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Anatomic Report

Microsurgical Anatomic Features and Nomenclature of the Paraclinoid Region

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Abstract

OBJECTIVE:

We describe the detailed microsurgical anatomic features of the clinoid (C5) segment of the internal carotid artery (ICA) and surrounding structures, clarify the anatomic relationships of structures in this region, and emphasize the clinical relevance of these observations. Furthermore, because the nomenclature of the paraclinoid region is confusing and lacks standardization, this report provides a glossary of terms that are commonly used to describe the anatomic features of the paraclinoid region.

METHODS:

The region surrounding the anterior clinoid process was observed in 70 specimens from 35 formalin-fixed cadaveric heads. Detailed microanatomic dissections were performed in 10 specimens. Histological sections of this region were obtained from the formalin-fixed cadaveric specimens.

RESULTS:

The clinoid segment of the ICA is the portion that abuts the clinoid process. This portion of the ICA can be directly observed only after removal of the clinoid process. The dura of the cavernous sinus roof separates to enclose the clinoid process. The clinoid segment of the ICA exists only where this separation of dural layers is present. Because the clinoid process does not completely enclose the ICA in most cases, the clinoid segment is shaped more like a wedge than a cylinder. The outer layer of the dura (dura propria) is a thick membrane that fuses with the adventitia of the ICA to form a competent ring that separates the intradural ICA from the extradural ICA. The thin inner membranous layer of the dura loosely surrounds the ICA throughout the entire length of its clinoid segment. The most proximal aspect of this membrane defines the proximal dural ring. The proximal ring is incompetent and admits a variable number of veins from the cavernous plexus that accompany the ICA throughout its clinoid segment.

CONCLUSION:

The narrow space between the inner dural layer and the clinoid ICA is continuous with the cavernous sinus via an incompetent proximal dural ring. This space between the clinoid ICA and the inner dural layer contains a variable number of veins that directly communicate with the cavernous plexus. Given the inconstancy of the venous plexus surrounding the clinoid ICA, we think that categorical labeling of the clinoid ICA as intracavernous or extracavernous cannot be justified.

Key words: Anatomy, Anterior clinoid process, Carotid cave, Cavernous sinus, Distal dural ring, Internal carotid artery, Proximal dural ring

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The clinoid (C5) segment of the internal carotid artery (ICA) ([4]) corresponds to the "knie der carotis," which was originally defined angiographically by Fischer ([14]). Since the illustration by Fischer of this portion of the ICA, this segment of the ICA has been largely unrecognized or overlooked; it has also been identified by numerous authors using various terms and/or descriptions (Table 1) ([4,10,14,18,24,26,32–34,39,43,49,50,52,55]). Lasjaunias and Santoyo-Vazquez ([33]) introduced the term clinoid segment in their classification of the ICA on the basis of its embryological development. Recently, Bouthillier et al. ([4]) proposed a new nomenclature for segments of the ICA. They defined the clinoid segment of the ICA as the portion of the ICA extending between the proximal and distal dural rings and they reassigned the segment as C5, using a numerical scale that reflects the direction of blood flow. This segment of the ICA, which is approximately 5 mm in length ([7,24]), is commonly encountered during cranial base procedures.

TABLE 1.

Various Terms for the Clinoid (C5) Internal Carotid Artery[a]

TABLE 1. Various Terms for the Clinoid (C5) Internal Carotid Artery[a]

Series (Ref. No.)	Term
Fischer, 1938 (14); Perneczky et al., 1985 (43); Lang and Kageyama, 1990 (32)	Anterior knee of the ICA
Yaşargil et al., 1977 (55)	Infraclinoid ICA
Gibo et al., 1981 (18); Dolenc, 1985 (10); Matsuoka et al., 1986 (34); Sekhar et al., 1987 (49)	Part of the cavernous ICA
Knosp et al., 1988 (26); Nutik, 1988 (40); Umansky et al., 1994 (52)	Paraclinoid ICA
Lasjaunias and Santoyo-Vazquez, 1984 (33); Inoue et al., 1990 (24); Bouthillier et al., 1996 (4); Seoane et al., 1998 (50)	Clinoid ICA

[a] ICA, internal carotid artery.

