The Medial Wall of the Cavernous Sinus: Microsurgical Anatomy

Alexandre Yasuda, M.D.
Department of Neurological Surgery, University of Florida, Gainesville, Florida

Alvaro Campero, M.D.
Department of Neurological Surgery, University of Florida, Gainesville, Florida

Carolina Martins, M.D.
Department of Neurological Surgery, University of Florida, Gainesville, Florida

Albert L. Rhoton, Jr., M.D.
Department of Neurological Surgery, University of Florida, Gainesville, Florida

Guilherme C. Ribas, M.D., Ph.D.
Department of Surgery and Clinical Anatomy, University of São Paulo Medical School, São Paulo, Brazil

Reprint requests:
Albert L. Rhoton, Jr., M.D., Department of Neurological Surgery, University of Florida College of Medicine, P.O. Box 100265, Gainesville, FL 32610-0265.
Email: rhoton@neurosurgery.ufl.edu

Received, August 20, 2003.
Accepted, February 23, 2004.

OBJECTIVE: This study was conducted to clarify the boundaries, relationships, and components of the medial wall of the cavernous sinus (CS).

METHODS: Forty CSs, examined under ×3 to ×40 magnification, were dissected from lateral to medial in a stepwise fashion to expose the medial wall. Four CSs were dissected starting from the midline to lateral.

RESULTS: The medial wall of the CS has two parts: sellar and sphenoidal. The sellar part is a thin sheet that separates the pituitary fossa from the venous spaces in the CS. This part, although thin, provided a barrier without perforations or defects in all cadaveric specimens studied. The sphenoidal part is formed by the dura lining the carotid sulcus on the body of the sphenoid bone. In all of the cadaveric specimens, the medial wall seemed to be formed by a single layer of dura that could not be separated easily into two layers as could the lateral wall. The intracavernous carotid was determined to be in direct contact with the pituitary gland, being separated from it by only the thin sellar part of the medial wall in 52.5% of cases. In 39 of 40 CSs, the venous plexus and spaces in the CS extended into the narrow space between the intracavernous carotid and the dura lining the carotid sulcus, which forms the sphenoidal part of the medial wall. The lateral surface of the pituitary gland was divided axially into superior, middle and inferior thirds. The intracavernous carotid coursed lateral to some part of all the superior, middle, and inferior thirds in 27.5% of the CSs, along the inferior and middle thirds in 32.5%, along only the inferior third in 35%, and below the level of the gland and sellar floor in 5%. In 18 of the 40 CSs, the pituitary gland displaced the sellar part of the medial wall laterally and rested against the intracavernous carotid, and in 6 there was a tongue-like lateral protrusion of the gland that extended around a portion of the wall of the intracavernous carotid. No defects were observed in the sellar part of the medial wall, even in the presence of these protrusions.

CONCLUSION: The CS has an identifiable medial wall that separates the CS from the sella and capsule of the pituitary gland. The medial wall has two segments, sellar and sphenoidal, and is formed by just one layer of dura that cannot be separated into two layers as can the lateral wall of the CS. In this study, the relationships between the medial wall and adjacent structures demonstrated a marked variability.

KEY WORDS: Cavernous sinus, Cranial nerves, Internal carotid artery, Medial wall, Microsurgical anatomy, Pituitary capsule, Pituitary tumors, Transsphenoidal surgery

Neurosurgery 55:179-190, 2004 DOI: 10.1227/01.NEU.0000126953.59406.77 www.neurosurgery-online.com

The cavernous sinus (CS) pair is located near the center of the head on each side of the sella and body of the sphenoid bone. Each sinus has dural walls that surround a venous space through which a segment of the carotid artery with its branches, the abducens nerve and the sympathetic plexus, course. The sinus extends from the superior orbital fissure in front to the area lateral to the dorsum sellae behind (20).

Each CS has four walls: lateral wall, medial and posterior walls, and a roof or superior wall. The lateral and medial walls join anteriorly along the superior orbital fissure and below along the upper border of the maxillary nerve to form a narrow edge that resembles the keel of a boat. The anatomy of and approaches to the CS have been studied extensively (2, 7, 9–14, 17–25, 27–29). Few reports, however, discuss the medial wall (7, 8, 32), which constitutes not only the medial boundary of the CS but also the lateral wall of the pituitary fossa. Some recent reports suggest that there is no medial wall and that it is the pituitary capsule that separates the pituitary gland from the CS (8, 32). The nature of the medial wall of the CS assumes a significant role in determining the direction of growth of pituitary adenomas and in planning pituitary surgery because the pituitary gland and adenomas frequently extend beyond the sellar border into the CS (7, 15, 32). This study was conducted to clarify the nature and boundaries of the medial wall of the CS and its relationships with the surrounding structures.

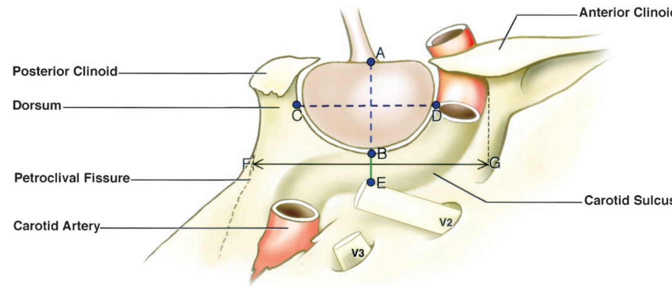

FIGURE 1. *Diagram showing measurements of the medial wall of the CS (see Table 1 for definitions).* V2, *second division of the trigeminal nerve;* V3, *third division of the trigeminal nerve.*

MATERIALS AND METHODS

The medial walls of 44 CSs from 22 adult cadaveric specimens were examined under ×3 to ×40 magnification after the arteries and veins were perfused with colored silicon. In 20 heads (40 CSs), the dissection was performed from lateral to medial in stepwise fashion to expose the medial wall. Structures removed in a stepwise fashion included the lateral and superior walls, the anterior clinoid process, cranial nerves, and the intracavernous segment of the carotid artery. Two heads (four CSs) were sectioned in the midline, and the dissection proceeded stepwise from the midline to lateral. Selected measurements were obtained (*Table 1*; *Fig. 1*).

RESULTS

Dural Relationships

The walls of the CS are formed by the dura lining the internal surface of the calvaria. This dura covering the inner table consists of two layers: an endosteal layer that lines the bone and also is referred to as the external or outer layer of the cranial dura; and a meningeal layer, also called the internal or inner layer, which faces the brain. In the lateral portion of the middle cranial fossa, the meningeal and endosteal layers are tightly adherent, but at the lateral aspect of the trigeminal nerve, they separate into two layers (*Fig. 2*). At the upper border of the maxillary nerve, which is the most inferior limit of the CS, the meningeal layer extends upward to form the outer part of the lateral wall of the CS, and it wraps around the anterior petroclinoid fold extending medially to form the roof of the CS and the upper layer of the diaphragm sella. The endosteal layer, at the level of the upper border of the maxillary nerve and the lower margin of the carotid sulcus, divides into two layers. One layer adheres to the sphenoid bone, covering the carotid sulcus and the floor of the sella, and the other layer extends upward to constitute the internal layer of the lateral wall and roof of the CS and diaphragm sellae. In our specimens, the thin sellar part was easily separable from the capsule of the pituitary gland. No defects were observed in the sellar part of the medial wall between the pituitary fossa and the venous spaces of the CS. The thin dural layer forming the medial wall could not be separated into an inner and an outer layer, as could the lateral wall. Thus, the single layer in the sellar part of the medial wall was thought to represent a continuation of the meningeal dural layer that faces the brain (*Fig. 2, A–C*). At the level of the sellar floor, the thin sellar part of the medial wall comes to rest and joins with the endosteal layer on the middle fossa floor that extends medially to line the sellar floor. Thus, two layers line the sellar floor and the lower surface of the pituitary gland, one that is adhered to the sphenoid bone and the other that comes from the diaphragm and wraps around the pituitary gland. It is easy to dissect one layer from the other, similar to the lateral wall of the CS (peeling), but in the majority of cases, this "virtual" space

TABLE 1. Measurements of the medial wall of the cavernous sinus

Measurements	Average (mm)	Range (mm)
Distance from the diaphragm to the sella floor (A–B)[a]	7.24	4.83 –9.33
Distance between the anterior and posterior limit of the sella (C–D)[a]	8.52	6.21–10.57
Distance from the sellar floor to the superior border of V2 (B–E)[a]	11.27	7.24–15.33
Distance from the most anterior limit of the carotid sulcus at the level of the anterior clinoid process to the superior limit of the petroclival fissure (F–G)[a]	19.21	16.24–21.42

[a] See *Figure 1*.

