily centered around cranial nerve dysfunction with one patient experiencing a cerebrovascular accident/stroke. To date, with a minimum follow-up of 5 months and a maximum follow-up of five and one-half years, there has been recurrent growth of meningioma in two cases felt to have men completely removed. No patients with subtotal removal have

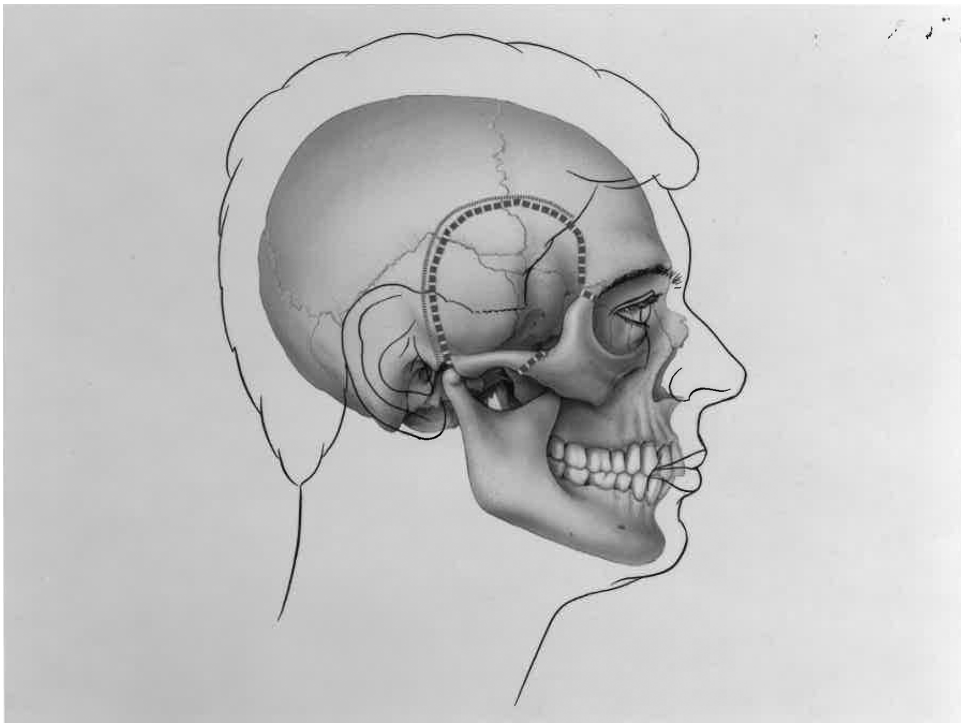


FIGURE 5 To expose the operative field, a pretragal skin incision is carried superiorly 8 cm and curved in an anterior direction following the hairline. Frontozygomatic and orbital bone cuts are made. A frontoparietal temporal craniotomy is performed.

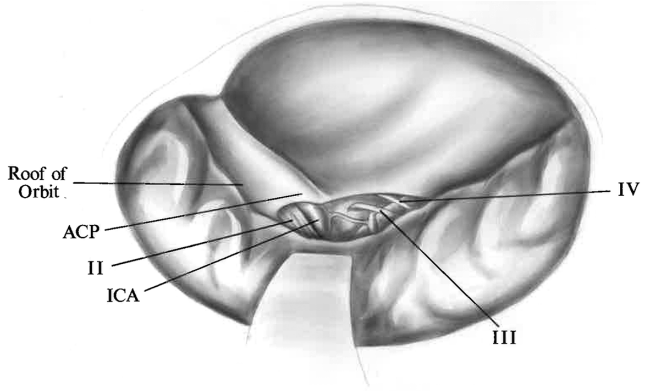


FIGURE 6 The dura is elevated from the floor of the anterior cranial fossa exposing the orbital roof and anterior clinoid process. Bone is drilled away giving exposure to the optic nerve and internal carotid artery. With wider exposure after dural incision, the IIIrd and IVth nerves can be followed to the superior orbital fissure.

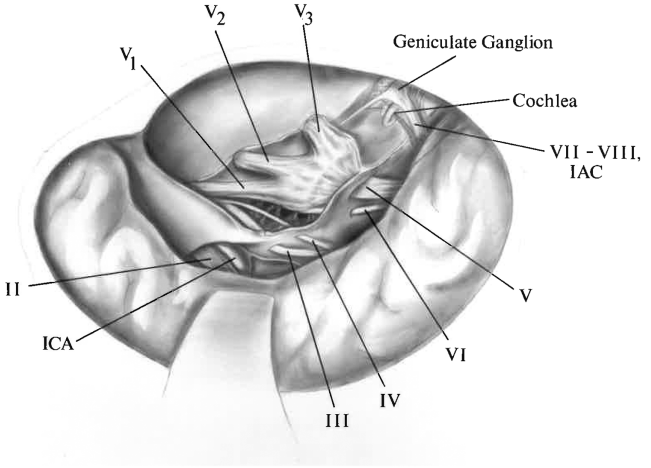


FIGURE 7 The middle fossa floor is exposed and the posterior margin of the field is defined by the internal auditory canal. The geniculate ganglion and greater superficial petrosal nerve are identified. Anteriorly, the trigeminal impression and divisions of the Vth nerve are identified under dural cover.

had changes in their clinical status. Tables 4–9, respectively, list the data pertinent to this patient population.

We are increasingly employing the Dolenc procedure for the majority of cavernous sinus lesions encountered. Figures 5–8 highlight the salient features of the dissection.

