Carotid Cave

Last Updated: April 7, 2021

ABSTRACT

OBJECTIVE: To further define the microanatomy of the carotid cave and its relationships to the adjacent structures.

METHODS: The cave and its relationships were examined in cadaveric specimens using 3 to 40× magnification.

RESULTS: The cave is an intradural pouch, found in 19 of 20 paraclinoid areas, that extends below the level of the distal dural ring between the wall of the ICA and the dural collar surrounding the ICA. The distal dural ring is tightly adherent to the anterior and lateral walls of the ICA adjacent the anterior clinoid process and optic strut but not on the medial and posterior sides of the artery facing the upper part of the carotid sulcus where the carotid cave is located. The superior hypophyseal artery frequently arises in the cave. The depth and circumferential length of the cave averaged 2.4 mm (range, 1.5–5 mm) and 9.9 mm (range, 4.5–12 mm), respectively. Aneurysms arising at the level of the cave, although appearing on radiological studies to extend below the level of the upper edge of the anterior clinoid, may extend into and may be a source of subarachnoid space.

CONCLUSION: The surgical treatment of aneurysms arising in the cave requires an accurate understanding of the relationships of the cave to the ICA, dural rings, and carotid collar.

INTRODUCTION

The carotid cave, named by Kobayashi et al in 1989, is a small recess or pouch that extends below the level of the distal (upper) dural ring on the

medial side of the wall of the internal carotid artery (ICA).1 The ICA enters the subarachnoid space and basal cisterns by passing through the proximal and distal dural rings, formed by the dura extending medially from the upper and lower surfaces of the anterior clinoid process to surround the artery. The clinoid segment of the ICA, which is the segment located between the proximal and distal dural rings, is positioned medial to and is exposed by removing the anterior clinoid process.2 The distal ring appears to form a tight collar around the artery, but careful inspection under the operating microscope reveals that there is often a recess, the carotid cave that extends between the arterial wall and the distal dural ring along the posteromedial aspect of the carotid artery. There are few reports concerning the microsurgical anatomy of the carotid cave. The objectives of this study were to further define the microanatomy of the carotid cave and its relationships to the adjacent structures.

METHODS AND MATERIALS

Twenty paraclinoid regions were examined in 10 cadaveric specimens by using 3 to 40x magnification of the surgical microscope after injecting the vessels with colored silicone. The carotid cave is a small recess outside the posteromedial side of the ICA that extends proximal to the distal dural ring (Figure 1). The length of the cave around the circumference of the ICA and the vertical depth of each cave were measured. The location of the carotid cave, when viewed from superior, were recorded in a clockwise manner with 12 o'clock being anterior, 3 o'clock lateral on the right ICA, 6 o'clock posterior, and 9 o'clock medial. The caves on the left side were converted to the right side for describing the location of the cave by the clock system.3 Other measurements taken include the distance between the origin of the ophthalmic artery and the anterior edge of where the ICA ascends through the distal dural ring; the distance between the origin of the ophthalmic artery and the site at which it penetrates the optic sheath to enter the orbital apex on the inferolateral aspect of the optic nerve; the length of the clinoid segment of the carotid between the proximal and distal dural rings or the lateral side of the ICA; and the diameter of the origin of the ophthalmic artery.

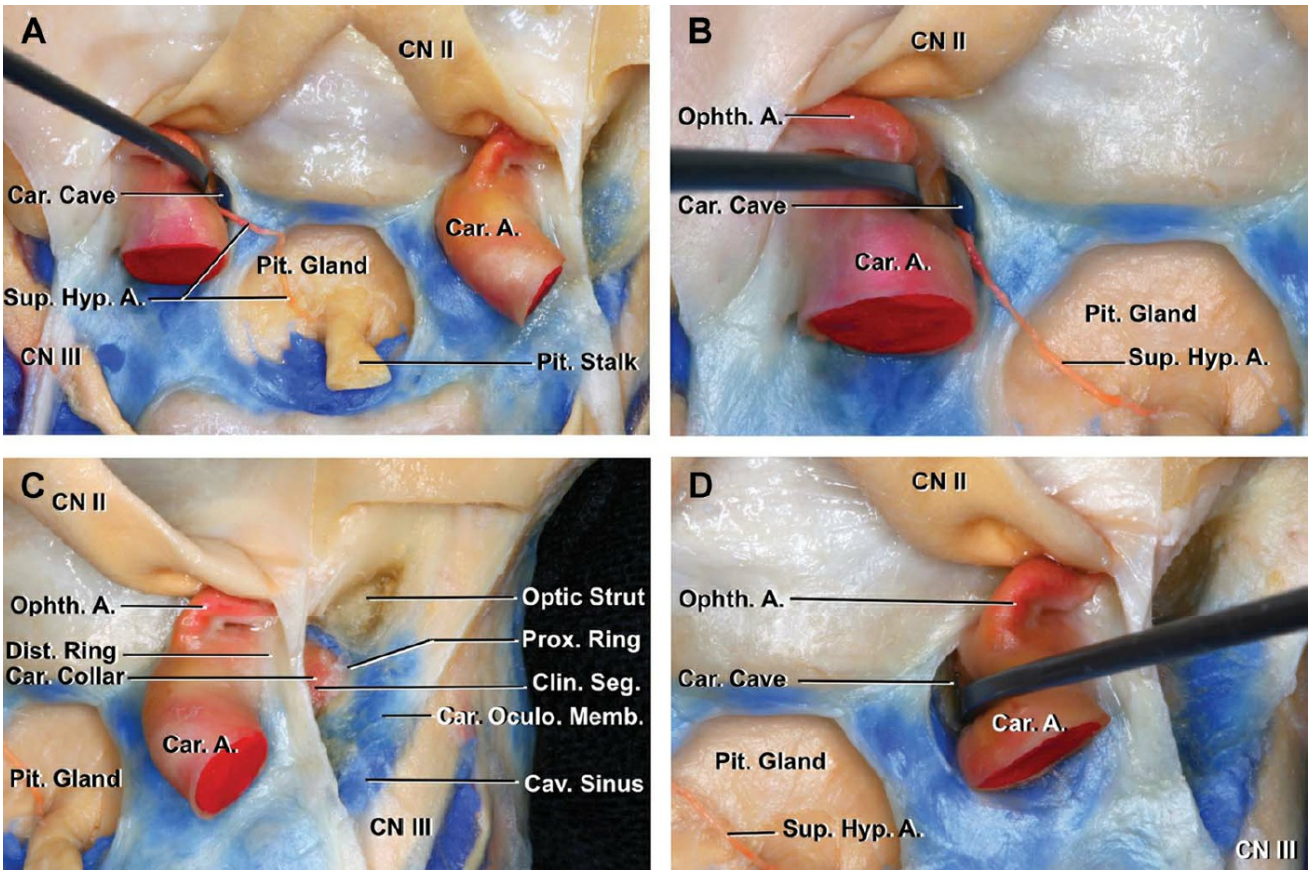


Figure 1. Superior view of the sellar region. A, the optic nerve and chiasm have been reflected forward to expose the ophthalmic arteries. A superior hypophyseal artery arises from the supraclinoid segment of the left ICA. The left ICA has been retracted laterally to expose the carotid cave, which extends below the level of the distal dural ring into the space between the carotid collar and the arterial wall. A superior hypophyseal artery arises in the upper part of the cave. B, enlarged view of the carotid cave. C, superior view of the right clinoid space created by removing the anterior clinoid process. The clinoid space is defined proximally by the carotid oculomotor membrane formed by the dura that separates the lower surface of the clinoid from the oculomotor nerve and extends medially to surround the carotid artery to form the proximal dural ring, and distally by the dura extending medially from the upper surface of the clinoid that surrounds the carotid artery to form the distal dural ring. From anteriorly to posteriorly the structures within the clinoid space include the optic strut, the carotid collar surrounding the ICA between the proximal and distal rings, and the anterior part of the roof of the cavernous sinus. D, the right carotid artery has been retracted laterally to expose the carotid cave. A., artery; Car., carotid; Cav., cavernous; Clin., clinoid; CN, cranial nerve; Dist., distal; Hyp., hypophyseal; Memb.,

membrane; Oculo., oculomotor; Ophth., ophthalmic; Pit., pituitary; Prox., proximal; Seg., segment; Sup., superior; ICA, internal carotid artery. (Images courtesy of AL Rhoton, Jr.)