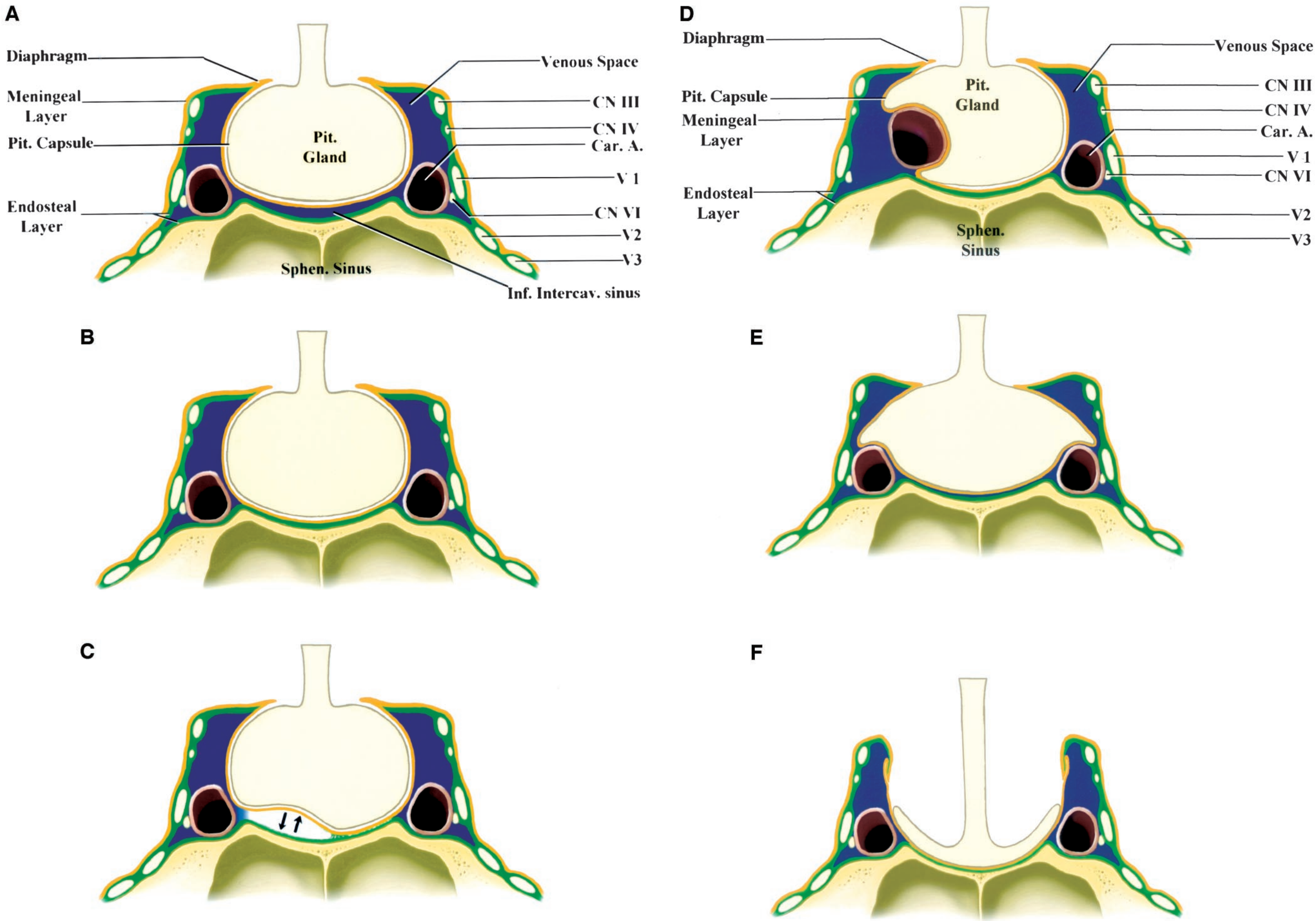

FIGURE 2. *Diagram of coronal sections through the CS and pituitary gland. The dura is shown to be divided into a meningeal layer* (orange*) and an endosteal layer (*green*). The two layers are tightly adherent in the floor of the middle cranial fossa, but at the upper edge of the second trigeminal division (V2), which is the most inferior limit of the CS, they separate into two layers. The meningeal layer extends upward to form the outer layer of the lateral wall and roof of the CS and the upper layer of the diaphragm sellae. The endosteal layer, at the level of the upper border of the maxillary nerve, divides into two layers. One layer extends upward to constitute the internal layer of the lateral wall and roof of the CS, and the other adheres to the sphenoid bone, covering the carotid sulcus and the sellar floor. From the free edge of the diaphragm, a thin layer of dura extends downward to wrap around but is easily separable from the pituitary gland. Our dissections suggest that the meningeal layer forms the sellar part of the medial wall of the CS and that the endosteal layer (*green layer*) forms the sphenoidal part of the medial wall.* A, *an inferior intercavernous sinus that connects the paired cavernous sinuses. These intercavernous sinuses extend across the midline between the meningeal-dural layer covering the inferior aspect of the pituitary gland and the endosteal layer covering the osseous sellar floor.* B, *no inferior intercavernous sinus, and the meningeal and endosteal layers of dura fuse into a single layer on the sellar floor.* C, *the ease of separating the meningeal layer covering the inferior aspect of the pituitary gland from the endosteal layer covering the bony sellar floor.* D, *the intracavernous carotid indenting and deforming the lateral surface of the pituitary gland to create protrusion of the gland above the artery.* E, *lateral tongue-like protrusions of the pituitary gland extending above the intracavernous carotid.* F, *an empty sella. The superior portion of the sellar part of the medial wall, formed by the meningeal layer (*orange*), separates the contents of the CS from the extension of the chiasmatic cistern into the sella.* A., *artery;* Car., *carotid;* CN, *cranial nerve;* Inf., *inferior;* Intercav., *intercavernous;* Pit., *pituitary;* Sphen., *sphenoid;* V1, *first division of the trigeminal nerve;* V2, *second division of the trigeminal nerve;* V3, *third division of the trigeminal nerve;* III, *oculomotor nerve;* IV, *trochlear nerve.*

became "real" in that the intercavernous sinuses course between the two layers (*Fig. 2A*). Therefore, with the exception of the paired lateral aspects of the sella and pituitary gland that are covered by one layer, two layers cover the other sellar surfaces.

The meningeal and endosteal layers of the lateral wall and roof of the CS and the diaphragm sellae continue anteriorly to line the anterior cranial fossa and posteriorly as the covering of the dorsum sellae and clivus. The meningeal layer also continues anteriorly to form the upper (distal) dural ring,