Surgical removal of the anterior clinoid process (ACP), i.e., anterior clinoidectomy, exposes the clinoid (C5) segment of the ICA. Since the original clinical report by Dolenc ([10]), anterior clinoidectomy has become an essential approach to enter the anterior cavernous sinus, to expose aneurysms of the C4–C6 segments of the ICA ([5,9,10,19,21,27,34,37–40,43,55]), and to resect the dural attachment and hyperostotic bone of clinoid, medial sphenoid wing, and cavernous sinus meningiomas ([1,56]). Recently, anterior clinoidectomy has been advocated as part of a transcavernous approach to produce wider exposure of basilar artery aneurysms of the upper clival region ([6,35]). The microanatomic relationships of the clinoid (C5) segment are complicated, and an understanding of these anatomic features is necessary for successful surgery in this region. The cavernous (C4), clinoid (C5), and supraclinoid (C6) segments of the ICA, the ophthalmic and superior hypophyseal arteries, Cranial Nerves II and III, and multiple dural reflections, including the proximal and distal dural rings, the diaphragma sellae, the anterior petroclinoid and interclinoid folds, the walls of the anterior cavernous sinus, and the dural wall of the superior orbital fissure, are located in an area of approximately 1 cm^3. Several authors previously described the anatomic features of this region ([4,5,7,8,11,13,24–27,30,31,36,39,47,52]). However, a more detailed microanatomic understanding of the relationships between the ICA and its dural rings and between the ICA and the anterior cavernous sinus and an answer to the basic question of whether the clinoid (C5) segment is intracavernous ([9,10,24,26,43,46,50,55]) or extracavernous ([5,7,11,32,39,52]) could enhance the ability of neurosurgeons to navigate within this limited but critical area. In this article, we present a detailed microsurgical anatomic description of the clinoid (C5) segment of the ICA and its surrounding structures and we clarify the anatomic relationships of structures in this region, with emphases on clinical relevance. Furthermore, the recent interest in this region has yielded a number of terms that have been imprecisely defined and improperly applied in the literature. In an effort to codify the anatomic features of this region, we offer a glossary of anatomic terms (see Appendix).

MATERIALS AND METHODS

The region of the ACP was examined in 70 specimens obtained from 35 formalin-fixed human cadaveric heads. In 10 specimens, the arterial and venous systems were injected, under pressure, with colored silicone rubber (Dow Corning, Midland, MI), via the ICAs and internal jugular veins, respectively. Microanatomic dissections were performed with magnification (×3 to ×40), using a Contraves Zeiss microscope (Carl Zeiss Co., Oberkochen, Germany).

Four cadaveric specimens were prepared for histological study. The region of the ACP was removed *en bloc* and placed in 10% neutral buffered formalin for 2 weeks. Specimens were decalcified in Decalcifier I and II (Surgipath, Richmond, IL) for 4 weeks and were then dehydrated, processed in a Citadel 2000 processor (Shandon, Pittsburgh, PA), and embedded in paraffin. Sections (6 μm) were obtained using a Reichert-Jung 2055 microtome (Cambridge Instruments, Heidelberg, Germany) and were heated at 65°C for 98 hours. Sections were stained with hematoxylin and eosin and with Gomori's one-step trichrome stain with aniline blue.