RESULTS

Osseous Relationships

The carotid cave is positioned on the side of the carotid artery facing the carotid sulcus, a shallow groove on the lateral aspect of the body of the sphenoid bone, along which the ICA courses (Figure 2). The intracavernous carotid sits against and is separated from the carotid sulcus by the dura of the medial sinus wall. The carotid sulcus begins below and lateral to the dorsum sellae at the intracranial end of the carotid canal. After an initial short vertical section, the carotid sulcus turns forward to groove the body of the sphenoid immediately below the lateral edge of the sella, and turns upward and courses just anterior to the lateral edge of the anterior sellar wall and along the posterior edge of the optic strut and medial edge of the anterior clinoid process. The carotid sulcus, in well-pneumatized sphenoid bones, forms a serpiginous prominence that can be seen in the lateral wall of the sphenoid sinus below the pituitary fossa. The bone in the lateral wall of the sphenoid sinus may be thin or even absent in some areas, thus allowing the artery and dura lining the sulcus to rest against the sinus mucosa.

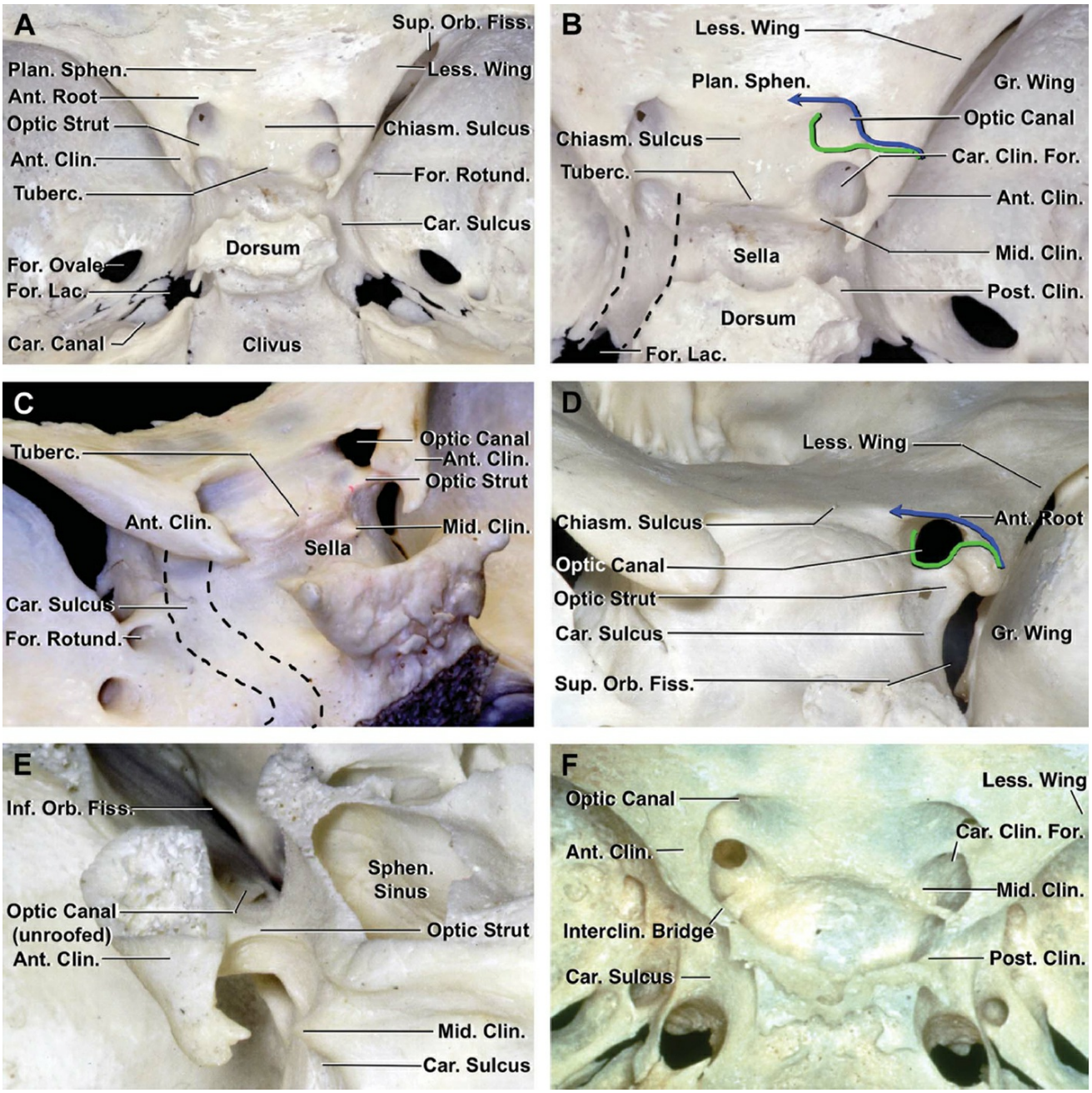


Figure 2. A, osseous relationship of the carotid cave, superior view. The clinoid segment of the ICA, the segment passing medial to the anterior clinoid process, is nearly encased by the anterior clinoid process laterally, the optic strut anteriorly, and carotid sulcus of the sphenoid bone medially. The carotid cave is located along the ICA wall facing the carotid sulcus. The base of the anterior clinoid is attached laterally to the medial end of the sphenoid ridge, formed by the lesser sphenoid wing, and attached medially to the anterior and posterior roots of the lesser wing. The anterior root of the lesser wing extends medially from the base of the anterior clinoid to the body of the sphenoid and forms the roof of the optic canal. The posterior root, called the optic strut, extends medially below the optic nerve to the body of the sphenoid bone and forms the floor of the optic canal. B, enlarged superior view. The chiasmatic sulcus,

a shallow depression between the paired optic canals, is bounded posteriorly by the tuberculum sellae and anteriorly by the planum sphenoidale. The tuberculum sellae is located in the midline along the ridge forming the posterior margin of the chiasmatic sulcus. The middle clinoid process projects upward on the medial side of the terminal part of the carotid sulcus toward the tip of the anterior clinoid process. An osseous bridge may extend from the middle clinoid to the anterior clinoid, thus creating a bony ring, referred to as a caroticoclinoidal foramen, through which the ICA passes. The dura lining the upper margin of the anterior clinoid extends medially above the optic nerve to form the falciform ligament (blue arrow) and slightly downward to line the upper margin at the optic strut and form the anterior part of the distal dural ring (green line). The margins of the left carotid sulcus are shown (interrupted lines). C, oblique posterior view. The carotid sulcus (interrupted lines) begins below and lateral to the dorsum sella, turns forward in a shallow groove below the lateral edge of the sellar floor, and turns upward to end medial to the anterior clinoid process. D, oblique posterior view of the right optic strut, the bridge of the bone that extends from the inferomedial aspect of the base of the anterior clinoid to the body of the sphenoid bone and separates the optic canal from the superior orbital fissure. The clinoid segment of the ICA rests against the posterior margin of the strut. The dura lining the upper margin of the anterior clinoid extends medial above the optic nerve to form the falciform ligament (blue arrow) and slightly downward to line the upper margin at the optic strut and form the anterior part of the distal dural ring (green arrow). The posterior surface of the strut widens as it slopes medially. E, superior view. The lesser sphenoid wing and the base of the left anterior clinoid, have been removed to unroof the optic canal and upper and posterior margin of the optic strut. The posterior margin of the optic strut is shaped to accommodate the anterior surface of the anterior bend of the intracavernous carotid. The pneumatization of the sphenoid sinus may extend through the strut into the anterior clinoid. The lateral wall of the sphenoid sinus forms the medial wall of the optic canal. F, superior view of specimen with bilateral caroticoclinoidal foramen and interclinoidal osseus bridges. An osseous bridge connects the tips of the anterior and

middle clinoid processes bilaterally, thus creating a bony ring around the artery called a caroticoclinoidal foramen, on each side. There are also interclinoidal osseus bridges connecting the anterior and posterior clinoid processes on both sides. Ant., anterior; Car., carotid; Car. Clin., caroticoclinoidal; Chiasm., chiasmatic; Clin., clinoid; Fiss., fissure; For., foramen; Inf., inferior; Interclin., interclinoidal; Lac., lacerum; Less., lesser; Mid., middle; Orb., orbital; Plan., planum; Post., posterior; Rotund., rotundum; Sphen., sphenoid, sphenoidale; Sup., superior; Tuberc., tuberculum; ICA, internal carotid artery. (Images courtesy of AL Rhoton, Jr.)