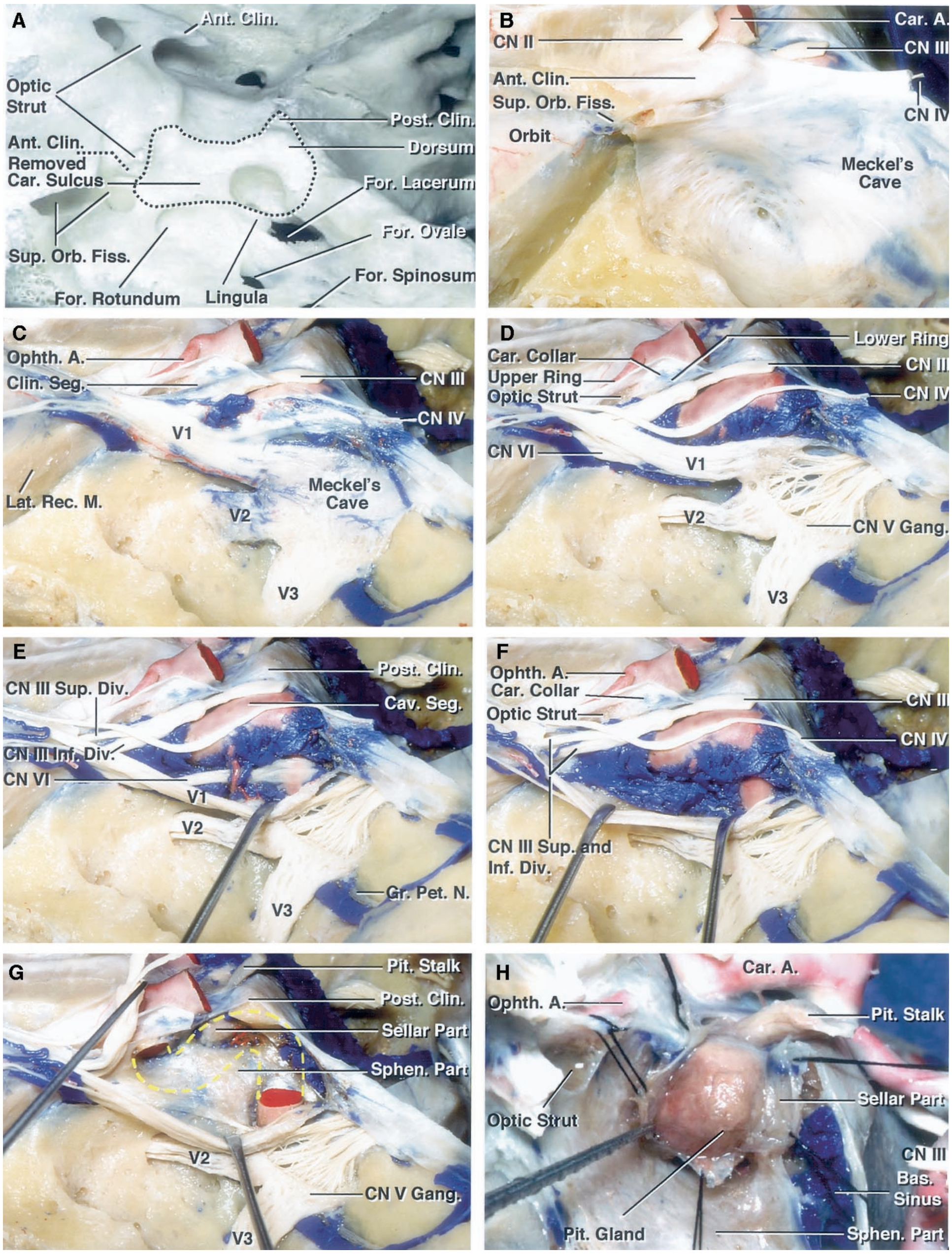

FIGURE 3. *Photographs showing stepwise dissection of the left CS.* A, *superolateral view of the left skull base. The left anterior clinoid process has been removed to expose the optic strut. The CS is located posterior to the superior orbital fissure, above the superior margin of the second division of the trigeminal nerve and the lingula of the sphenoid bone, inferior to the diaphragm sellae, and anterior to the dorsum sellae. The bony structures on the sphenoid bone related to the CS are (*dotted lines*): the anterior clinoid process, optic strut, carotid sulcus, lingula, dorsum sellae, and posterior clinoid process.* B, *the lateral wall of the CS extends downward from the tentorial edge and blends into the dura covering Meckel's cave and the middle fossa. The oculomotor and trochlear nerves enter the roof of the CS. The carotid artery exits the CS on the medial side of the anterior clinoid process.* C, *the outer layer of dura (meningeal layer) has been peeled away from the lateral wall of the CS and the thin inner layer (endosteal layer) that invests the nerves has been preserved. The lateral wall of Meckel's cave and the anterior clinoid process have been removed to expose the clinoidal segment of the carotid artery. This exposes the oculomotor, trochlear, and ophthalmic nerves in the roof and lateral wall of the CS and passing forward through the superior orbital fissure. The thin layer covering Meckel's cave consists in part of the arachnoid membrane extending forward from the posterior fossa and surrounding the trigeminal nerve to the level of the trigeminal ganglion.* D, *the thin inner layer of dura covering the lateral wall (endosteal layer) has been removed. The oculomotor, trochlear, and ophthalmic nerves converge on the superior orbital fissure. The optic strut separates the optic canal and superior orbital fissure. The dura extending medially off the upper surface of the anterior clinoid forms the upper dural ring around the internal carotid artery, and the dura lining the lower margin of the clinoid extends medially to form the lower dural ring. The clinoidal segment of the carotid artery, located between the upper and lower dural ring, is enclosed in a dural sheath, referred to as the carotid collar.* E, *the ophthalmic nerve has been depressed to expose the abducens nerve, which courses medial to the ophthalmic nerve. The oculomotor nerve splits into superior and inferior divisions just behind the level of the superior orbital fissure.* F, *the ophthalmic and abducens nerves have been depressed to expose the venous space of the cavernous sinus and the cavernous segment of the internal carotid artery.* G, *the cranial nerves have been displaced, and the intracavernous carotid has been removed to expose the sellar and sphenoidal parts of the medial wall. The superior and inferior margins of the removed segment of the carotid artery that coursed along all the pituitary gland are shown (*yellow dotted line*).* H, *another specimen in which the sellar part of the medial wall of the left CS has been opened and reflected away from the capsule of the pituitary gland. The sellar part of the medial wall separates easily from the pituitary capsule that is attached to the gland.* A., *artery;* Ant., *anterior;* Bas., *basilar;* Car., *carotid;* Cav., *cavernous;* Clin., *clinoid, clinoidal;* CN, *cranial nerve;* Div., *division;* Fiss., *fissure;* For., *foramen;* Gang., *ganglion;* Gr., *greater;* Inf., *inferior;* Lat., *lateral;* M., *muscle;* Ophth., *ophthalmic;* Orb., *orbital;* Pet., *petrosal;* Pit., *pituitary;* Post., *posterior;* Rec., *rectus;* Seg., *segment;* Sphen., *sphenoidal;* Sup., *superior;* V, *trigeminal nerve.*

around the carotid artery and the optic sheath, whereas the endosteal layer continues anteriorly and medially to form the lower (proximal) dural ring around the carotid (*Figs.* 3 and 4).

The lateral wall of the CS is easily split into two layers, the inner and outer layers. Elevating this outer layer of dura, which faces the brain and thus would be the meningeal layer,