RESULTS

Bony anatomic features

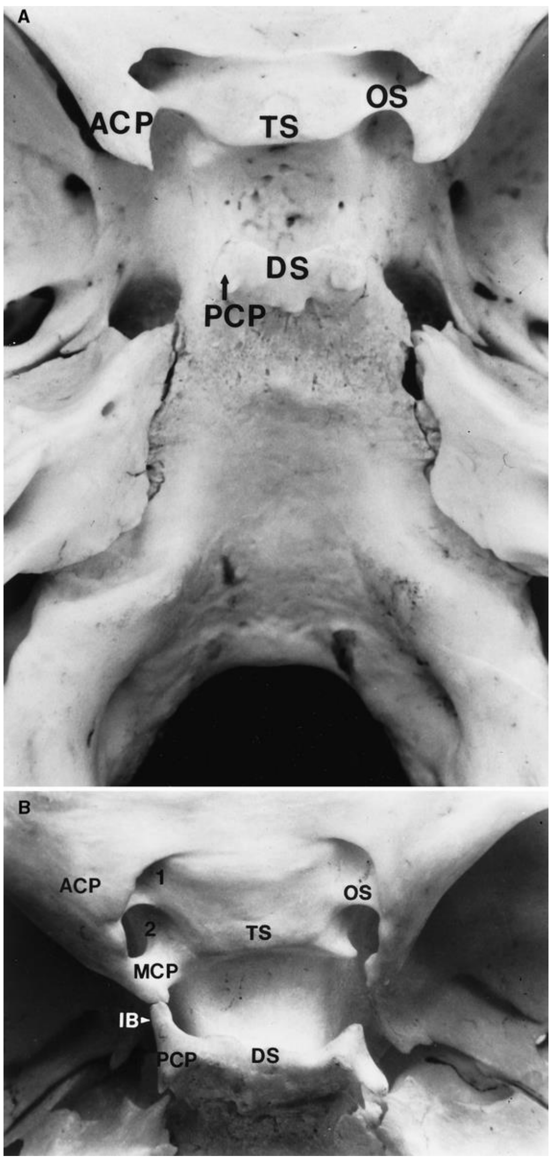
Important bony anatomic features associated with the clinoid (C5) segment of the ICA include structures of both the anterior and middle cranial fossae. The sphenoid bone consists of a cubicle, from the sides of which arise the greater wings (alisphenoids) and from the anterior aspect of which arise the lesser wings (orbitosphenoids). The body consists of two inseparable parts, i.e., an anterior presphenoid portion, which is in the anterior and middle cranial fossae, and a posterior basisphenoid bone, which constitutes the center of the middle cranial fossa. The posterior aspect of the presphenoid portion is marked by the planum sphenoidale (jugum sphenoidale), limbus sphenoidale, chiasmatic sulcus, and tuberculum sellae. The lesser wings spread from the presphenoid portion and cover the apices of the orbit. The superior, or cerebral, surface of the body of the sphenoid bone contains the hypophyseal fossa (i.e., sella turcica). Behind the hypophyseal fossa is the dorsum sellae, a raised plate of bone that is continuous with the basioccipital bone or clivus. At the lateral aspects of the dorsum sellae, pointing both anteriorly and posteriorly, are the posterior clinoid processes, to which the tentorium cerebellae is secured (Fig. 1 A).

At each lateral surface of the sphenoid body is the carotid sulcus (groove) for the ICA. This sulcus is well marked only at its posterior aspect, where the artery enters from the petrous apex.

The carotid sulcus is bounded medially by a small tubercle, the petrosal process, and laterally by a bony projection, the lingula, which projects posteriorly (to variable lengths) across the foramen lacerum.

FIGURE 1.

Photographs illustrating the bony anatomic features of the sellar region. *PCP*, posterior clinoid process; *OS*, optic strut; *TS*, tuberculum sellae; *DS*, dorsum sella; *IB*, interosseous bridge; *1*, optic foramen; *2*, caroticoclinoid foramen. *A*, typical configuration of the sellar region (reprinted with permission from the Mayfield Clinic). *B*, superior aspect of the sellar region, showing a specimen with a caroticoclinoid foramen and an interosseous bridge (reprinted with permission from, van Loveren HR, Guthikonda M, El-Kalliny M, Keller JT: Surgery of the cavernous sinus, in Wilkins RH, Rengachary SS [eds]: *Neurosurgery*. New York, McGraw-Hill, 1996, vol 2).



The ACP is a posterior and medial continuation of the lesser sphenoid wing, and it is connected to the body of the sphenoid bone (basisphenoid bone) by two roots, i.e., a superior root and an inferior root. The superior (anterior) root is flat, forms the roof of the optic canal, and continues as the planum sphenoidale. The inferior (optic strut) root forms the lateral and ventral walls of the optic canal and connects the lesser wing with the basisphenoid bone. The ACP is normally composed of a thin shell of cortical bone and an inner trabecular (cancellous) bone. Occasionally, the ACP contains air cells that communicate with the sphenoid sinus via the optic strut ([16]). The length of the ACP was measured in dry crania (n = 135), from the level of the optic canal roof to the tip of the process. The ACP exhibited an average length of 7.7 mm (range, 3–8 mm) and a width of 4 mm (range, 4–7 mm) ([10]).

The middle clinoid process (MCP) is an often-overlooked bony projection that arises from the lateral surface of the body of the sphenoid bone, approximately 1 to 2 mm below the tuberculum sellae. It was identified in 75% of the crania examined. A complete bony fusion between the ACP and MCP can exist, forming a caroticoclinoid foramen (13%). Incomplete fusion of the ACP and MCP was noted in 24% of the crania examined (Fig. 1B).