9 | DISCUSSION

The earliest description of the region that is presently identified as the cavernous sinus was reported by Ridley in 1695.[166] In his text on the anatomy of the brain, he observed that the internal carotid artery was noted to lie against the lateral dural wall with a small venous space between it and the pituitary.[166] The venous space was recognized to be in continuity with the contralateral side. It, however, was not until 1732 when Winslow made his classic comparison of the gross anatomy of the region with the corpus cavernosum of the penis and applied the term cavernous to this surgical anatomic site.[32] Despite the complete lack of association from a physiologic perspective the name has remained popular and in use while reference was made to the anatomy of the cavernous sinus in several generations of texts during the 19th and 20th centuries![167]

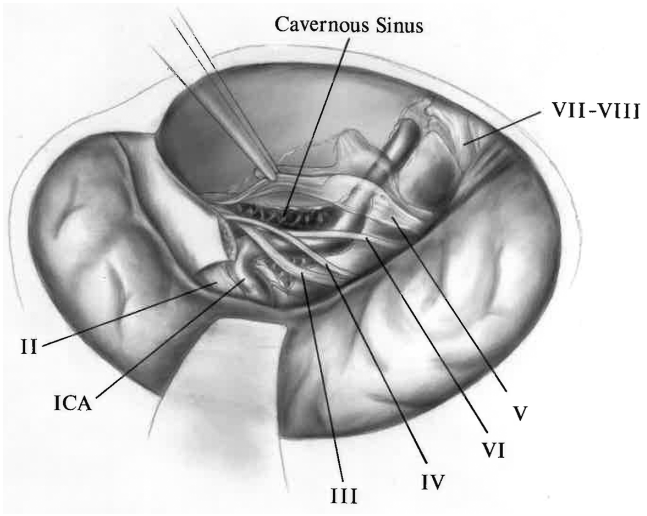
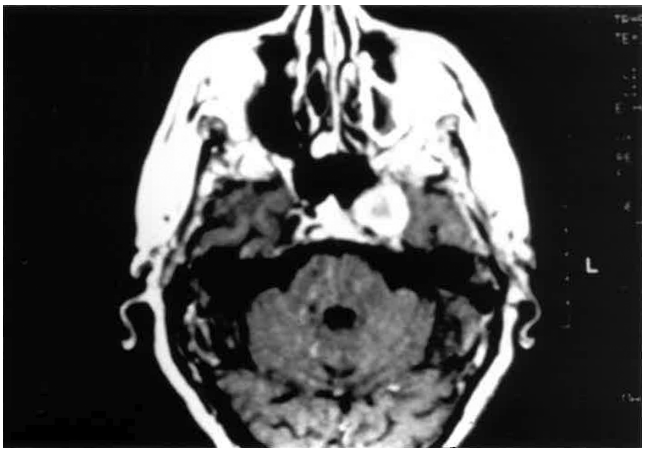
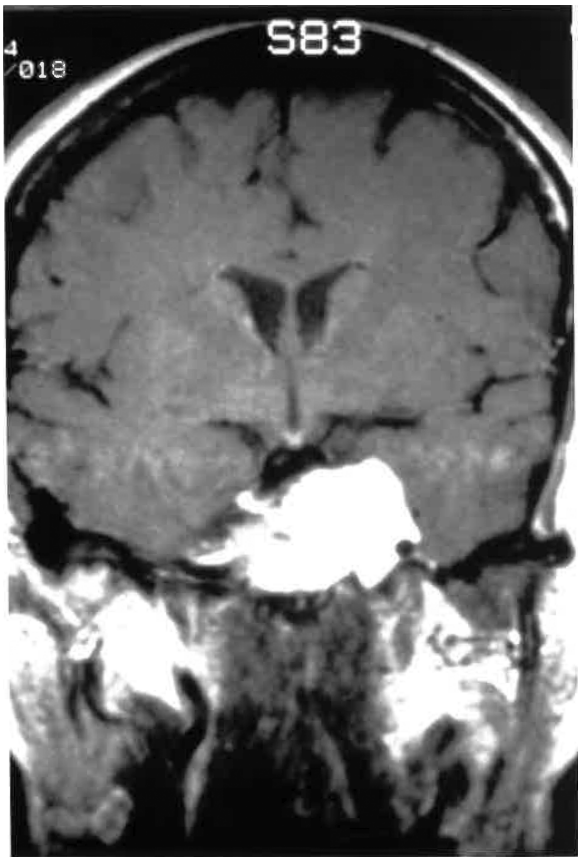


FIGURE 8 Glasscock's triangle is opened exposing the horizontal petrous internal carotid artery. Once fully exposed to the cavernous sinus, the dural sheath may be opened and intracavernous dissection is performed.



RADIOGRAPH IMAGE 5 Hyperintense mass is noted in the left cavernous sinus. The differential diagnosis included neuroma and meningioma. However, a thrombosed angioma was found at surgery.