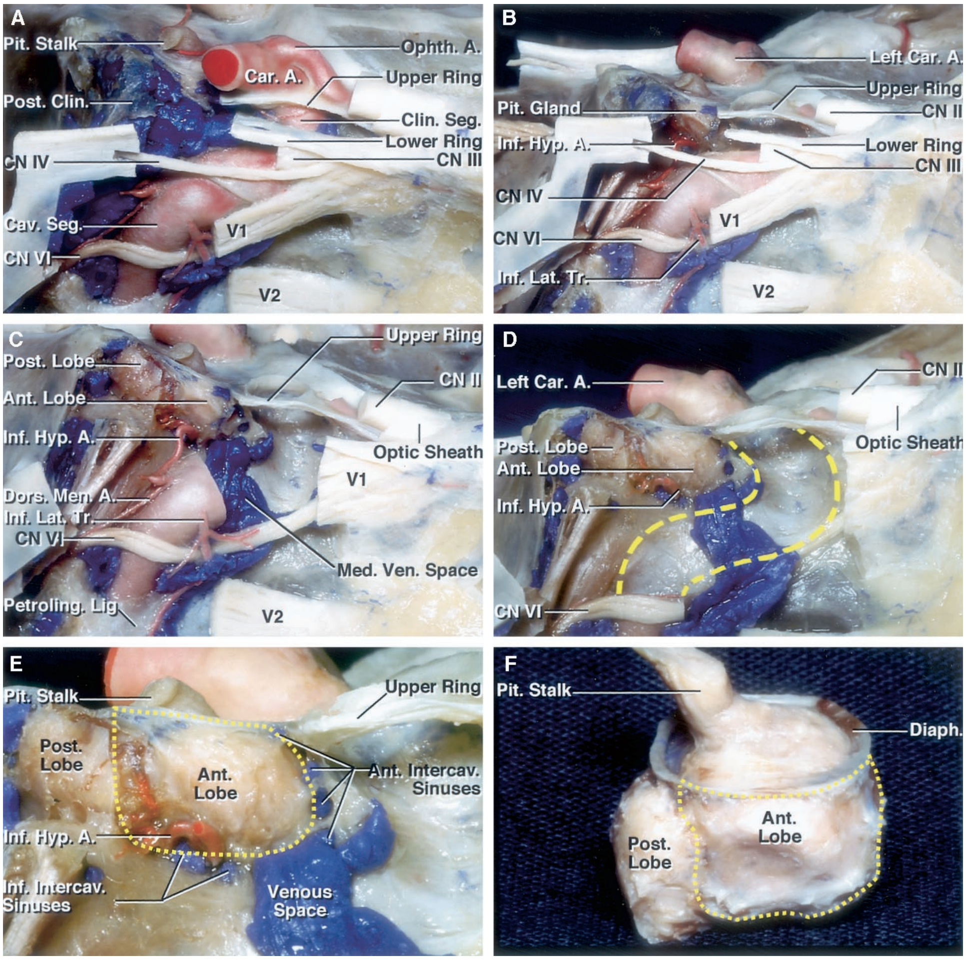

FIGURE 4. *Photographs showing stepwise dissection of the right CS.* A, *the anterior clinoid and the posterior portion of the oculomotor, ophthalmic, and maxillary nerves have been removed. The CS extends down to just below the intracavernous carotid and the carotid sulcus on the body of the sphenoid bone and to the level of, but not below, the upper edge of the maxillary nerve. The dura extending medially off the upper surface of the anterior clinoid forms the upper dural ring around the internal carotid artery, and the dura lining the lower margin of the anterior clinoid extends medially to form the lower dural ring. The clinoidal segment of the carotid artery is located between the upper and lower dural ring.* B, *the venous space superior to the horizontal segment of the intracavernous carotid has been evacuated. The pituitary gland can be observed through the medial sinus wall. The inferolateral trunk arises from the lateral side of the midportion of the horizontal segment of the intracavernous carotid and passes above and lateral to the abducens nerve.* C, *the intracavernous carotid, distal to the origin of the inferolateral trunk, has been removed to expose the medial wall and the medial venous space. The posterior clinoid and dorsum sellae also have been removed to expose the posterior lobe of the pituitary gland. The inferior hypophyseal and dorsal meningeal arteries arise from the meningohypophyseal trunk.* D, *the part of the intracavernous carotid above the level of the superior edge of the abducens nerve has been removed to expose the sphenoidal part of the medial wall. The inferior hypophyseal artery runs in the dura that covers the posterior inferior part of the anterior lobe and pierces the pituitary capsule at the level of the posterior lobe. The superior and inferior margins of the intracavernous carotid are marked (*yellow dotted line*). In this case, the horizontal segment of the intracavernous carotid courses below the level of the sellar floor and the pituitary gland.* E, *enlarged view of the medial wall. In this specimen, the intercavernous sinuses are located along the anterior and inferior margins of the pituitary gland. The dorsum sellae has been removed. The sellar part of the medial wall (*dotted line*) covers the lateral surface of the anterior lobe but not the posterior lobe, which sits in the concavity of the dorsum sellae behind the sellar part of the medial wall.* F, *the pituitary gland and the sellar part of the medial wall have been removed from the sella. The sellar part of the medial wall (outer margin,* yellow dotted line*) does not extend lateral to the posterior lobe but blends into the lateral margin of the dorsum in front of the posterior lobe, which sits in the concavity of the dorsum.* A., *artery;* Ant., *anterior;* Car., *carotid;* Cav., *cavernous;* Clin., *clinoid, clinoidal;* CN, *cranial nerve;* Diaph., *diaphragm;* Dors., *dorsal;* Hyp., *hypophyseal;* Inf., *inferior;* Lat., *lateral;* Lig., *ligament;* Men., *meningeal;* Ophth., *ophthalmic;* Petroling., *petrolingual;* Pit., *pituitary;* Post., *posterior;* Seg., *segment;* Tr., *trunk;* V, *trigeminal nerve.*

exposes the inner layer or endosteal layer. The endosteal layer invests the cranial nerves coursing in the lateral wall of the CS. These layers also extend to the sinus roof, where an outer layer that faces the brain can be peeled away from an inner layer.

The Medial Wall of the CS

The medial wall of the CS has two parts: sellar and sphenoidal. The sellar part separates the sella and the pituitary gland from the venous spaces in the sinus. The sphenoidal part is formed by the dura lining the carotid sulcus on the lateral aspect of the sphenoid body. The medial wall of the CS is located lateral to the sella and carotid sulcus on the body of the sphenoid bone (*Figs. 3–5*). Its anterior limit extends along a line that starts at the junction of the optic strut with the body of the sphenoid bone and passes downward along the medial edge of the superior orbital fissure to the superior edge of the foramen rotundum. The superior limit is located at the level of the diaphragm sellae and is formed by a line extending backward from the superior edge of the junction of the optic strut with the body of the sphenoid bone to the posterior clinoid process. Inferiorly, the lower edge of the medial wall extends backward from the superior edge of the foramen rotundum across the anterior portion of the lingula of the sphenoid bone to reach its posterior limit at the superior end of the petroclival fissure. Its posterior edge is located along a line

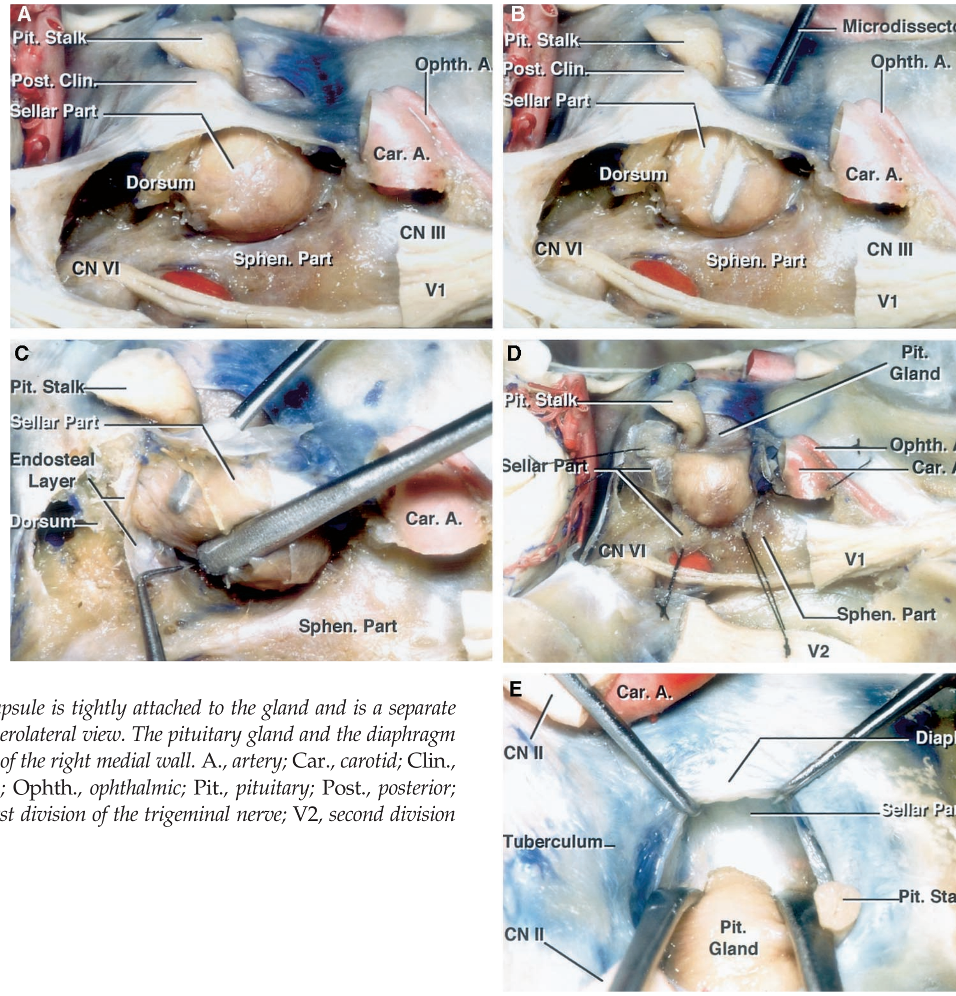

FIGURE 5. *Photographs showing the medial wall of the CS.* A**,** *the sellar part of the medial wall is in contact with the lateral surface of the pituitary gland; the sphenoidal part of the medial wall covers the body of the sphenoid bone above the superior border of the maxillary nerve. The posterior vertical and horizontal segments of the intracavernous carotid have been removed, but the abducens nerve has been preserved.* B**,** *a microdissector has been placed through the diaphragm sellae, between the sellar part of the medial wall and the pituitary gland.* C**,** *three microdissectors have been placed. One is placed between the sellar part of the medial wall and the pituitary gland, another is elevating the pituitary gland, and the angled microdissector is in contact with the endosteal layer that covers the concave surface of the dorsum sellae and blends into the endosteal layer in the sellar floor. The posterior lobe of the pituitary gland is located in the concave anterior surface of the dorsum sellae, behind the point at which the medial wall attaches to the lateral margin of the dorsum sellae.* D**,** *the sellar part of the medial wall has been opened and the leaves retracted away from the gland. The pituitary capsule is tightly attached to the gland and is a separate structure from the medial wall of the CS.* E**,** *superolateral view. The pituitary gland and the diaphragm sellae have been retracted to show the sellar part of the right medial wall.* A., *artery;* Car., *carotid;* Clin., *clinoid;* CN, *cranial nerve;* Diaph., *diaphragm;* Ophth., *ophthalmic;* Pit., *pituitary;* Post., *posterior;* Sphen., *sphenoidal;* VI, *abducens nerve;* V1, *first division of the trigeminal nerve;* V2, *second division of the trigeminal nerve.*

connecting the posterior clinoid process and the superior limit of the petroclival fissure (*Figs. 2* and *3A*). Two areas, sellar and sphenoidal, are easily recognized (*Figs. 4–7*).

The Sellar Part

The sellar part of the medial wall of the CS forms to the lateral wall of the sella (*Figs. 3–7*). In all specimens, it was in direct contact with but easily separated from the capsule of the pituitary gland (*Figs. 3H* and *5, B–D*). The dura forming the medial wall of the CS is very thin and cannot be separated into two layers, as can the thicker dura lining the superior, inferior, anterior, and posterior walls of the sella. With the exception of both lateral aspects of the pituitary gland, which are covered by just one very thin layer of dura, the other four surfaces of the gland (superior, inferior, anterior, and posterior) are covered by dura that can be separated into two layers and between which the intercavernous sinuses course. The pituitary capsule, which is separate from the medial wall of the CS, is a very thin, semitransparent membrane that is tightly attached to the gland.

The average superior to inferior length of the sellar part of the medial wall of the CS at its center was 7.24 ± 1.23 mm, and the average anterior to posterior length at the center was 8.52 ± 1.25 mm (*Table 1*; *Fig. 1*). One specimen (two CSs) had an empty sella turcica, and in this case, the sellar part of the medial wall separated the contents of the CS from the downward extension of the chiasmatic cistern into the sella (*Figs. 2F* and *8*).