The anterior clinoid process projects posteriorly from the lesser wing of the sphenoid bone. The base of the anterior clinoid process has 3 sites of attachment to the adjacent sphenoid bone. Anteriorly and laterally, the base of the anterior clinoid process attaches to the medial edge of the lesser sphenoid wing. Medially, there are 2 attachment sites, one to the anterior and another to the posterior root of the lesser sphenoid wing. The anterior root of the lesser sphenoid wing extends medially from the base of the anterior clinoid process above the optic nerve and forms the roof of the optic canal. The posterior root, called the optic strut, extends medially below the optic nerve to the body of the sphenoid bone and forms the floor of the optic canal. The medial edge of the base of the anterior clinoid process forms the lateral edge of the optic canal. The medial margin of the optic canal is formed by the adjacent part of the body of the sphenoid bone. The anterior clinoid process is the attachment site of the anteromedial part of the tentorium and the anterior petroclinoid and interclinoid dural folds.[4]

The optic strut is a small bony bridge that extends medially from the inferomedial aspect of the base of the anterior clinoid process to the body of the sphenoid bone just in front of the carotid sulcus. It separates the medial part of the roof of the superior orbital fissure from the optic canal. The upper surface of the strut forms the floor of the optic canal, and the lower surface forms the superomedial edge of the superior orbital fissure. The strut sits at the junction of the orbital apex anteriorly with the superior orbital fissure and optic canal posteriorly. It is triangular in cross

section with superior, inferior, and posterior surfaces. The posterior surface of the optic strut is shaped to accommodate the anterior surface of the anterior bend of the clinoid segment of the carotid artery, which rests against the posterior surface of the optic strut as it ascends on the medial side of the anterior clinoid process.

The clinoid segment of the ICA, defined as the segment medial to the anterior clinoid process, is tightly surrounded on its lateral, medial, and anterior sides by osseous structures, leaving only a narrow space between the bone and artery. The lateral wall of the clinoid segment has tight dural attachments to the medial surface of the anterior clinoid process, and the anterior wall has dural attachments to the posterior aspect of the optic strut. The posterior aspect of the clinoid segment of the carotid artery is in contact with the cavernous sinus and not rigid bony structures. Medially, the clinoid segment faces the distal end of the carotid sulcus on the body of sphenoid where the dural anchoring of the artery is less than laterally and anteriorly where the artery faces the clinoid and optic strut.

Dural Relationships

The dural relationships important in planning surgical approaches to the paraclinoid area and cave are complicated (Figures 3 and 4). The dura, extending medially from the upper surface of the base of the anterior clinoid process, extends directly medial and attaches to the ICA at the axial level of the upper surface of the anterior clinoid. This dura also extends medially from the upper surface of the clinoid and above the optic nerve at the axial level of the upper surface of the anterior clinoid process to line the anterior root of the lesser wing and the posterior edge of the planum sphenoidale. However, the dura that extends medially from the upper surface of the anterior clinoid process to line the upper surface of the optic strut and form the anterior part of the distal dural ring, slopes downward as it proceeds medially, so that the medial part of the distal dural ring actually lies at an axial level lower than the upper surfaces of the anterior clinoid and optic canal. Just behind the anterior root of the lesser wing is a dural fold, the falciform ligament that extends above the optic nerve just proximal to the nerves entry into the optic canal. The

falciform ligament blends medially into the dura covering the planum sphenoidale. The dura lining the upper surface of the optic strut extends posterior and medial to the ICA near the distal end of the carotid sulcus to form the posterior and medial parts of the upper ring. The distal ring joins with the proximal dural ring at the posterior tip of the anterior clinoid process to form a single dural layer that blends posteriorly into the diaphragm sella (Figure 4).

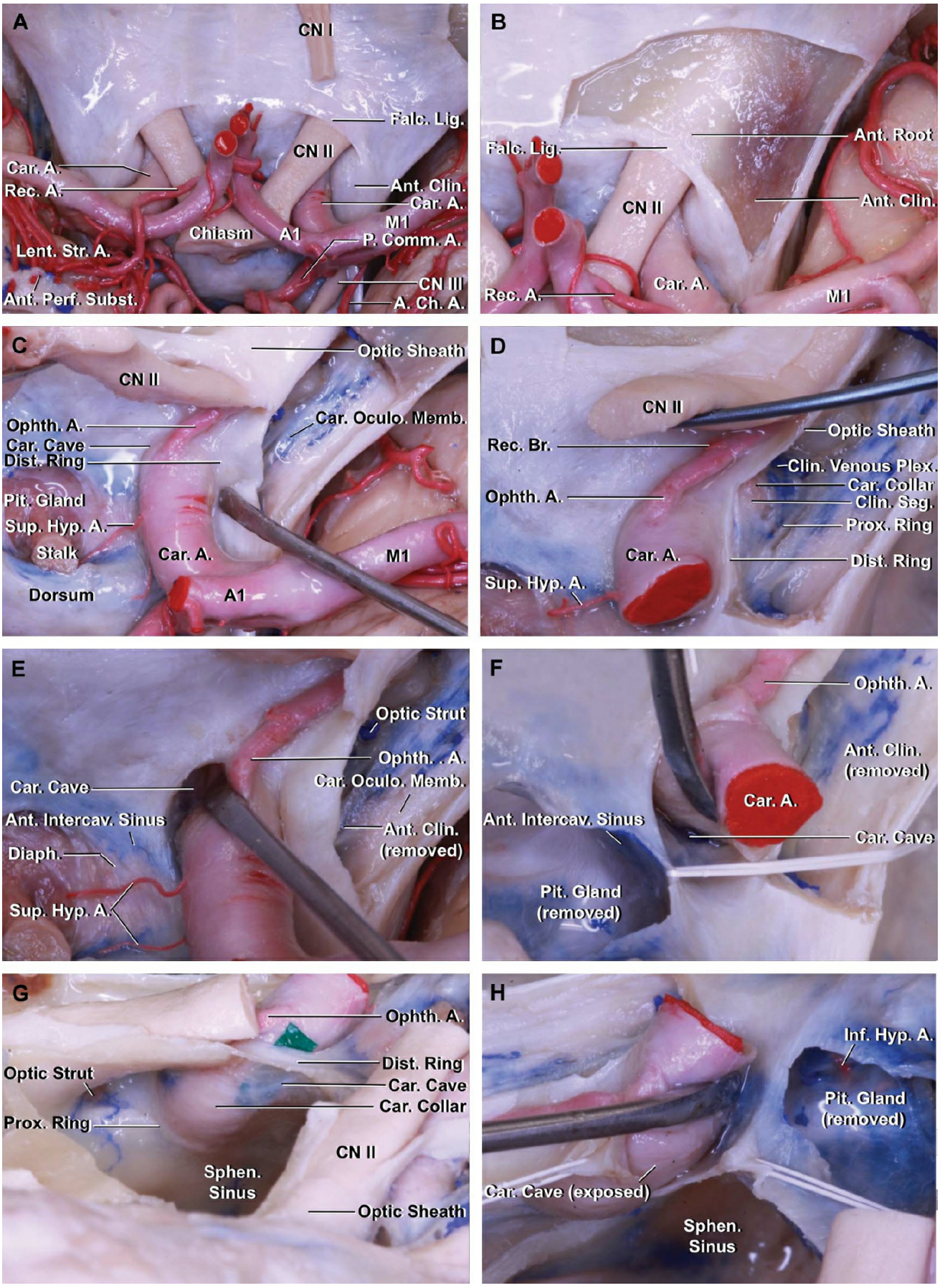


Figure 3. Superior view of the suprasellar area. A, the carotid artery enters the cranial cavity by passing along the medial side of the anterior clinoid process and below the optic nerve. The dura lining the upper surface of the anterior clinoid process extends medially in 2 directions:

the upper extension passes above the optic nerve to line the anterior root of the lesser wing of the sphenoid bone and form the falciform ligament; and the lower extension passes slightly downward to line the upper margin of the optic strut and form the anterior part of the distal dural ring. B, the dura lining the roof of the optic canal and anterior clinoid has been removed. The falciform ligament extends along the posterior edge of the anterior root of the lesser wing and above the optic nerve to blend medially into the dura mater covering the planum sphenoidale. C, the optic nerve and chiasm have been elevated to expose the pituitary stalk, ophthalmic artery, and a superior hypophyseal artery. The anterior clinoid process has been removed to expose the carotid oculomotor membrane formed by the dura lining the lower margin of the clinoid that separates the clinoid from the oculomotor nerve and extends medially to form the proximal dural ring. The dura that extends medially off the upper surface of the anterior clinoid process to line the upper surface of the optic strut also forms the anterior part of the distal dural ring, which defines the upper edge of the clinoid segment of the ICA. This dura forming the proximal ring slopes downward as it proceeds medially, so that the medial part of the distal dural ring actually lies at the level of the lower rather than the upper surface of the anterior clinoid. The lateral part of the distal ring near the origin of the ophthalmic artery tightly adheres to the lateral wall of the ICA. D, the clinoid segment of the ICA, located between the proximal and distal dural rings, has been exposed by removing the anterior clinoid. The ICA between the proximal and distal ring is enclosed in a thin layer of dura referred to as the carotid collar. The proximal ring is loosely applied to the clinoid segment and allows the clinoid venous plexus, a thin venous plexus that courses inside the carotid collar and outside the carotid wall, to communicate inside the ring with the anterior part of the cavernous sinus. E, the right ICA has been retracted laterally to expose the carotid cave. The dura along the posterior edge of the carotid cave contains the anterior intercavernous sinus. F, the clinoid segment has been retracted anteriorly to expose the part of the cave adjacent the diaphragm sellae. G, oblique anterior superior view. The roof of the sphenoid sinus has been removed to expose the medial side of the right ICA. A green piece has been inserted

into the carotid cave. The cave, the short downward directed pouch inside the carotid collar, extends below the level of the distal dural ring between the arterial wall and the carotid collar. H, the distal dural ring and the carotid collar have been divided and the dural flaps retracted with white silk to expose the carotid cave, the space between the carotid collar and the outer carotid wall that opens upward into the intradural space. A., artery; Ant., anterior; Br., branch; Car., carotid; Ch., choroidal; Clin., clinoid; CN, cranial nerve; Comm., communicating; Diaph., diaphragma; Dist., distal; Falc., falciform; Hyp., hypophyseal; Intercav., intercavernous; Lent. Str., lenticulostriate; Lig., ligament; Memb., membrane; Oculo., oculomotor; Ophth., ophthalmic; P., posterior; Perf., perforating; Pit., pituitary; Plex., plexus; Prox., proximal; Rec., recurrent; Seg., segment; Sphen., sphenoid; Subst., substance; Sup., superior; ICA, internal carotid artery. (Images courtesy of AL Rhoton, Jr.)