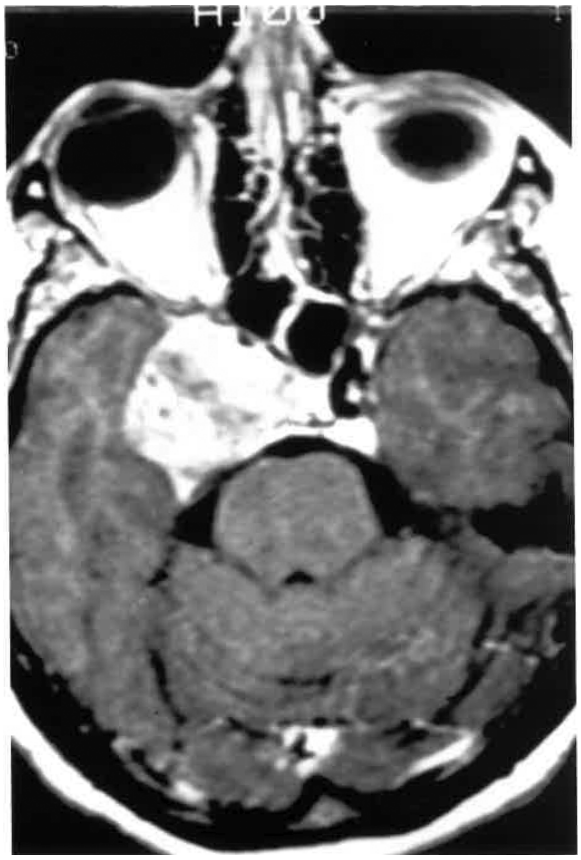


RADIOGRAPH IMAGE 6 Contrast enhanced T1 weighted image demonstrating a clival chordoma expanding superiorly and laterally into the cavernous sinus. The internal carotid artery is displaced but not obstructed.

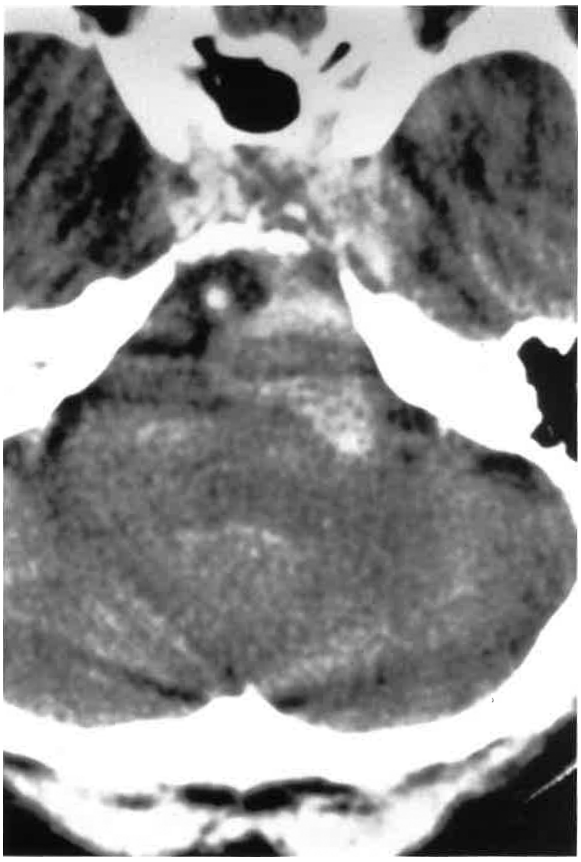
Browder, in 1936, was the first to report the direct surgical exposure of the cavernous sinus.[168] Subsequently, several authors reported increasing experiences with the management of lesions involving the cavernous sinus.[169–174] Despite this fact, Taptas reported in 1982 that a review of the modern surgical literature revealed no less than 16 variations on the description of the anatomy and morphology of the cavernous sinus.[37] These will be addressed shortly. Umansky and Nathan observed that the cavernous sinus space lies between two layers of dura, an endosteal layer forming the floor and mesial wall of the sinus, and a dural layer forming its roof, lateral wall and upper part of the medial wall.[39] Citing works by Christenson, Romanes, and Warwick, these authors agree with the widely held observation that the IIIrd, IVth and V_1, and V_2, divisions of the Vth cranial nerve are intimately related to the lateral wall of the sinus. Moreover, it was observed by these authors that the internal carotid artery, the sympathetic plexus and VIth nerve lie in the central core of the cavernous sinus.[175,176]

Rouviere and others have defined the lateral wall of the cavernous sinus as a space divided between superficial and deep layers. The cranial nerves are known to run deep through the dividing septum and not in the superficial layer. A variant theme is subscribed to by several authors who have stated that the cavernous sinus dural folds appear to split into medial and lateral layers. Most prominent among these is Rhoton,[29,52,177] who clearly defines the layers and states that the cranial nerves noted previously appear to run between these two layers.

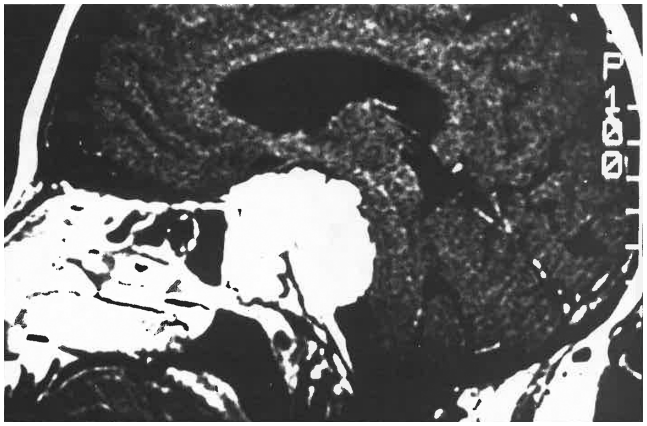
Because of the differences found in previously performed anatomic studies, Umansky and Nathan reported on the dissection of 70 cavernous sinuses from cadavers and autopsy material.[39] These authors found that with a dissection beginning in the posterior/superior angle of the lateral wall of the cavernous sinus, at the site of the entrance of the IVth cranial nerve, a clearly defined dural layer could be separated from a deeper layer containing the IVth and Vth cranial nerves. As in dissection studies performed by Rhoton, the lateral wall of the cavernous sinus was found in all cases to be formed by two layers, a smooth superficial layer and a deep layer containing



RADIOGRAPH IMAGE 7 Chondrosarcoma of the cavernous sinus.