The Sphenoidal Part

The sphenoidal part has a more complicated configuration than the simple quadrilateral shaped sheet of dura forming the sellar part (*Figs. 2–7*). Three portions or subareas can be identified. The anterior portion is formed by the dura lining the carotid sulcus on the medial side of the clinoidal segment of the carotid artery. This segment is limited superiorly and inferiorly by the upper (distal) and lower (proximal) dural rings, respectively, formed by the dura extending medially from the upper and lower surfaces of the anterior clinoid process to surround the carotid artery (*Fig. 4*). The middle

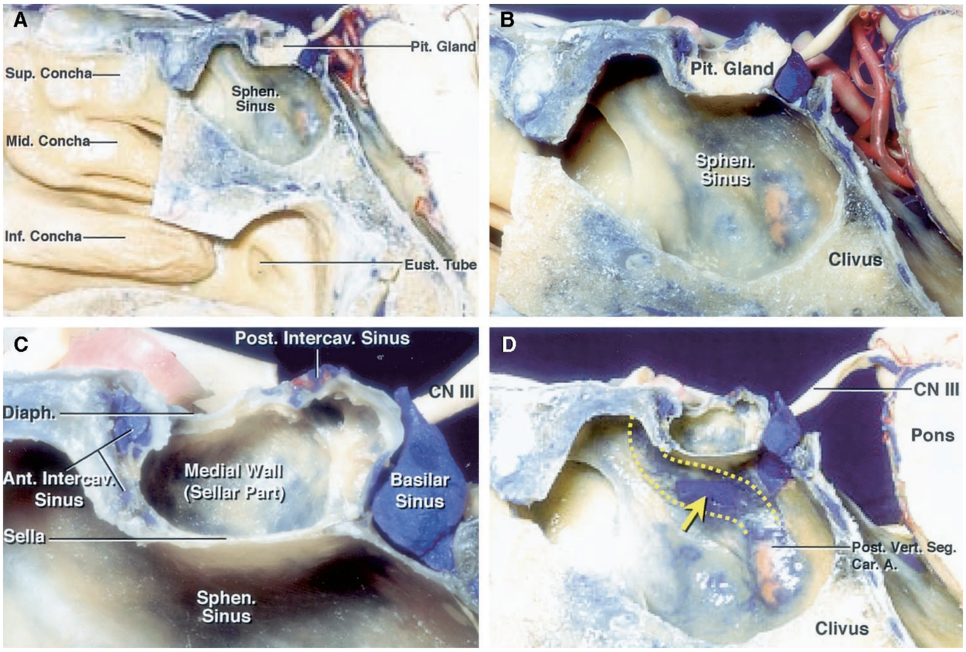

FIGURE 6. *Photographs showing stepwise dissection medial to lateral.* A, *sagittal section at the level of the midline. Part of the nasal septum has been removed. The sphenoid sinus is located in the body of the sphenoid bone. The conchae have been preserved.* B, *enlarged view of the pituitary gland and sphenoid sinus. The mucosa of the sphenoid sinus has been removed.* C, *the pituitary gland has been removed to expose the sellar part of the medial wall. The blue color of the venous space and plexus medial to the intracavernous carotid is observed through the sellar part of the medial wall. The anterior intercavernous sinus crosses anterosuperior to the pituitary gland and the basilar sinus crosses posterior to the gland and dorsum.* D, *the bone forming the lateral wall of the sphenoid sinus has been removed to expose the sphenoidal part of the medial wall (*yellow dotted line*). A rectangular window of dura has been removed to show the venous space inside the CS (*yellow arrow*) that separates the intracavernous carotid from the dura forming the sphenoidal part of the medial wall. The posterior vertical segment of the intracavernous carotid can be observed through the dura of the medial wall. The horizontal segment of the intracavernous carotid courses lateral to the venous space.* A., *artery;* Ant., *anterior;* Car., *carotid;* CN, *cranial nerve;* Diaph., *diaphragm;* Eust., *Eustachian;* Inf., *inferior;* Intercav., *intercavernous;* Mid., *middle;* Pit., *pituitary;* Post., *posterior;* Seg., *segment;* Sphen., *sphenoid;* Sup., *superior;* Vert., *vertical.*

portion is formed by the dura lining the carotid sulcus coursing below the lateral edge of the floor of the sella (*Figs. 3–5*). The posterior portion extends along the lateral border of the posterior clinoid process and dorsum sellae and ends at the superior limit of the petroclival fissure (*Fig. 4D*). The sphenoidal part of the medial wall is formed by just one layer of dura, as well as the sellar part, but the sphenoidal part is formed by endosteal layer and the sellar part is formed by meningeal layer (*Fig. 2*).

The average distance from the center of the sellar floor to the superior border of the maxillary nerve was 11.27 ± 2.13 mm. The average distance between the most anterior limit of the carotid sulcus to the dorsum sellae (petroclival fissure) was 19.21 ± 1.37 mm (*Table 1*; *Fig. 1*).

The Intracavernous Carotid and the Medial Wall

In 21 CSs (52.5%), the intracavernous carotid was in direct contact with the pituitary gland, separated only by the sellar part of the thin medial wall of the CS. In the remaining 19 CSs (47.5%), a venous space and a posterior extension of the orbital fat were interposed between the intracavernous carotid and the pituitary gland. In the latter group, the shortest distance between the artery and gland averaged 2.55 ± 1.16 mm.

The venous spaces of the CS extended between the intracavernous carotid and the dura of the carotid sulcus in 39 of 40 CSs. The thickness and length of that venous component varied among specimens (*Figs. 4C* and *7, A* and *B*). The thickest portion of the venous space or plexus was observed near the edges of the carotid sulcus (average, 1.92 ± 0.51 mm), and the thinnest part was observed near the midportion of the carotid sulcus (average, 0.78 ± 0.2 mm).

The position of the intracavernous carotid, in relation to the sellar part of the medial wall, varied markedly (*Figs. 3G, 4D, 7B,* and *9*). The lateral aspect of the pituitary gland was divided longitudinally into superior, middle, and inferior thirds (*Fig. 9*). The intracavernous carotid coursed along only the inferior third in 14 CSs (35%) (*Fig. 7B*), along some part of both the inferior and middle thirds in 13 CSs (32.5%), and along some part of all the thirds in 11 CSs (27.5%) (*Fig. 3G*). In two CSs (5%), the intracavernous carotid coursed along the sphenoid bone below the level of the sellar floor and the pituitary gland (*Fig. 4D*). The inferior hypophyseal artery coursed along the posteroinferior part of the sellar part of the medial wall to reach the posterior lobe (*Figs. 4E* and *7E*).

The Pituitary Gland and the Medial Wall

The pituitary gland is composed by anterior and posterior lobes (*Fig. 4, C–F*). The sellar part of the medial wall of the CS covers the lateral surface of the anterior lobe (*Fig. 5A*), but the posterior lobe is positioned behind both the anterior lobe and the medial wall of the CS in the concavity of the dorsum sellae (*Fig. 4, C–F*). The posterior lobe sits in the concave anterior surface of the dorsum sellae, at which the sellar part of the medial wall of the CS blends into the dura along the lateral edge of the inner surface of the dorsum.

In our specimens, the shape of the pituitary glands varied markedly. In 18 (45%) of the 40 CSs, the pituitary gland had a lateral protrusion. The protrusion was located in the superior