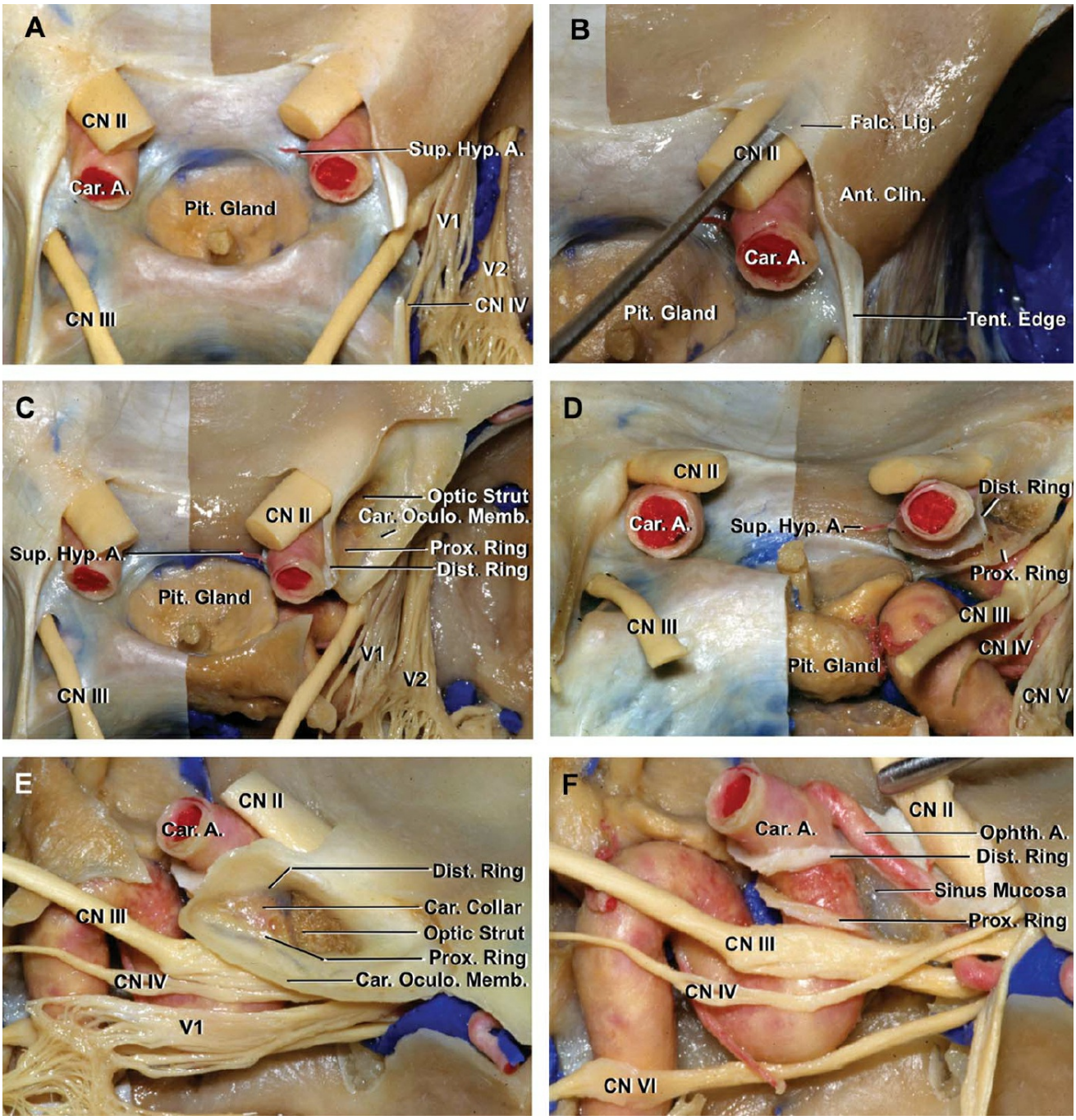


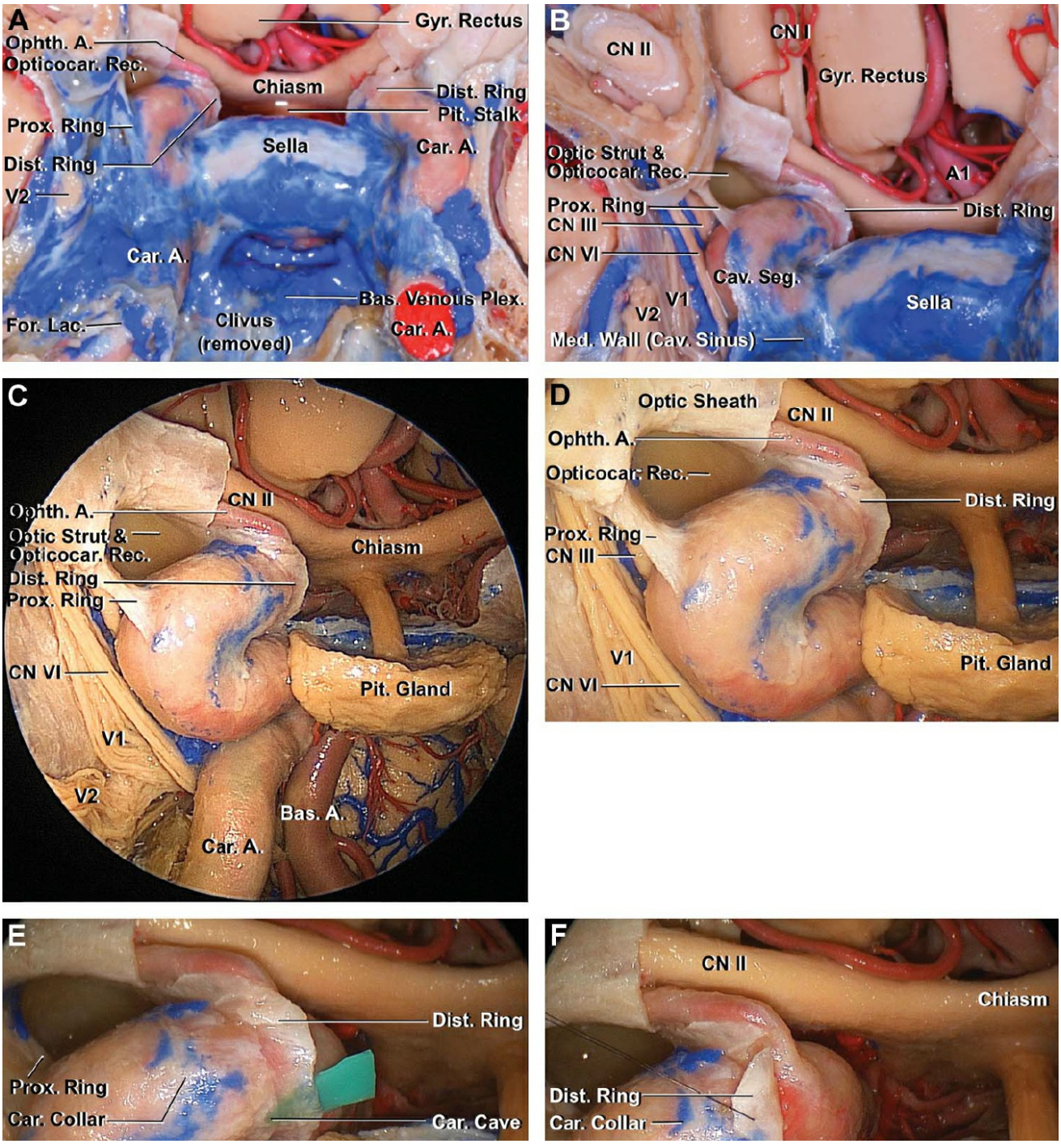
Figure 4. A, superior view of the sellar region. The dura roofing the anterior clinoid process, optic canal, and lateral wall of the right cavernous sinus has been removed. The stump of a right superior hypophyseal artery has been preserved. An absent diaphragm exposes the upper margin of the pituitary gland. B, a dissector has been advanced below the falciform ligament into the optic canal. C, the anterior clinoid process has been removed while preserving the carotid oculomotor membrane and the proximal and distal dural rings. The optic strut and clinoid segment are exposed in the space created by removal of the anterior clinoid process. The dura forming the proximal and distal rings join on the outer wall of the artery to form a dural collar, the carotid collar, around the ICA. The carotid cave is positioned along the medial

and posterior side of the ICA and extends downward between the distal dural ring and carotid collar and the outer wall of the artery. D, posterior superior view. The proximal and distal dural rings converge as they extend along the posterior margin of the carotid where they blend into a single layer forming the diaphragm sellae. E, lateral view of the proximal and dural rings. The proximal and distal dural rings converge posteriorly where both rings blend into the dural layer forming the diaphragm sellae. The clinoid segment of the carotid artery is surrounded by the carotid collar. F, lateral view of the cavernous sinus and the proximal and dural rings. The distal dural ring is formed by the dura extending medially from the upper surface of the anterior clinoid process. The proximal ring is formed by the dura that separates the lower margin by the anterior clinoid from the oculomotor nerve and extends medially around the ICA. In this specimen, the mucosa lining the sphenoid sinus extends into the optic strut, and in some cases, the sinus may pneumatize through the strut into the anterior clinoid process. A., artery; Ant., anterior; Car., carotid; Clin., clinoid; CN, cranial nerve; Dist., distal; Falc., falciform; Hyp., hypophyseal; Lig., ligament; Memb., membrane; Oculo., oculomotor; Ophth., ophthalmic; Pit., pituitary; Prox., proximal; Sup., superior; Tent., tentorial; ICA, internal carotid artery. (Images courtesy of AL Rhoton, Jr.)

The dural membrane that lines the lower margin of the anterior clinoid process and separates the anterior clinoid process from the oculomotor nerve extends medially to surround the ICA and forms the proximal dural ring. This membrane is called the carotid oculomotor membrane because it separates the lower surface of the clinoid from the upper margin of cranial nerve III. This membrane extends medially and forward to line the lower surface of the optic strut and forms the anterior part of the proximal ring. The carotid oculomotor membrane blends on the medial side of the artery into the dura lining the carotid sulcus, but does not form as distinct a proximal ring on the medial side of the artery facing the carotid sulcus as it does along the anterior and lateral margins of the artery.

The lateral part of the distal ring tightly adheres to the lateral wall of the ICA at the level of the upper margin of the clinoid, but on the posteromedial aspect of the ICA, the dura turns downward before

becoming firmly fixed to the ICA wall, thus creating a recess, the carotid cave, between the distal ring and outer carotid wall through which the arachnoid membrane can push to create both an intradural and subarachnoid space below the level of the distal ring (Figures 3 and 5). The cave, the downward-projecting recess, extends a variable distance below the level of the upper ring between the carotid artery laterally and the dura lining the carotid sulcus medially. The cave may extend down to near the lower ring and may be the site of an aneurysm-producing hemorrhage into the subarachnoid space even though its neck, on angiography, is positioned below the level of the upper margin of the anterior clinoid process.[3]