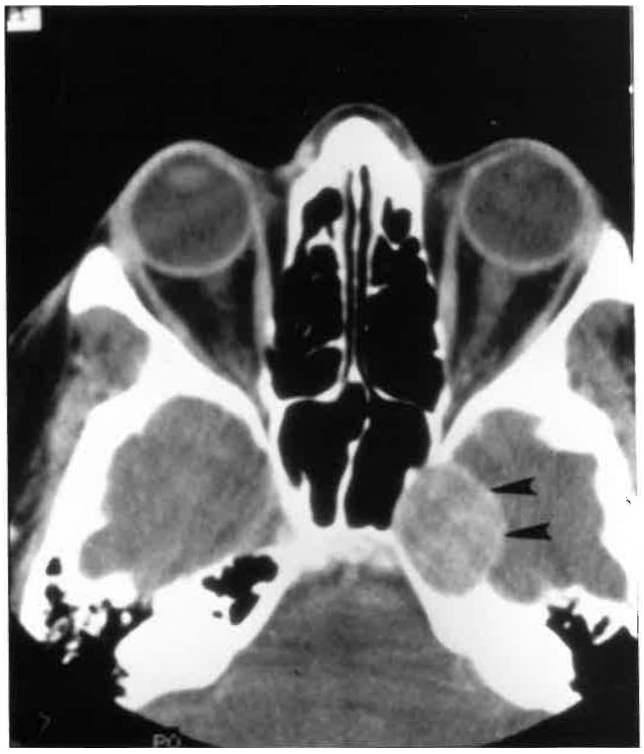
RADIOGRAPH IMAGE 9 A large clival chordoma with posterior fossa and cavernous invasion.



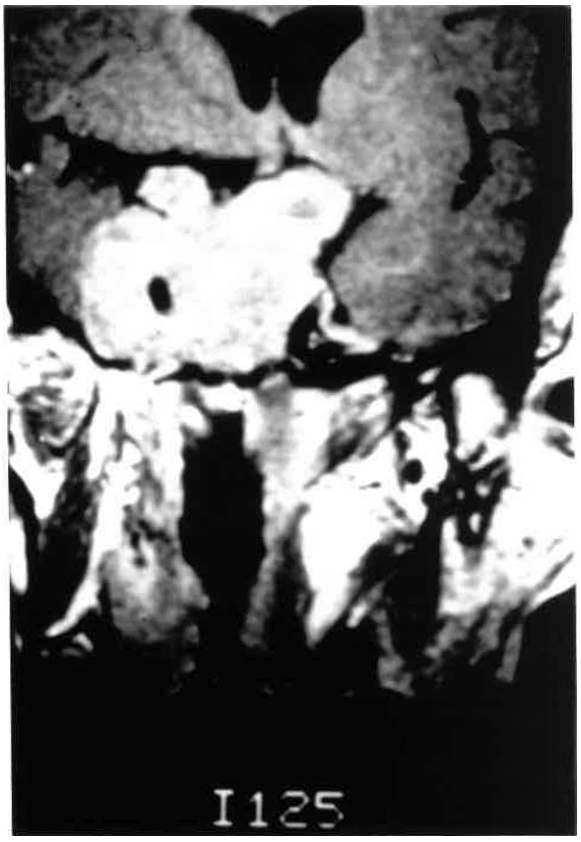
RADIOGRAPH IMAGE 8 Hyperintensive mass on T1 weighted image consistent with meningioma.

the IIIrd, IVth and Vth nerves. These layers were noted to be loosely juxtaposing one another and readily separated except at the point where the nerves crossed and intimately met one another just proximal of the introitus to the superior orbital fissue. Photolllustration 4 in the cadaver dissections clearly demonstrates these two dural planes. The relationship of these dural coverings has been studied in detail by Conesa et al.[33] These authors found that the meningeal folds related to neural, vascular, and osteologic structures were dependent on the conformation of the tentorial circumferences, with the dural layers separated at the apical level of the petrous ridge and projected toward the sphenoid bone anteriorly and the clivus medially.

In addition to the distinct dural layers which are intimately related to the neural structures and could readily be separated at the level of the petrous ridge, especially at Meckel's cave, a fine reticular membrane was noted to lie between the various nerve sheaths. Knosp et al.[178] are in full agreement with Umansky and Nathan that the cranial nerves appear to be separated in the deeper layer of the lateral wall of the cavernous sinus. From a surgical perspective, it is interesting to note that this layer, in fact, may be absent in the area of Parkinson's triangle. Based upon the detailed injection and freeze dried studies by Knosp,[178] Parkinson,[35,36] and Rhoton,[52] it is evident that the lateral wall of the cavernous sinus receives its vascular supply from principle arterial sources, deriving from the internal carotid artery. These vessels respectively are the MHT and inferior lateral trunk (Table 10). While the latter is directed toward the superior orbital fissure, joining with and supplying the cranial nerves as they enter the superior orbital fissure, the MHT supplies blood in a cephalie direction with tributaries contributing to the VIth nerve as it clears Dorello's canal and in a more posterior direction toward the Gasserian ganglion. Further, several authors note the fact that both of these vessels (MHT and inferior lateral trunk) have an intimate relationship with



RADIOGRAPH IMAGE 10 A CT scan with a large lesion involving the petrous apex with extension into the cavernous sinus consistent with a trigeminal neuroma.