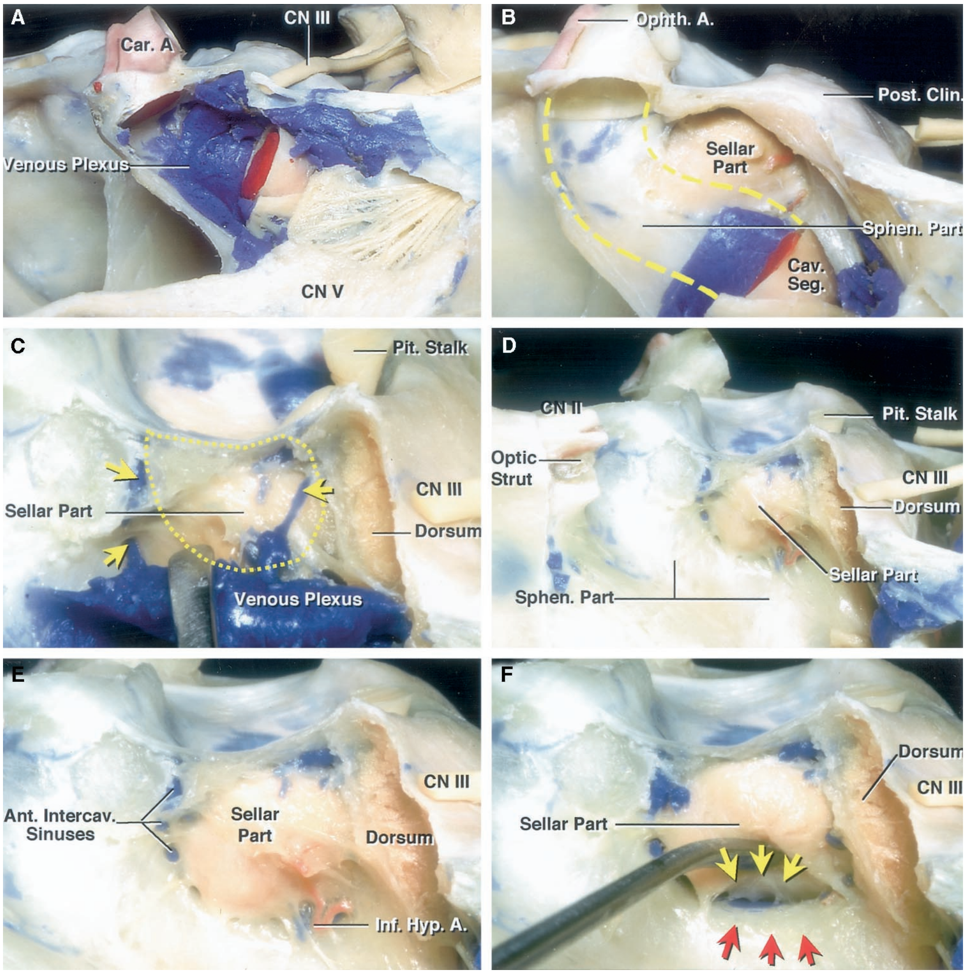

FIGURE 7. *Photographs showing lateral view of the medial wall of the CS.* A, *The lateral wall and roof, anterior and posterior clinoids, a segment of the cranial nerves, and part of the intracavernous carotid have been removed to expose the venous space located in direct contact with the medial wall of the CS. The thickest portion of the venous space is located near the superior and inferior margins of the carotid sulcus.* B, *the venous space medial to the intracavernous carotid has been partially evacuated to expose the sellar and sphenoidal parts of the medial wall. The superior and inferior margins of the intracavernous carotid (*yellow dotted line*) course along the inferior third of the pituitary gland.* C–F, *left medial wall of another specimen.* C, *enlarged lateral view of the sellar part of the medial wall. The lateral wall of the CS, cranial nerves, and intracavernous carotid have been removed. The material in the venous space has been retracted downward to show the sellar part (*yellow dotted line*) of the medial wall. Intercavernous sinuses cross the anterior and posterior margins of the pituitary gland and connect both CS (*yellow arrows*).* D, *the material in the venous space has been removed to expose the sellar and sphenoidal parts of the medial wall.* E, *the sellar part of the medial wall is located at the area lateral to the anterior lobe but not the posterior lobe because the posterior lobe sits in the concavity of the anterior surface of the dorsum sellae behind the medial wall. The inferior hypophyseal artery runs in the posterior inferior part of the sellar part of the medial wall to pierce the pituitary capsule at the level of the posterior lobe.* F, *the endosteal layer of the dura lining the sellar floor (*red arrows*) separates easily from the meningeal layer that forms the sellar part of the medial wall (*yellow arrows*) and extends below the pituitary gland. The intercavernous sinuses cross the midline between the meningeal and endosteal layers of dura to communicate the paired CS.* A., *artery;* Ant., *anterior;* Car., *carotid;* Cav., *cavernous;* Clin., *clinoid;* CN, *cranial nerve;* Hyp., *hypophyseal;* Inf., *inferior;* Intercav., *intercavernous;* Ophth., *ophthalmic;* Pit., *pituitary;* Post., *posterior;* Seg., *segment;* Sphen., *sphenoidal.*

third of the lateral surface of the gland in 13 CSs (32.5%), in the middle third in 3 CSs (7.5%), in the inferior third in one CS (2.5%), and one CS (2.5%) had a protrusion in the anterior part of all three thirds. In six CSs, the intracavernous carotid indented the gland, and the tongue-like extension protruded laterally above the artery (*Figs. 2, D* and *E,* and *8A*). The sellar part of the medial wall of the CS, even in the areas covering the protrusions, was intact throughout without a defect through which the gland herniated.

The Intercavernous Sinuses and the Medial Wall

The periphery of the sellar part of the medial wall of the CS, at its junction with the sphenoidal part, was a frequent site of venous sinuses of varied size and distribution that crossed the midline interconnecting the paired CSs (*Figs. 2A, 4E, 6C,* and *8, B–D*). Intercavernous sinuses most frequently crossed the anterior and inferior margins of the sella and the gland (27 CSs). Other patterns included sinuses in the anterior, inferior, and posterior margins in seven CSs; in the anterior and posterior margins in three CSs, and only in the anterior margin in three CSs. The intercavernous sinuses were positioned between the meningeal and endosteal layers of dura that line the anterior and posterior walls and floor of the sella (*Fig. 2A*).

DISCUSSION

A dural wall was observed between the lateral surface of the pituitary gland and the CS in each of 40 CSs examined. This contrasted with results of some previous studies, which suggested an absence of dural wall between the gland and the CS (8, 32). Yokoama et al. (32) observed small histological defects in the sellar part of the medial wall in 3 of 30 sections of 10 adult cadavers, and the authors suggested that those defects are important sites of adenoma extension. We did not

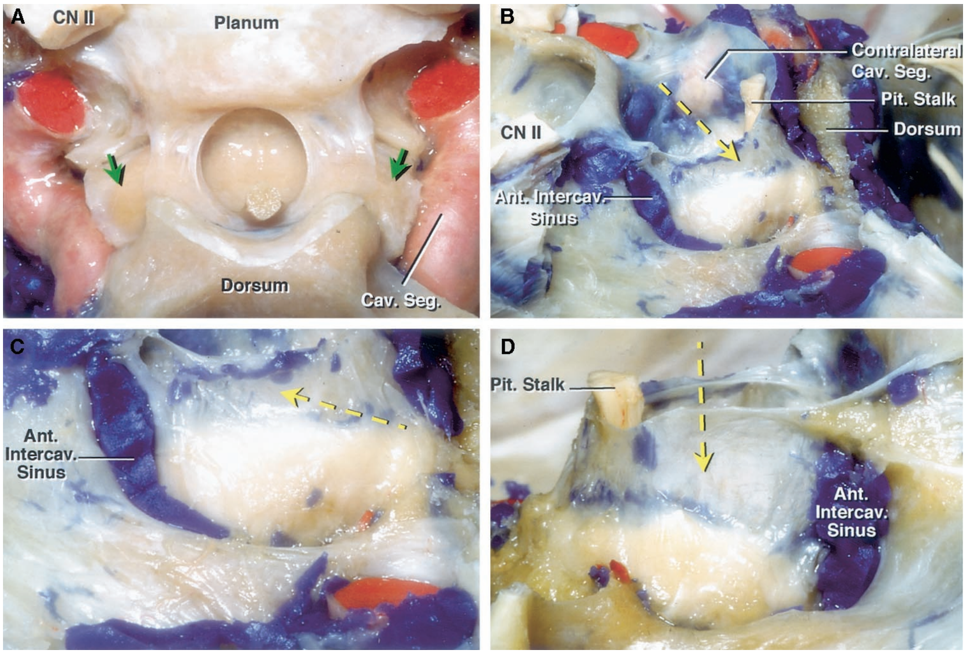

FIGURE 8. *Photographs of three specimens.* A, *posterosuperior view of a specimen with bilateral protrusions of the pituitary gland above the intracavernous carotids* (green arrows)*. The lateral wall of the CS, the anterior clinoid, the cranial nerves, and the clinoidal and supraclinoidal segments of the carotid artery have been removed on both sides.* B, *superolateral view of a left CS in another specimen, with a partially empty sella* (yellow arrow)*. The left intracavernous carotid, the material in the venous spaces, and the cranial nerves have been removed. The contralateral (right) intracavernous carotid artery is observed through the medial wall. The chiasmatic cistern extends into the sella* (yellow arrow) *and rests against the superior half of the sellar part of the medial wall.* C, *a large anterior intercavernous sinus crosses between the layers of dura lining the sellar walls. The sellar part of the medial wall is in direct contact with the inferior extension of the chiasmatic cistern into the partial empty sella* (yellow arrow)*.* D, *lateral view of the right medial wall of the specimen shown in* C. *This specimen presents a large anterior intercavernous sinus with extension of the chiasmatic cistern into the partial empty sella* (yellow arrow)*.* Ant., *anterior;* Cav., *cavernous;* CN, *cranial nerve;* Intercav., *intercavernous;* Pit., *pituitary;* Seg., *segment.*

find such defects in the 40 CSs examined under ×3 to ×40 magnification as provided by the operating microscope.

After the study of Umansky and Nathan (28, 29), it was widely accepted that the lateral wall and the roof of the CS are formed by dura that can be split into two layers. However, the characteristics of the medial wall remain poorly understood. The division of the medial wall in two different areas (sellar and sphenoidal areas) and the thinness of the sellar part aid in understanding the path of spread of pituitary tumors. The findings that the sellar part of the medial wall is formed by a single very thin layer, in contrast with the other, thicker walls of the CS that separate into two layers, and the fact that the lateral aspect of the pituitary fossa does not have an osseous wall similar to the anterior, inferior, and posterior surfaces of the fossa, explains the tendency of pituitary tumors to extend into the CS. The thin single layer nature of the medial wall also explains the difficulty of visualization of the medial wall on magnetic resonance imaging scans (6, 8, 15).