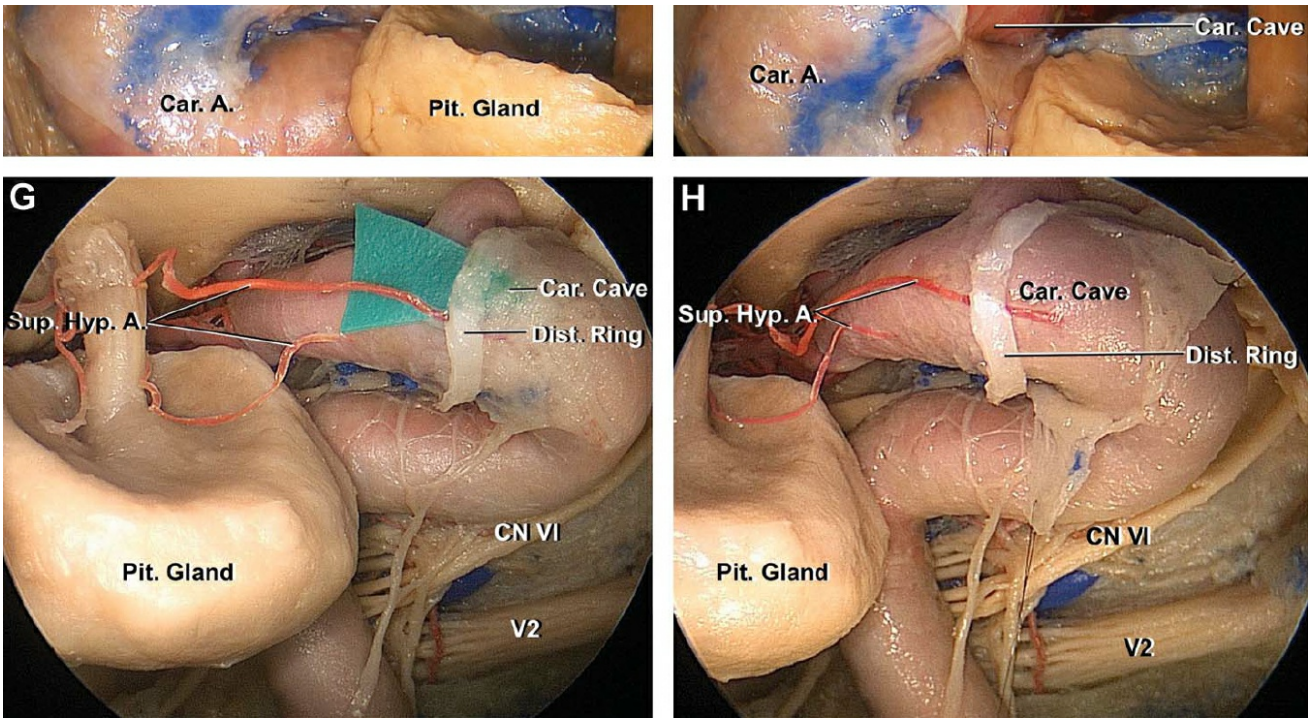


Figure 5. A, anterior view. Coronal section anterior to the sella and optic chiasm. The distal dural rings have been preserved. The walls of the sphenoid sinus has been removed to expose the anterior sella wall and the ICAs. The opticocarotid recess extends into the optic strut. The right proximal dural ring extends medially below the opticocarotid recess and does not form as distinct a proximal ring on the medial side of the artery as does the distal ring. The basilar venous plexus is the largest communicating channel between the cavernous sinuses. B, enlarged view of right parasellar area and the opticocarotid recess that extends into the optic strut. The dura lining the lower margin of the optic strut continues posteriorly to form the proximal dural ring. The dura on the upper surface of the optic strut extends around the ICA to form the distal dural ring. The abducens nerve passes around the lateral surface of the carotid and ascends medial to the ophthalmic nerve in the cavernous sinus. C, enlarged view after removing the dura in the sellar region and along the medial wall of the right cavernous sinus. The opticocarotid recess, a pneumatized diverticulum of the sphenoid sinus extends laterally into the optic strut, which separates the optic nerve in the optic canal from the nerves passing through the superior orbital fissure. The dura forming the proximal dural ring does not form as distinct a ring on the medial side of the artery adjacent the carotid sulcus as it does along the anterior and lateral surface of the artery. D, enlarged view. The distal dural ring encases the carotid artery just below the level of the origin of the

ophthalmic artery. The proximal ring blends into the dura surrounding the artery on the side of the carotid sulcus. E, a triangular piece of green material has been inserted into the carotid cave located between the dura forming the collar around the artery and the outer wall of the ICA. The proximal ring is not as distinct on the medial side of the artery as is the distal ring. F, the distal dural ring and upper medial part of the carotid collar has been incised and retracted with black sutures to expose the arterial wall in the carotid cave. G, transnasal exposure of the left parasellar region in another specimen. One superior hypophyseal artery arises in the carotid cave proximal to the distal ring and ascends to exit the cave and pass to the pituitary stalk. Another superior hypophyseal artery arises above the level of the distal dural ring. A triangular piece of green material has been placed inside the cave. H, the carotid collar, below the level of the distal ring, has been opened to expose the origin of the superior hypophyseal artery in the carotid cave. The proximal ring is not as distinct on the medial side of the ICA as is the distal ring. A., artery; Bas., basilar; Car., carotid; Cav., cavernous; CN, cranial nerve; Dist., distal; For., foramen; Gyr., gyrus; Lac., lacerum; Med., medial; Ophth., ophthalmic; Opticocar., opticocarotid; Pit., pituitary; Prox., proximal; Rec., recess; Seg., segment; ICA, internal carotid artery. (Images courtesy of AL Rhoton, Jr.)

The carotid cave was present in 19 of 20 paraclinoid areas examined in this study. The caves were located along the posteromedial aspect of the ICA and opened upward into the intradural space at the level of the distal ring. The caves were located between 3 o'clock and 11 o'clock along the circumference of the artery with the mean maximal depth at 7 o'clock in the area facing the carotid sulcus near the midpoint of their circumferential position around the ICA. In the 19 parasellar areas having a carotid cave, the average depth and length along the circumference of the artery was 2.4 mm (range, 1.5–5 mm), and 9.9 mm (range, 4.5–12 mm), respectively.

The carotid collar is formed by the dura of the lower ring turning upward to surround the segment of the ICA between the proximal and distal rings (Figure 3 to 5). The carotid collar does not tightly adhere to the wall of the

ICA until it reaches the upper dural ring, where it blends into and is continuous with the upper dural ring, which is tightly attached to the outer wall of the ICA except in the area facing the cave. The clinoid venous plexus, a thin venous plexus that courses between the carotid collar and the outer wall of the clinoid segment of the ICA, empties between the proximal ring and outer wall of the ICA into the anterior part of the cavernous sinus. The dura forming the collar is so thin that the arterial wall and the clinoid venous plexus can be seen through the thin dural collar. The carotid collar disappears posterior to the tip of the clinoid process, where the dura lining the upper and lower surfaces of the anterior clinoid process fuses into a single dural layer that forms the posterior part of the roof of the cavernous sinus and blends into the diaphragm sellae (Figure 4).

The carotid collar and the upper and lower rings slope downward as they extend medially from the anterior clinoid process. The distal dural ring is inclined downward as it proceeds in a posteromedial direction so that the anterolateral part is the highest part of the distal ring.[3] The separation between the upper and lower rings on the lateral side of the ICA is greater than along the posterior aspect of the ICA where the rings join and blend into the diaphragm. The distance between the upper and lower rings along the lateral aspect of the ICA averaged 3.6 mm (range, 2.5–5.2 mm).

Arterial Relationships

The 2 arteries arising from the ICA in the region of the carotid cave are the ophthalmic and superior hypophyseal arteries (Figures 3 and 5). It is the latter that may arise in the carotid cave. The superior hypophyseal arteries are a group of 1 to 5 (average, 2) small branches that arise from the ophthalmic segment of the ICA and terminate on the pituitary stalk and gland, but also send branches to the optic nerves and chiasm and the floor of the third ventricle.[5-7] Fifteen of the 20 paraclinoid areas in this study had small, medially directed arteries arising on the ventromedial side of the ICA near and in the carotid cave. These small arteries, the superior hypophyseal arteries, arose below the level of the distal dural ring in the carotid cave in 7 of the 20 paraclinoid areas examined.

The ophthalmic artery usually arises above the distal ring from the medial half of the superior aspect of the anterior bend of the ICA and passes forward under the optic nerve. The average diameter of the origin of the ophthalmic artery was 1.9 mm (range, 1.2–2.1 mm). The distance between the origin of the ophthalmic artery and the ICA adjacent the distal dural ring averaged 3 mm (range, 2–4 mm). The ophthalmic artery enters the intracranial end of the optic canal and penetrates the dura lining the floor of the optic canal to enter the orbit on the inferolateral aspect of the optic nerve. The distance between the arteries' origin and the point of dural penetration averaged 8.6 mm (range, 6–13 mm). The ophthalmic artery in the optic canal sometimes gives off a recurrent branch to the intracranial segment of the optic nerve. The ophthalmic artery may arise extradurally either from the clinoid or intracavernous segment of the ICA in 2% to 8% of cases, in which case the artery usually passes through the superior orbital fissure or an anomalous foramen in the optic strut to enter the orbit.[5,8,9] The ophthalmic artery may rarely originate from the middle meningeal or basilar artery.[10-12] The ophthalmic artery arose from the clinoid segment below the distal dural ring in 1 of 20 paraclinoid areas in this study.

Neural Relationships

The oculomotor nerve penetrates the roof of the cavernous sinus and courses along the inferomedial margin of the anterior clinoid process (Figures 3 to 5). The proximal dural ring separates the oculomotor nerve from the lower margin of the anterior clinoid process. The oculomotor nerve is surrounded by a short cistern in the roof of the cavernous sinus and does not become firmly incorporated into the lateral sinus wall until it reaches the posterior tip of the anterior clinoid process where the cistern ends.

The trochlear nerve enters the roof of the cavernous sinus posterolateral to the entry point of the oculomotor nerve and courses below the oculomotor nerve in the posterior part of the lateral wall. At the level of the base of the anterior clinoid process, the trochlear nerve courses upward along the lateral surface of the oculomotor nerve and turns

medially between the upper surface of the oculomotor nerve and the dura lining the lower margin of the anterior clinoid process in its course to the medial orbit and the superior oblique muscle.