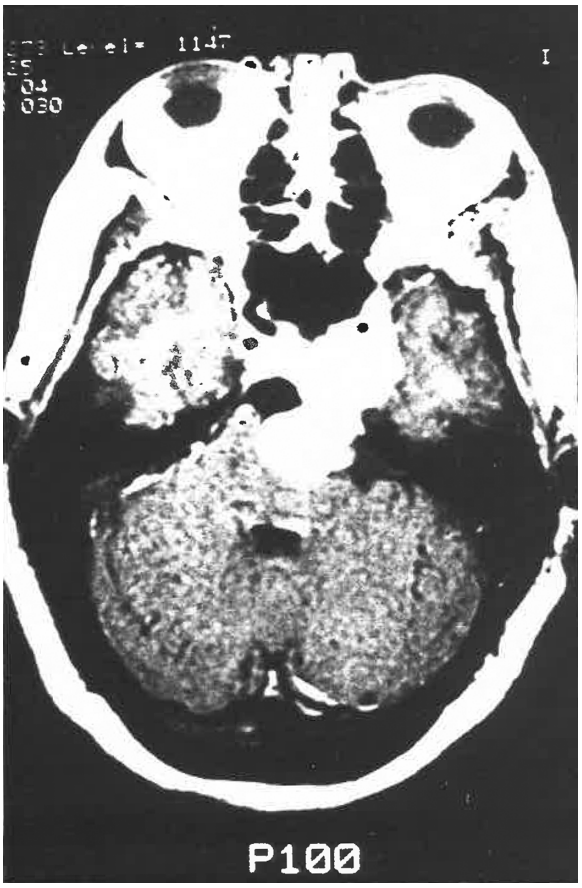
RADIOGRAPH IMAGE 11 A giant recurrent prolactinoma is shown on this T1 contrast enhanced study. Note the involvement, but patency of the internal carotid artery.

branches of the ophthalmic artery, the middle meningeal artery and branches of the internal maxillary system. It is important to be cognizant of the fact that since the blood supply is directed from a medial to lateral direction, exposure of the cranial nerves by opening the lateral wall of the cavernous sinus through the superficial dural plane will not compromise the blood supply to the neural structures.

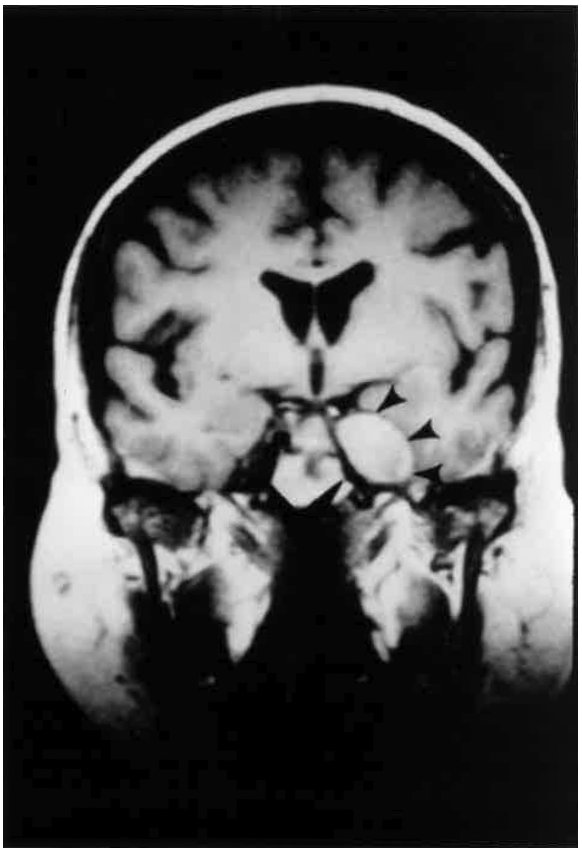
Further, it should be appreciated that the MHT takes origin from the posterior intracavernous loop of the internal carotid artery while the inferior lateral trunk commonly originates from the horizontal portion of the cavernous internal carotid artery. Knosp et al. further report that the capsular arteries of McConnell,[179] taking origin from the medial surface of the internal carotid artery do not supply the cranial nerves of the cavernous sinus. The inferior lateral trunk is noted to divide into four branches, an anteromedial branch, anterolateral branch, a posterior branch and a superior branch. The MHT, respectively, divides into a tentorial branch, an inferior hypophyseal branch and a clival branch. Finally, it should be noted that in several large studies including those of Parkinson,[1,60] Lasjaunias,[22,27] and Lang,[180] the inferior lateral trunk was found in approximately 80% of the cadaver specimens, whereas the MHT was identified in all preparations reported here. It will be recalled the ophthalmic artery was noted to take origin within the cavernous sinus in approximately 8% of cases as reported by Harris and Rhoton.[50] The anteromedial branch of the inferior lateral trunk was considered by Knosp to be a remnant of the dorsal primitive ophthalmic artery.[178] This would explain on an embryologic basis the intracavernous take-off of this noted vessel.