Furthermore, the results of this study support the notion that the dural layer that covers the osseous surfaces of the sella is a two-layered type: one layer of the endosteal type that faces the bone and a layer of the meningeal type that faces the gland. The endosteal layer originates at the upper border of the maxillary nerve, and the dura that wraps around the part of the gland facing the bony surfaces of the sella is a continuation of the meningeal layer in the diaphragm (*Fig. 2*). Thus, there is two-layered dura between the gland and the bony walls of the sella. In our dissections, the medial wall of the CS seems to be a continuation of the meningeal dura of the diaphragm sellae. With the exception of the sellar and sphenoidal parts of the medial wall, two dural layers cover the other four surfaces. This double layer lining the osseous sellar walls allows the interposition of venous sinuses along the anterior, inferior, and posterior margins of the sella. In our specimens, no venous sinuses crossed in the single-layered sellar part of the medial wall.

The relationship between the intracavernous carotid and the medial wall of the CS is important in managing pituitary tumors. There was direct contact between the intracavernous carotid and the normal pituitary gland in more than half (52.5%) of the specimens, with only the thin medial wall separating the two structures. In six CSs, a large pituitary protrusion extended laterally, crossing the superior surface of the intracavernous carotid. The intracavernous carotid also may indent and compress the lateral surface of the pituitary gland, causing protrusions of the gland that spread around the artery (*Figs. 2D* and *8A*). The preoperative diagnosis of CS invasion by pituitary adenomas has been the subject of several studies (6, 15, 16). Knosp et al. (15) proposed a classification based on coronal magnetic resonance imaging scans revealing the pituitary gland and the intracavernous carotid. The assumption was that protrusions of gland around a part of the arterial wall indicated cavernous extension, but in six CSs in our study, there were tongue-like protrusion of the normal gland around the artery. Cottier et al. (6) proposed use of the venous spaces of the CS as a method for evaluating CS invasion. If the medial venous space between the adenoma and the intracavernous carotid was observed on the coronal sections, the CS was considered free of invasion. However, we determined that 52.5% of the intracavernous carotid was in direct

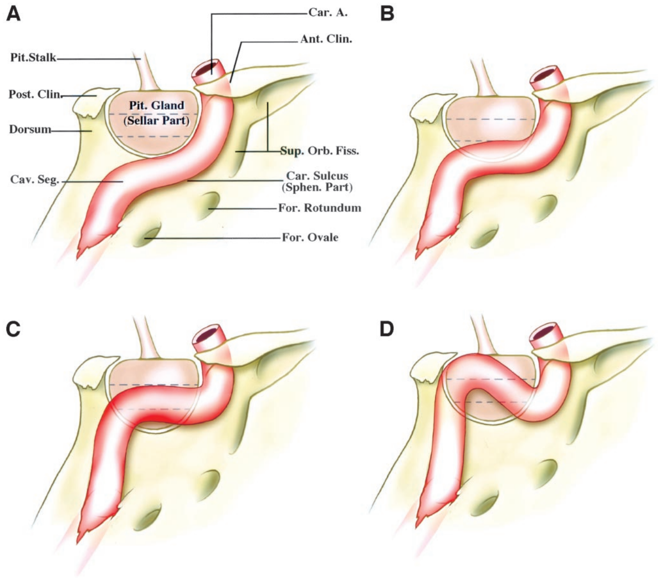

FIGURE 9. *Diagrams of lateral views of the right CS showing the different relationships between the intracavernous carotid and the sellar part of the medial wall.* A, *the intracavernous carotid courses on the carotid sulcus without any contact with the sellar part of the medial wall.* B, *the intracavernous carotid courses lateral to the inferior third of the gland and the medial wall.* C, *the intracavernous carotid courses lateral to some part of the middle and lower thirds of the gland and the medial wall.* D, *the intracavernous carotid courses lateral to all thirds of the gland and the medial wall.* A., *artery;* Ant., *anterior;* Car., *carotid;* Cav., *cavernous;* Clin., *clinoid;* Fiss., *fissure;* For., *foramen;* Orb., *orbital;* Pit., *pituitary;* Post., *posterior;* Seg., *segment;* Sphen., *sphenoidal;* Sup., *superior.*

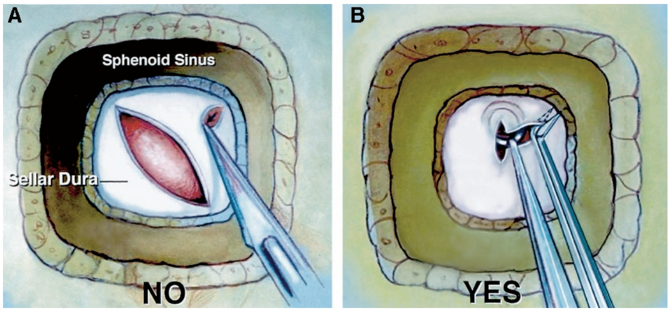

FIGURE 10. *Diagram illustrating the dural opening after a transsphenoidal approach to the sella.* A, *the use of a knife for opening the dura in corners of the anterior sellar exposure should be avoided because the intracavernous carotids can indent the lateral aspect of the gland or a tumor and may be damaged by the knife during the lateral part of the dural opening.* B, *the senior author (ALR) opens the dura beginning with a short vertical incision in the midline. A small, blunt, right-angle ring curette introduced through the small vertical dural opening separates the dura from the gland and tumor. After the dura is freed, a pair of 45-degree-angle scissors is selected to open the dura in an x-shaped cut from corner to corner. The dura should be elevated away from the gland with the blade of the scissors that is inserted inside the dura, so that the blade can be observed through the dura to ensure no other structure is cut.*

contact with the thin sellar part of medial wall. Cottier et al. (6) also proposed that invasion of the CS was highly probable if the venous plexus along the carotid sulcus was not observed. This cavernous venous plexus was observed in 97.5% (39 of 40 CSs) of the CSs we studied. Therefore, the thinness of the medial wall and the variability in the shape, size, and distribution of the venous plexus render it an unreliable method of identifying CS invasion on computed tomographic or magnetic resonance imaging scans.

That the intracavernous carotid was placed laterally at the level of the inferior third of the pituitary gland more frequently than lateral to the middle and superior thirds suggests that the risk of exposing or damaging the intracavernous carotid is greatest in exposing the area along the lower third of the sellar part of the medial wall of the CS. Care is required to avoid damage to the intracavernous carotid when opening the anterior sellar dura during transsphenoidal surgery, especially if there is protrusion of the artery into the gland. The use of a sharp knife to open the dura in the corners of the dural incision should be avoided (*Fig. 10A*). The senior author (ALR) performs a short vertical midline dural incision with a knife as the initial step. A small, blunt, right-angled ring curette is inserted through the small vertical dural opening, and the dura is separated from the anterior surface of the gland or tumor. After the dura is freed, a pair of 45-degree-angle alligator scissors, rather than a knife, is selected to open the dura in an x-shaped cut from corner to corner, because a pointed knife may damage the carotid artery in the far lateral corners of the exposure (*Fig. 10*). The sellar dura is lifted away from the gland or tumor with the distal blade of the 45-degree-angle scissors so that the scissors blade inside the dura can be observed not to extend into any structure deep to the dura. In the study specimens, we also noted that the inferior hypophyseal artery was in contact with the posteroinferior area of the sellar part of the medial wall, where it would be at risk of damage.

The pituitary gland was covered inside the pituitary fossa by a thin capsule separate from the medial wall of the CS. The nature and origin of the pituitary capsule have not been completely defined. Different authors support different theories (3–5, 26, 30, 31). Wisloki (30, 31) and Ciric (4) proposed that the pituitary capsule derives from the dura or pia arachnoid, respectively, whereas Chi and Lee (3) thought that it derives from the Rathke's pouch (1, 8, 18, 27, 32).

CONCLUSION

There is a dural medial wall of the CS that has two segments (sellar and sphenoidal) and is formed by just a thin layer of dura that cannot be separated surgically into two layers. The relationships between this wall and the structures around demonstrated a markedly variability.

REFERENCES

1. Alfieri A, Jho HD: Endoscopic endonasal cavernous sinus surgery: An anatomical study. **Neurosurgery** 48:827–837, 2001.