An interclinoid osseous bridge (a bony connection) can form between the ACP and the posterior clinoid processes. This connection was identified in eight (6%) crania. It was present unilaterally in three crania and bilaterally in five crania. In all of the crania examined, an interosseous bridge was associated with a caroticoclinoid foramen (either complete or incomplete) (Fig. 1B).

Dural rings and folds

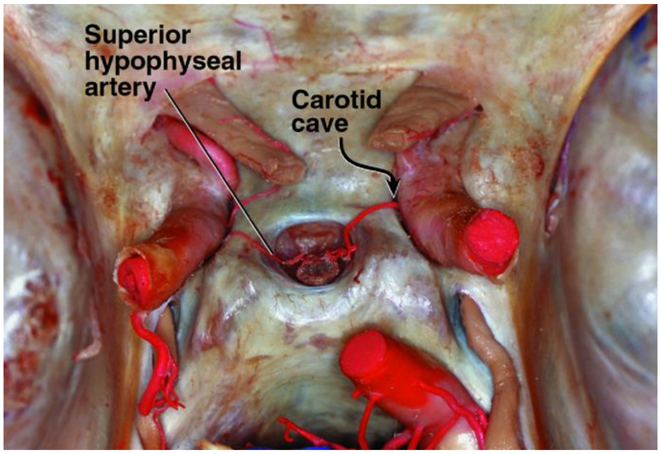
The roof of the cavernous sinus is formed by two layers of dura mater. An outer dural layer covers the superior surface of the ACP, and an inner dural layer covers the inferior surface of this process. These two dural layers thus separate to envelop the ACP. An anterior clinoidectomy creates a space, which is referred to as the clinoid space ([49]). It should be understood that the clinoid space is strictly a potential space that is filled with the clinoid process in undisturbed crania.

The outer dural layer of the roof of the cavernous sinus, which overlies the superior surface of the ACP, continues medially and fuses with the adventitia of the ICA to form the distal dural ring. In addition to the distal dural ring, the outer dural layer covers the planum sphenoidale and tuberculum sellae and forms the falciform ligament, the dural sheath of the optic nerve, and the diaphragma sellae.

The distal dural ring is tightly bound to the ICA. Therefore, blunt dissection of the distal dural ring from the ICA is nearly impossible without tearing of the adventitial layer. The anterior petroclinoid ligament is a dural fold that connects the petrous apex with the ACP, merges with the distal dural ring at its lateral aspect, and strengthens that portion of the dural ring. The distal ring is not a true circle; rather, it is eccentric, which often results in the creation of a small subarachnoid recess along the medial aspect of the ICA, just as it penetrates the dura. This subarachnoid pouch is known as the carotid cave ([27]). A carotid cave was macroscopically identified in 54 of 70 (77%) specimens (Fig. 2).

FIGURE 2.

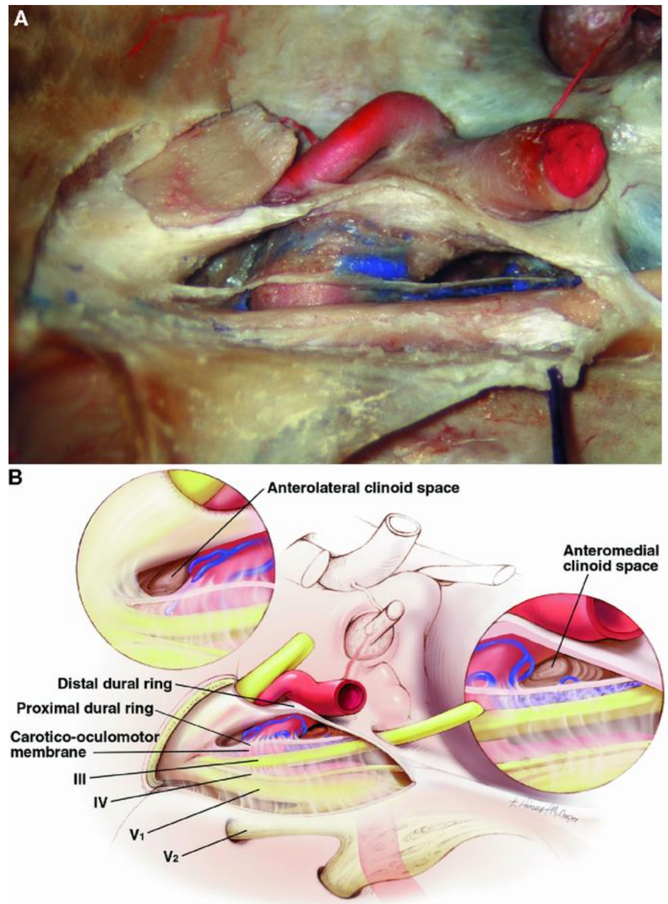
Photograph of a cadaveric specimen, showing a superior view of the sellar region. A carotid cave can be observed on the right, and one of three superior hypophyseal arteries is identified on the left (reprinted with permission from the Mayfield Clinic).