Further, it should be noted that the superior branch of the inferior lateral trunk running parallel to IVth cranial nerve and supplying the medial portion of the tentorium has been described by numerous authors under a variety of names including the central meningeal artery, as noted by Lang,[180] the artery of the free margin of the tentorium as noted by Lasjaunias,[27] and finally the artery of Bernasconi and Casserini.[181] Interestingly, Knosp observed that this artery may originate from either the middle meningeal itself or from the ophthalmic artery. In either case, it exclusively supplies blood to the IVth cranial nerve. Because of this theoretical anastomosis, Sigfried et al. have stated that injury to the accessory meningeal artery at foramen ovale, in manipulation of the Gasserian ganglion, may result in opthalmoplegia if the inferior lateral trunk is not present. The intracavernous venous spaces are longer than the lateral wall venous space; the lateral wall venous space being rather small. Rhoton notes that the aforementioned space and medial wall may at times be collapsed and lie against the internal carotid artery properly.[52] The space is so narrow that Bedford defined the lateral wall as the carotid artery itself recognizing that the lateral wall venous space can be collapsed by the internal carotid artery.[31]

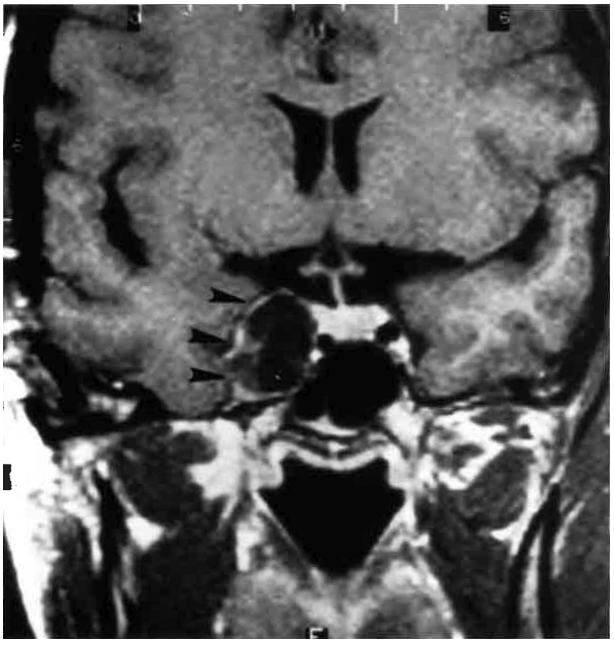
The literature reflects a multiplicity of descriptions for the venous space as previously commented upon by Taptas.[37] There are several definitions of the nature of the cavernous sinus that have been cited



RADIOGRAPH IMAGE 12 A large petroclival meningioma is shown with cross cavernous extension.



RADIOGRAPH IMAGE 14 Metastatic melanoma to the cavernous sinus.

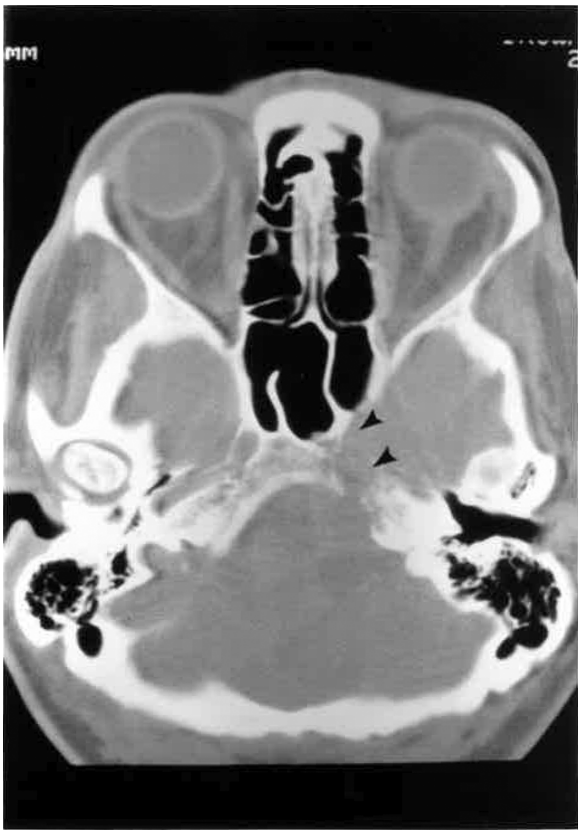


RADIOGRAPH IMAGE 13 Low signal intensity is shown in this T1 contrasted scan of an epidermoid. Note sign of enhancement along the dura.

and used to describe this area. Among the more popular ones are those included as follows:

1. Rhoton feels the cavernous sinus is largely an unbroken trabeculated venous channel.[152]
2. Parkinson views the cavernous sinus not as a large venous cavern, but rather a plexus of various sized veins which divide and coalesce and incompletely surround the internal carotid artery.[1] Parkinson's definition implies that you can work within the sinus without violating either the arterial or venous system.
3. Bedford felt that the cavernous sinus reflected an unbroken venous channel and not a plexus of veins.[31]
4. Bonnet took an extreme perspective commenting that the cavernous sinus as such does not exist but is a space bounded by layers of dura filled with the internal carotid artery surrounded by veins—the trabeculation that are seen on cross section constitute the cut ends of the veins.[182]

Despite these studies, the morphology of the venous space remains controversial. The current study would indicate that the venous spaces as related to the sphenopetrous junction, the sella, and the clivus are a confluence of veins—a plexus—that because of numerous coalescing venous channels, will have a trabeculated nature. Once involved with an inflammatory process or tumor invasion the walls



RADIOGRAPH IMAGE 15 Chondroma with significant bone destruction along the bony skull base noted at the petrous apex.

collapse and distort. Postmortem changes will alter the histoarchitecture of the vein walls and account in part for the variance of opinions.