DISCUSSION

The carotid cave, the small recess that extends proximal to the distal ring between the part of the carotid collar facing the carotid sulcus and the posteromedial part of the ICA wall, was first described by Kobayashi et al, who noted its relationship to aneurysms rising in the area.[1,13,14] The carotid cave has been identified in 68% to 77% of the cadaveric specimens.[15,16] The distal dural ring is formed by dura extending medially from the upper surface of the anterior clinoid, posteriorly from the upper surface of the optic strut, laterally from the distal end of the carotid sulcus, and anteriorly from the upper surface of the diaphragm sella and posterior clinoid process.[3] Hitotsumatsu et al [15] noted that the posteromedial aspect of the distal dural ring, the site of the carotid cave, is not in contact with any bony structures. The distal end of the osseous carotid sulcus usually ends proximal to the level of the distal dural ring, which provides the circumstance for the formation of the carotid cave, a finding consistent with our study. The dura adjacent the carotid cave contains the cavernous and anterior intercavernous sinuses. The carotid cave should not be confused with the clinoid space, which is created by removing the anterior clinoid process and is located lateral to the ICA and above the anterior part of the cavernous sinus.[17]

Of the 15 paraclinoid areas in our study, having medially directed branches near the level of the distal ring, 7 had small branches arising in the carotid cave below the level of the distal dural ring. These branches, all superior hypophyseal arteries, arose from the medial wall of the intradural paraclinoid ICA, and ranged in number from 1 to 5 in comparison wit 1.8 to 2.2 in the literature.[5,6] Tanaka et al[18] reported that aneurysms arising from the superior hypophyseal artery projected medially or inferomedially at the clinoid or infraclinoidal levels. All aneurysms at the infraclinoidal level arose at the origin of a superior hypophyseal artery. Therefore, carotid cave aneurysms constitute a

subgroup of superior hypophyseal lesions that originate from the most proximal part of the intradural carotid artery.[18] Some investigators defined carotid cave aneurysms as the most proximal intradural ICA lesion because they are embedded in the cave.[1,3]

The ophthalmic arteries usually arise below the optic nerve and above the distal dural ring from the medial third of the superior surface of the supraclinoid carotid and pass anterolaterally below the optic nerve to enter the optic canal and orbit. However, an extradural or interdural origin of the ophthalmic artery have also been reported.[8,19] In a previous study, 85.7% of the ophthalmic arteries originated from intradural ICA, 7.6% from extradural ICA, and 6.7% from the interdural level between the proximal and distal rings.[20] Clipping the neck of ophthalmic and superior hypophyseal aneurysms usually requires removal of the anterior clinoid process, mobilization of the ophthalmic artery and optic nerve, and division of at least part of the distal dural ring.[18] It may be difficult to differentiate an origin of the ophthalmic artery from the area just above the upper ring from one arising from the clinoid segment between the proximal and distal rings or below the proximal ring in the cavernous sinus. Therefore, extreme care should be taken to avoid injury to the ophthalmic artery during the sectioning of the distal dural ring if the ophthalmic artery is not visualized above the distal ring.

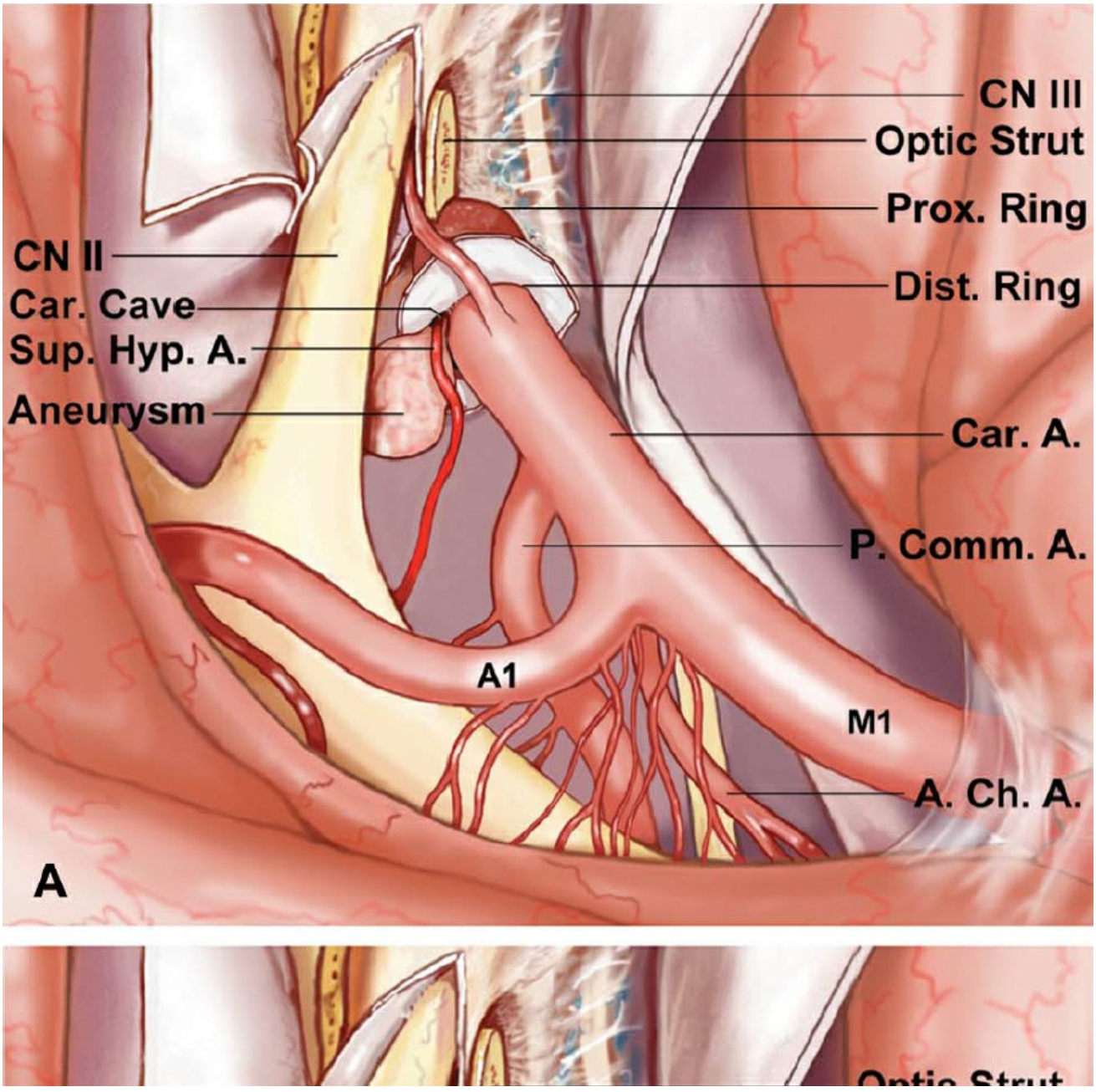
Approaches to the paraclinoid area are by either the pterional or orbitozygomatic approach. Opening the sylvian fissure and carotid cistern exposes the anterior clinoid process and the supraclinoid carotid. From here, the exposure is facilitated by several steps that aid in extending the exposure proximally along the ICA and around the optic nerve. These steps include removal of the clinoid process, opening part of the distal dural ring and unroofing the optic canal and opening the falciform ligament.

The anterior clinoid process is an obstacle to exposing lesions extending into the carotid cave. There is no consensus on whether to perform a clinoidectomy extradurally or intradurally. The proponents of extradural clinoidectomy note that the dura acts as a barrier protecting the aneurysm

during the drilling while reducing the possibility of the introduction of bone dust into the subarachnoid space.[21,22] In patients with a long anterior clinoid process or a giant paraclinoid aneurysm, intradural clinoidectomy is recommended.