Mobilization of the outer dural layer of the roof of the cavernous sinus reveals the inner dural layer, which is thin and occasionally fenestrated ([11,52]). The interclinoid ligament connects the ACP to the posterior clinoid processes and merges with the inner layer along its entire length, conceptually dividing the roof of the cavernous sinus into two triangular areas, i.e., a posterolaterally placed oculomotor trigone and an anteromedially placed carotid trigone ([52]). Within the oculomotor trigone, the inner layer contributes to the formation of the dural sheath of the oculomotor nerve and continues as the inner layer of the lateral wall of the cavernous sinus. Anteriorly, the inner dural layer covers the inferior surface of the ACP, surrounds the ICA to form the proximal dural ring, and continues along the clinoid (C5) segment to fuse with the distal dural ring. The clinoid (C5) segment of the ICA is thus wrapped in a dural "sleeve" formed by the inner dural layer (Fig. 3). Unlike the distal dural ring, the proximal dural ring does not fuse with the ICA adventitia and is relatively incompetent. The floor of the clinoid space is formed by the inner dural layer, whereas the roof of the clinoid space is formed by the outer dural layer (Fig. 4 A). A small space exists between the inner dural layer and the portion of the ICA that it surrounds. This space is a rostral continuation of the anterior cavernous sinus space, and the veins of the cavernous sinus can extend through an incompetent proximal dural ring up to the distal dural ring (Fig. 4B).

FIGURE 3.

Microanatomic features of the ACP and clinoid (C5) segment of the ICA. *A*, photograph of a cadaveric specimen, showing a lateral view of the left cavernous sinus after an anterior clinoidectomy. The inner dural layer of the roof of the cavernous sinus reflects off the oculomotor nerve (Cranial Nerve III) to form the proximal dural ring and then courses along the clinoid (C5) segment of the ICA, where it fuses with the distal dural ring. A small space exists between the inner dural layer and the clinoid ICA, which admits veins from the cavernous sinus through the proximal dural ring (reprinted with permission from the Mayfield Clinic). *B*, artist's interpretation of *A*. The two circles detail the bony removal required to demonstrate the anatomic features shown. This particular specimen had both an ACP and a MCP, which were removed to demonstrate the relevant anatomic features (reprinted with permission from the Mayfield Clinic).