Recent reports have suggested that operations within the sinus for tumor extirpation can be successful with minimal morbidity. Nevertheless, the potential for operative or perioperative catastrophe is ever present. Before any suggestion is made regarding surgery for a lesion of the cavernous sinus, we believe that a patient should be symptomatic and fully evaluated. Incidental findings of lesions involving the cavernous sinus are better off being followed to establish growth patterns. The choice of approach is predicated upon the type of lesion involved and its growth pattern.

A combination superior and lateral approach affords the optimal surgical field visualization of the cavernous sinus. Furthermore, it allows for a most complete dissection and control of the intracavernous internal carotid artery. In 1990, Inoue et al. performed an elegant microsurgical study of the various approaches to the cavernous sinus.[26] They concluded that:

1. No single approach was adequate to fully provide access to all parts of the cavernous sinus.
2. A superior intradural approach through a pterional craniotomy gave good exposure to the paraclinoid carotid segment and anterior cavernous sinus but did not allow for adequate visualization of the nerves in the lateral wall or the more proximal internal carotid artery.

TABLE 3 Tumors of the cavernous sinus.

Peripheral nerve tumors
- —Schwannomas
- —Neuromas
- —Neurofibromas

Neuroectodermal tumors
- —melanoma
- —Esthesioneuroblastoma
- —Meningioma
- —Pituitary tumors

Soft tissue tumors
- —Chordoma
- —Sarcoma
- —Fibrosarcoma
- —Chondroma
- —Chondrosarcoma

Paragangliomas
- —Orbital
- —Jugular

Vasoformative tumors
- —Hemangioblastoma
- —Hemangiopericytoma
- —Angiofibroma

Teratomas
- —Dermoid
- —Epidermoid

Nasopharyngeal—Sinonasal tract tumors
- —Juvenile nasopharyngeal angiofibroma
- —Squamous cell
- —Adenocarcinoma
- —Adenoid cystic carcinoma

TABLE 4 Patient data.

Male—$N = 8$
Female—$N = 12$
Age range—13–67 years
Mean age—44 years

TABLE 5 Tumors.

Tumor type	*N*	%
Meningioma	11	55
Adenoma	2	10
Epidermoid	2	10
Chondrosarcoma	1	5
Chordoma	1	5
Juvenile nasopharyngeal angiofibroma	1	5
Neuroma	1	5
Osteoblastoma	1	5

TABLE 6 Tumor extirpation.

Extent of tumor extirpation	Fraction (out of 20 total patients)	%
Total	11/20	55
Subtotal	8/20	40
Partial	1/20	5

3. Expanding the previously noted exposure with an extradural dissection allowed for better visualization of the lateral wall including the posterior superior compartment of the cavernous sinus.
4. The superomedial approach by way of a supraorbital craniotomy gave good exposure to the parasellar cavernous sinus.
5. The inferomedial transnasal exposure was limited.
6. Lateral approaches either intradural, or extradural provided wide field exposure of the internal carotid artery and neural elements of the cavernous sinus. When combined with a superior exposure, optimal visualization was obtained.

Sekhar et al. independently reported similar findings and conclusions.[79,183,184]

All candidates for surgery undergo angiographic evaluation with balloon test occlusion of the internal carotid artery. Reconstruction of the cavernous internal carotid artery has been reported to be successful by Sekhar.[183] In all cases intraoperative electrophysiologic monitoring is used when neural function is present. Median nerve stimulus electrodes are placed on the right and left wrists, and insert earphones are placed in the right and left ears. Response electrodes are placed at C3, C4, CZ, F2, Al, and A2. In addition, facial and trigeminal nerve responses are monitored with needle electrode pairs placed in the orbicularis oris and masseter muscles. Responses are monitored throughout the surgical procedure. The surgeons are notified of P1 latency changes for the median nerve response, latency and amplitude shifts on ABR, and waveform morphology changes related to Vth and VIIth nerve function.

Complications associated with surgery of the cavernous sinus are not unique but reflect those encountered in other skull base procedures. Vascular compromise and hemodynamic changes resulting in poor perfusion and venous occlusion may lead to severe neurologic defects. Cranial neuropathy due to devascularization or direct neural manipulation may occur. In exposing the posterior cavernous sinus by opening Kawase's triangle, anacusis may occur if the cochlea is violated. Cerebrospinal fluid leakage may occur thru numerous sites including the sphenoid sinus, petrous apex, eustachian tube, and tegmen plate. Postoperative meningitis may occur. Finally, but perhaps of no less importance, is the enormous psychologic stress placed upon many patients and families coming to terms with the magnitude of the

TABLE 7 Surgical approaches.

Surgical approaches	Fraction (out of 20 total patients)	%
Dolenc	10/20	50
Fisch	5/20	25
Kawase	4/20	20
Cocke	1/20	5

TABLE 8 Clinical characteristics of patients presenting with cavernous sinus tumor.