2. Bergland RM, Ray BS, Torack RM: Anatomical variations in the pituitary gland and adjacent structures in 225 human autopsy cases. **J Neurosurg** 28:93–99, 1968.
3. Chi JG, Lee MH: Anatomical observations of the development of the pituitary capsule. **J Neurosurg** 52:667–670, 1980.
4. Ciric I: On the origin and nature of the pituitary gland capsule. **J Neurosurg** 46:596–600, 1977.
5. Conklin JL: The development of the human fetal adenohypophysis. **Anat Rec** 160:79–92, 1968.
6. Cottier JP, Destrieux CD, Brunereau L, Bertrand P, Moreau L, Jan M, Herbreteau D: Cavernous sinus invasion by pituitary adenoma: MR imaging. **Radiology** 215:463–469, 2000.
7. Destrieux C, Kakou MK, Velut S, Lefrancq T, Jan M: Microanatomy of the hypophyseal fossa boundaries. **J Neurosurg** 88:743–752, 1998.
8. Dietmann JL, Kehrli P, Maillot C, Diniz R, Reis M Jr, Neugroschl C, Vinclair L: Is there a dural wall between the cavernous sinus and the pituitary fossa? Anatomical and MRI findings. **Neuroradiology** 40:627–630, 1998.
9. Dolenc VV: Direct microsurgical repair of intracavernous vascular lesions. **J Neurosurg** 58:824–831, 1983.
10. Dolenc VV: A combined epi- and subdural direct approach to carotid-ophthalmic artery aneurysms. **J Neurosurg** 62:667–672, 1985.
11. Hardy J: Transsphenoidal microsurgery of the normal and pathological pituitary. **Clin Neurosurg** 16:185–217, 1969.
12. Harris FS, Rhoton AL Jr: Anatomy of the cavernous sinus. **J Neurosurg** 45:169–180, 1976.
13. Inoue T, Rhoton AL Jr, Theele D, Barry ME: Surgical approaches to the cavernous sinus: A microsurgical study. **Neurosurgery** 26:903–932, 1990.
14. Kawase T, van Loveren HR, Keller JT, Tew JM Jr: Meningeal architecture of the cavernous sinus: Clinical and surgical implications. **Neurosurgery** 39: 527–536, 1996.
15. Knosp E, Steiner E, Kitz K, Matula C: Pituitary adenomas with invasion of the cavernous sinus space: A magnetic resonance imaging classification compared with surgical findings. **Neurosurgery** 33:610–618, 1993.
16. Korogi Y, Takahashi M, Sakamoto Y, Shinzato J: Cavernous sinus: Correlation between anatomic and dynamic gadolinium-enhanced MR imaging findings. **Radiology** 180:235–237, 1991.
17. Parkinson D: A surgical approach to the cavernous portion of the carotid artery: Anatomical studies and case report. **J Neurosurg** 23:474–483, 1965.
18. Parkinson D: Surgical anatomy of the lateral sellar compartment (cavernous sinus). **Clin Neurosurg** 36:219–39, 1990.
19. Renn WH, Rhoton AL Jr: Microsurgical anatomy of the sellar region. **J Neurosurg** 43:288–298, 1975.
20. Rhoton AL Jr: The cavernous sinus, the cavernous venous plexus, and the carotid collar. **Neurosurgery** 51[Suppl 1]:S1-375–S1-410, 2002.
21. Rhoton AL Jr: The sellar region. **Neurosurgery** 51[Suppl 1]:S1-335–S1-374, 2002.
22. Rhoton AL Jr, Hardy DG, Chambers SM: Microsurgical anatomy and dissection of the sphenoid bone, cavernous sinus and sellar region. **Surg Neurol** 12:63–104, 1979.
23. Sekhar LN, Burgess J, Akin O: Anatomical study of the cavernous sinus emphasizing operative approaches and related vascular an neural reconstruction. **Neurosurgery** 21:806–816, 1987.
24. Sen C, Chen CS, Post KD: *Microsurgical Anatomy of the Skull Base and Approaches to the Cavernous Sinus*. New York, Thieme, 1997, pp 42–62.
25. Seoane E, Rhoton AL Jr, de Oliveira EP: Microsurgical anatomy of the dural collar (carotid collar) and rings around the clinoid segment of the internal carotid artery. **Neurosurgery** 42:869–886, 1998.
26. Sunderland S: The meningeal relations of the human hypophysis cerebri. **J Anat** 79:33–37, 1945.
27. Taptas JN: The so-called cavernous sinus: A review of the controversy and its implications for neurosurgeons. **Neurosurgery** 11:712–717, 1982.
28. Umansky F, Nathan H: The lateral wall of the cavernous sinus. **J Neurosurg** 56:228–234, 1982.
29. Umansky F, Valarezo A, Elidan J: The superior wall of the cavernous sinus: A microanatomical study. **J Neurosurg** 81:914–920, 1994.
30. Wislocki GB: The meningeal relations of the hypophysis cerebri: Part I—The relations in adult mammals. **Anat Rec** 67:273–293, 1937.
31. Wislocki GB: The meningeal relations of the hypophysis cerebri: Part II—An embryological study of the meninges and blood vessels of the human hypophysis. **Am J Anat** 61:95–130, 1937.
32. Yokoyama S, Hirano H, Moroki K, Goto M, Imamura S, Kuratsu J: Are nonfunctioning pituitary adenomas extending into the cavernous sinus aggressive and/or invasive? **Neurosurgery** 49:857–863, 2001.

Acknowledgments

We thank Ronald Smith, the director of the microanatomy laboratory, for technical support and assistance, Laura Dickinson for help with the manuscript, David Peace and Margaret Barry for expertise in medical illustration, and Maristela Carvalho Costa for unconditional support and comprehension to accomplish this work.

COMMENTS

The never-ending story: what is the structure of the medial cavernous sinus wall? Of what is it composed? Strangely enough, little has been written about it; therefore, this contribution is of particular interest.

The topographic relationships between the pituitary capsule and the medial wall of the cavernous sinus and those of the internal carotid and the pituitary, which are of major interest to surgeons, are well described. However, I am doubtful as to whether it is legitimate to discuss a consistently present venous plexus within the cavernous sinus. In the overwhelming majority of our injected specimens, we observe wide lacunae rather than communicating veins.

Manfred Tschabitscher
Vienna, Austria

This is an excellent anatomic article that clearly describes and finely illustrates the microsurgical anatomy of the medial wall of the cavernous sinus. Instead of the two layers of dura that we observed in the lateral and superior walls of the cavernous sinus (1, 2), the authors demonstrated that the medial wall is formed by a single dural layer. The sellar part of the medial wall is formed by a very thin meningeal layer, which is a continuation of the upper layer of the diaphragm sellae. The sphenoidal part of the medial wall was observed to be formed by a single layer of endosteal dura mater.

In our own unpublished observations, we observed a double meningeal layer over the pituitary gland (sellar part of the medial wall of the cavernous sinus). This apparent discrepancy may be a result of the anatomic nature of the so-called pituitary capsule, which we consider a part of the wall at this level. We also observed fibrous bands inside the cavernous sinus anchoring the intracavernous internal carotid artery to the medial wall of the sinus. The significance of these bands is unclear. One explanation may involve the thrombosis and subsequent fibrosis of some venous channels that occurs in aging cadaveric specimens. This article is of clinical importance because of the close relationship of this area to intrasellar abnormalities frequently approached via the transsphenoidal route.

Felix Umansky
Jerusalem, Israel

1. Umansky F, Nathan H: The lateral wall of the cavernous sinus with special reference to the nerves related to it. **J Neurosurg** 56:228–234, 1982.
2. Umansky F, Valarezo A, Elidan J: The superior wall of the cavernous sinus: A microanatomical study. **J Neurosurg** 81:914–920, 1994.

Having spent more than 2 decades in anatomic studying central cranial base diseases anatomically and clinically, I am enthusiastic regarding dissection of the parasellar and sellar space . However, the authors' assertion that there are few reports of the medial wall, which constitutes not only the medial boundary of the cavernous sinus but also the lateral wall of the pituitary fossa, is incorrect. The authors cite their reports, of which two were published in 1998 and one in 2001. This membrane between the sellar and parasellar compartments was known much earlier, and it was described and well documented (1). The same is true of the intercavernous sinuses, which were grouped into three different groups: anterior, basal, and posterior channels connecting both parasellar compartments on the left and on the right through the sellar space around the pituitary body. It is true that visualization of these structures is better in the present report, and for this the authors deserve credit. It should be mentioned also that on the basis of the knowledge of existence of the medial wall–the membrane between the parasellar and sellar compartments–the spread of pituitary tumor has been well understood. Diagnostic sampling to obtain the level of pituitary hormones in venous blood has been practiced for several years. The spreading of pituitary tumors into the parasellar compartment(s) or in another direction has had a great impact on surgical approaches to these tumors, as has been reported repeatedly (2, 3).

The present report is excellent, but the authors' technical contribution would be as important if they were to admit the pioneering reports that demonstrated the existence of the wall, its physiological importance for flow of hormones, and its function as a possible barrier to tumor spread into and from the parasellar compartment. The authors also might reconsider their rigid statement that the medial wall is complete and has no fenestration. Incompleteness of the medial wall has been demonstrated (1, 3), and this characteristic is great practical importance in tumorous diseases. For unknown reasons, the relevant literature is missing.

Vinko V. Dolenc
Ljubljana, Slovenia

1. Dolenc VV: *Anatomy and Surgery of the Cavernous Sinus*. New York, Springer-Verlag, 1989, pp 122–128.
2. Dolenc VV: Transcranial epidural approach to pituitary tumor beyond the sella. **Neurosurgery** 41:542–552, 1997.
3. Dolenc VV, Rogers L: *Microsurgical Anatomy and Surgery of the Central Skull Base*. Wien, Springer-Verlag, 2003, pp 43–46.