If the anterior clinoid process is to be resected extradurally, a critical step is the division of the meningoperiorbital dural fold at the lateral edge of the superior orbital fissure. The meningoperiorbital dura at the lateral edge of the superior orbital fissure tethers the dura to the adjacent skull base and prevents exposure of the posterior part of the clinoid process. After division of the meningoperiorbital dural fold, the frontal and temporal dura can be peeled backward to expose the posterior tip of the anterior clinoid for clinoidectomy. The central cancellous bone of the clinoid process is drilled, leaving a thin shell of outer cortical bone. The remaining shell of the anterior clinoid process is separated from the surrounding dura with a fine curette, taking care to avoid damage to the carotid artery and optic nerve along the medial edge, and the oculomotor nerve along the lower edge of the clinoid. The posterior tip of the clinoid may project medially behind the carotid toward the middle clinoid, to which it may be united by an osseous bridge, thus forming a complete bony ring, called the caroticoclinoidal foramen, around the artery at the roof of the cavernous sinus. The anterior clinoid may also extend toward the posterior clinoid to which it may be joined by an interclinoidal osseous bridge between the anterior and posterior clinoids (Figure 2). Skeletonizing and unroofing the optic canal and opening the falciform ligament and optic sheath facilitates exposure of the origin of the ophthalmic artery below the optic nerve and a lesion in the cave on the medial side of the ICA. Opening the lateral part of the distal dural ring aids in exposure of the paraclinoid carotid artery. It is best to open the dura just outside the junction of the distal ring with the carotid collar, leaving a small cuff of dura attached to the artery rather than separating the adherent lateral part of the distal ring from the arterial wall, which may injure the artery and open into the venous spaces inside the carotid collar that communicate with the cavernous sinus. The incision in the distal ring is confined to the area anterior, lateral, and anteromedial to the ICA,

which may yield an exposure adequate to place a clip across the neck of an ophthalmic aneurysm or a temporary clip on the carotid artery below the origin of the ophthalmic artery. Opening the ring along the posterior part of the artery bordering the carotid cave will commonly open into the junction of the anterior intercavernous and the cavernous sinuses with brisk bleeding that can usually be controlled with gentle packing of a hemostatic agent. The most commonly used clip on a cave aneurysm is an angle ring (fenestrated) clip with straight or slightly curved blades advanced from distal to proximal along the ICA and around the neck of the aneurysm (Figure 6). Care is required to avoid occluding the origins of the ophthalmic, superior hypophyseal, posterior communicating, anterior choroidal, and perforating arteries that may not be seen on the lateral side of the exposed ICA.



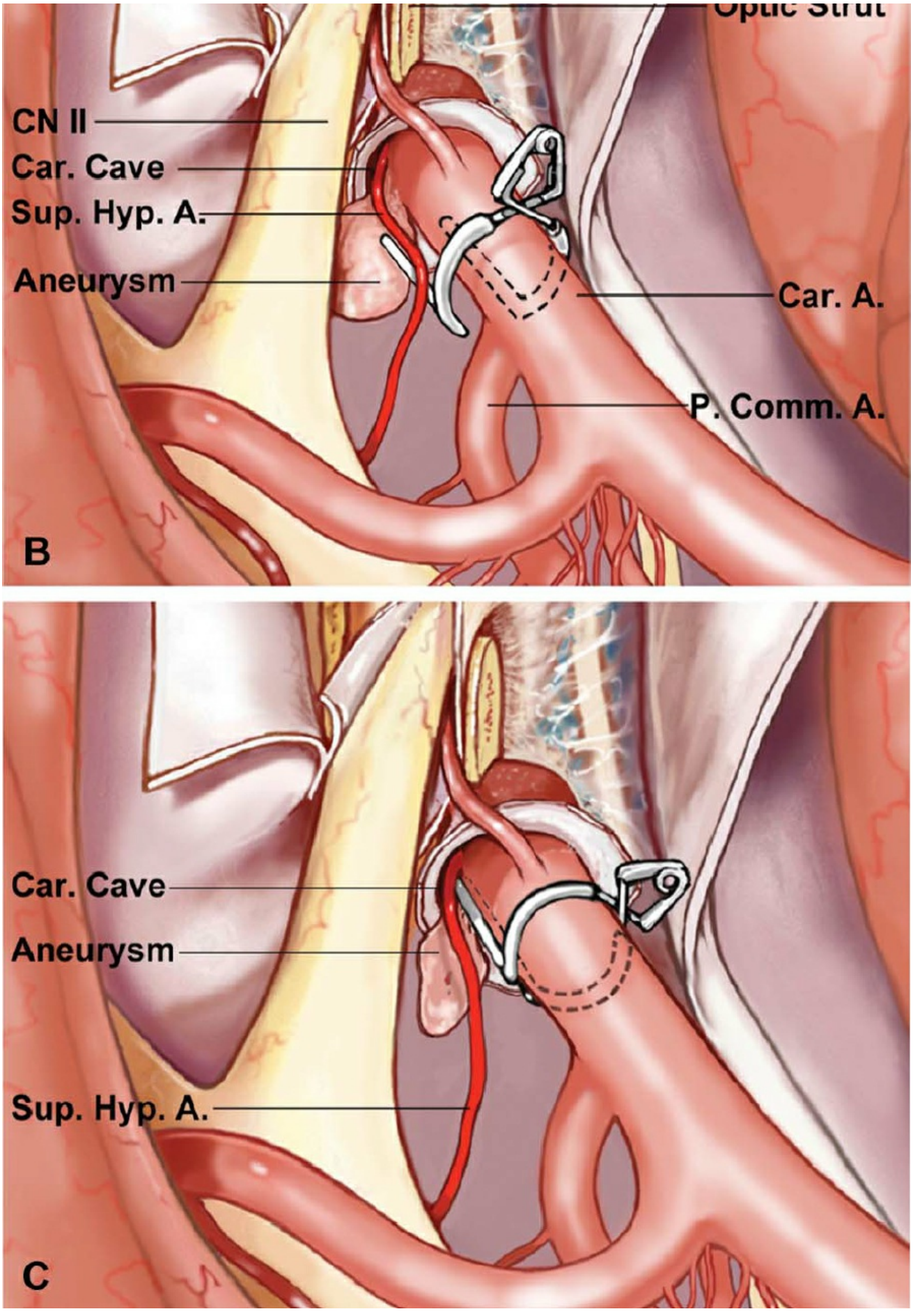


Figure 6. A, superolateral view of a right carotid cave aneurysm. The neck of the aneurysm is located in the cave below the distal dural ring just above the origin of the superior hypophyseal artery. The anterior clinoid

process has been removed and the dura forming the lateral and anterior margins of the distal ring has been opened. B, the most common clip application for this type of aneurysm is an angled fenestrated clip advanced from distal to proximal across the aneurysm neck. The margin of the cave has been retracted to expose the aneurysm neck. The clip is being advanced toward the aneurysm neck. Care is required to avoid occluding the origins of the ophthalmic, superior hypophyseal, posterior communicating, anterior choroidal, and perforating arteries arising from the ICA. C, the clip has been closed and the aneurysm has been deflated. There is a shadow across the ICA at the level at which the ring surrounded the artery before the dissection. A., artery; A.Ch.A., anterior choroidal artery; Car., carotid; CN, cranial nerve; P.Comm.A., posterior communicating artery; Dist., distal; Hyp., hypophyseal; Prox., proximal; Sup., superior; ICA, internal carotid artery.

The involvement of the optic canal by suprasellar tumors, such as tuberculum sella meningiomas, has been reported to occur in as many as 20% of patients.[23,24] It seems likely that suprasellar tumors, especially those involving the tuberculum sellae, medial part of the distal dural ring and optic canal, would extend into the carotid cave, but this has not been reported, possibly because of a lack of awareness of the cave.

CONCLUSION

The carotid cave is positioned on the posteromedial side of the ICA at the anterolateral edge of the diaphragm sella, and just below the distal dural ring. It extends downward between the outer wall of the ICA and the distal dural ring and carotid collar. The origin of superior hypophyseal arteries and neck of the superior hypophyseal aneurysm may arise in the carotid cave. It seems likely that tumors involving the tuberculum sellae and optic canal may also expand into the cave.

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Content from Joo W, Funaki T, Yoshioka F, Rhoton AL, Jr. Microsurgical anatomy of the carotid cave. *Oper Neurosurg (Hagerstown)*

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