Case number	Age	Sex	Chief complaint	Major focus	Pathology
1	14	M	Nasal obstruction, epistaxis	Nasopharynx	Juvenile nasopharyngeal angiofibroma
2	64	M	Diplopia, oculomotor nerve palsy	Pituitary	Pleomorphic microadenoma
3	67	F	Dysfunction of optic and oculomotor nerves, lower extremity weakness	Sphenopetroclival	Meningioma
4	53	M	Paresthesia of ophthalmic (V1) and maxillary (V2) divisions of trigeminal nerve	Petroclival	Meningioma
5	13	F	Hearing loss	Petroclival	Trigeminal neuroma
6	59	F	Diplopia, lower extremity spasticity	Clivus	Chondrosarcoma
7	55	F	Hearing loss	Petroclival	Meningioma
8	36	F	Ophthalmoplegia	Petroclival	Chordoma
9	60	F	Progressive acromegaly	Pituitary	Adenoma
10	67	F	Rapid onset visual field deficits, periorbital pain	Petroclival	Meningioma
11	50	F	Visual loss	Sellae	Meningioma
12	46	F	V_1 paresthesia, hearing loss	Petroclival	Meningioma
13	16	M	V, hearing loss	Petroclival	Osteoblastoma
14	46	M	Visual changes, Vth N paresthesia	Petroclival	Meningioma
15	56	M	VII/VIII dysfunction	Petroclival	Meningioma
16	40	F	Pulsatile tinnitus	Petroclival	Meningioma
17	68	F	Mental status changes	Petroclival	Meningioma
18	24	M	Retro-orbital pain		Epidermoid
19	37	F	Vth N paresthesia		Epidermoid
20	16	M	Vth N paresthesia	Petroclival	Meningioma

TABLE 9 Surgical outcomes of patients with cavernous sinus tumors.

Case number	Approach	Extent removed	Complications	Current House-Brackmann[a]
1	Dolenc	Total	None	
2	Dolenc	Subtotal	III, IV paralysis	
3	Dolenc	Subtotal	Ophthalmoplegia (III)	
4	Dolenc	Total	V2 and V3 anesthesia	
5	Combined Kawase and suboccipital exposure	Total	V, VIII (moderate—severe sensorineural hearing loss)	
6	Cocke	Subtotal	Meningitis, hydrocephalus with infected lumbar peritoneal shunt	
7	Dolenc	Subtotal	III, IV, and VI paralysis; CSF leak	
8	Dolenc	Total	III, IV, V, and IV paralysis	
9	Dolenc	Subtotal	CVA	
10	Dolenc	Subtotal	Ophthalmoplegia (III, IV, VI)	
11	Dolenc	Total	II	
12	Fisch C	Total	V2, V3, VII	4/6
13	Fisch C	Subtotal	VII	4/6
14	Fisch C	Total	VII	3/6
15	Fisch C	Subtotal	VII, VIII, CSF leak	6/6
16	Fisch C	Total	VII	2/6
17	Dolenc	Partial	None	
18	Kawase	Total	None	
19	Kawase	Total	None	
20	Kawase	Total	V2 and V3 anesthesia	

[a]For patients followed for at least 1 year.
Abbreviations: CSF, cerebrospinal fluid; CVA, cerebrovascular accident/stroke; III, oculomotor nerve (cranial nerve 3) injury; IV, trochlear nerve (cranial nerve 4) injury; V, trigeminal nerve (cranial nerve 5) injury; V2, maxillary division of trigeminal nerve injury; V3, mandibular division of trigeminal nerve; VI, abducens nerve (cranial nerve 6) injury; VII, facial nerve (cranial nerve 7) injury; VIII, vestibulocochlear nerve (cranial nerve 8) injury.

TABLE 10 Intracavernous arterial distribution.[52,185]

1. Meningohypophyseal A. (100%)[a]
A. Tentorial A.
B. Inferior hypophyseal A.
C. Medial clival A.
D. Lateral clival A.
2. Inferior cavernous sinus A. (84%)
A. Anteromedial Br.
B. Posterior Br.
C. Superior Br.
3. McConell's capsular A. (28%)
4. Ophthalmic A. (8%)
5. Dorsal meningeal A. (6%)

[a]The percentiles noted cite the frequency of these branches found in Rhoton's exhaustive dissection series. As noted, the MHT was identified in 92% of our series with the inferior cavernous sinus artery, also identified as the ILT, noted 70% of the time. The MCA was identified in 36% of the dissections; however, in no cases did we note an intracavernous ophthalmic after the DMA was also not appreciated as an independent artery although it may have been confused with the superior branch of the ILT.
Abbreviations: DMA, dorsal meningeal artery; ILT, inferior lateral trunk; MCA, McConnell's capsular artery; MHT, meningohypophyseal trunk.

procedure and perioperative process. Nevertheless, as this frontier of skull base surgery is advanced, greater safety, lessened morbidity, and an increasing fund of knowledge regarding the nature of lesions in the cavernous sinus is being acquired. Refinements of technique and the open exchange of information is requisite; fortunately, this is being addressed by several newly formed societies of interdisciplinary specialists interested in surgery of the skull base.

10 | CONCLUSION

The cavernous sinus is a tripartite venous osteomeningeal compartment intimately neighboring vital structures, including the optic tracts, pituitary gland, cranial nerves III, IV, V, V, VI, and the internal carotid artery. Furthermore, because of its apposition to the sphenoid wing and petrous ridge as well as the clivus, regional structures may be effected by pathophysiologic changes within the sinus.[185] Within the past quarter century because of (1) increased anatomic study, (2) development of sophisticated diagnostic imaging techniques, (3) interventional radiologic procedures, and (4) refinement of microsurgical skill, management of lesions involving the cavernous sinus has evolved and matured as surgery of the skull base has

become a more defined discipline. The careful selection of surgical candidates, appropriate radiographic studies, close cooperation between otolaryngologists and neurosurgeons, strict attention to perioperative management details, and patient follow-up allows us to provide optimal care to this select patient population.

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CONFLICT OF INTEREST STATEMENT

The author declares that there are no conflicts of interests regarding the publication of this article.

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