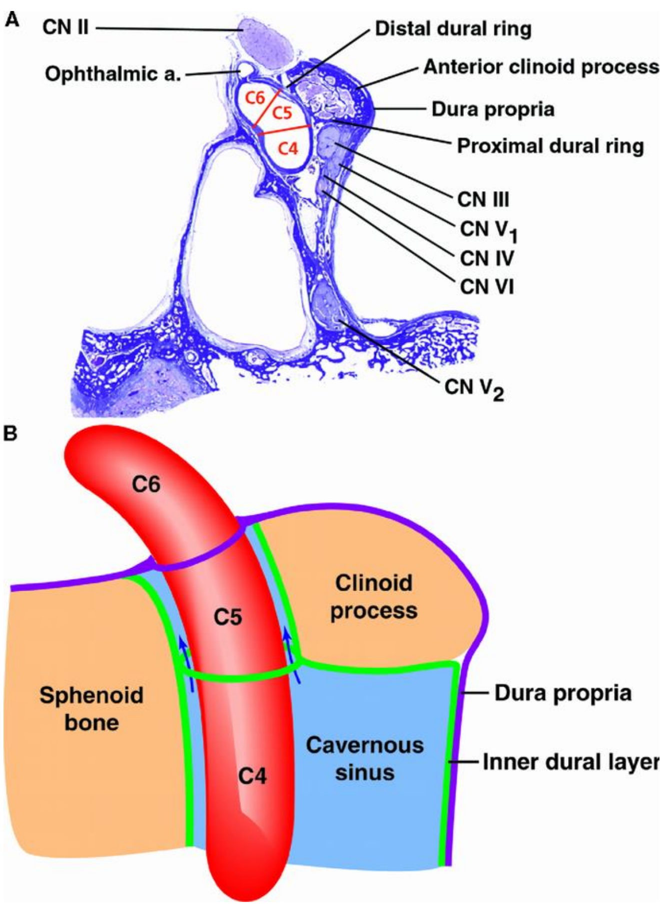


Arterial branches of C5 and C6 segments

Generally, no arterial branch originates from the clinoid (C5) segment of the ICA. In the 70 specimens examined in this study, 64 (91%) ophthalmic arteries originated just distal to the distal dural ring. Forty-seven (67%) ophthalmic arteries arose within 1 mm of the distal dural ring, and 17 (24%) arose within 1 to 5 mm of the distal dural ring. In four (6%) cases, the ophthalmic artery arose from the clinoid (C5) segment below the distal dural ring. In two (3%) cases, the ophthalmic artery arose at the insertion of the distal dural ring, with the ring being attached to the ophthalmic artery itself. Also identified in one specimen with a larger primary ophthalmic artery was an accessory ophthalmic artery that arose from the cavernous (C4) segment of the ICA. Incidental aneurysms were identified in two cadaveric specimens, one on the dorsal surface of the ophthalmic (C6) segment and the other at the origin of an ophthalmic artery that arose distal to the distal dural ring.

FIGURE 4.

A, photograph of a coronal histological section, demonstrating the relationship between the ACP and the ICA. The positions of the proximal and distal dural rings are indicated by *red lines*. Note that the clinoid (C5) segment of the ICA is wedge-shaped (reprinted with permission from the Mayfield Clinic). *B*, schematic drawing showing the small space that exists between the inner dural layer and the clinoid ICA. This space admits the passage of veins (through the incompetent proximal dural ring) that are in direct communication with the anterior cavernous sinus (reprinted with permission from the Mayfield Clinic).



One hundred sixty-two superior hypophyseal arteries were identified in the 70 specimens examined. All superior hypophyseal arteries originated from the medial or posterior aspect of the ICA, including 108 (67%) that arose from the proximal one-half of the ophthalmic (C6) segment of the ICA and 54 (33%) that arose from the distal one-half. Of the 70 specimens, 39 (56%) exhibited superior hypophyseal arteries from both the proximal and distal ophthalmic (C6) segments. The mean number of superior hypophyseal arteries was 2.3/side (range, 1–4/side). Of the 54 specimens with a carotid cave, 43 (80%) exhibited one or two superior hypophyseal arteries that arose from the ICA adjacent to the carotid cave.

DISCUSSION

Surgical exposure of the clinoid (C5) segment of the ICA has become a critical component of many contemporary neurosurgical approaches (e.g., exposure of ophthalmic segment aneurysms, cavernous sinus neoplasms, or clinoid meningiomas). Knowledge of the complex bony, dural, vascular, and neural relationships of this segment is necessary to enhance the safety and efficacy of these approaches. We have described the proximal and distal dural rings, the clinoid (C5) segment of the ICA, the clinoid space, the carotid cave, variations of the ophthalmic and superior hypophyseal arteries, and the dural layers surrounding these structures.

Dural rings

The intracavernous ICA is separated from the intradural space by the wall of the cavernous sinus, a dural boundary that consists of two layers, i.e., an outer dura propria and an inner membranous layer. At the clinoid process, these two dural layers split; the dura propria embraces the lateral and superior aspect of the clinoid process, whereas the thin inner membranous layer embraces the inferior and medial surface of the clinoid process. Where the ICA abuts the inferior surface of the clinoid process, this thin membranous layer also encircles the ICA and forms the proximal dural ring. As the intracavernous (C4) ICA passes through the proximal ring, it becomes the clinoid (C5) ICA.

A portion of the proximal ring separates the clinoid ICA from the oculomotor nerve. This tissue was described by Nutik ([39]) and was named the carotico-oculomotor membrane by Inoue et al. ([24]). This membrane is where the roof of the cavernous sinus proper encounters the clinoid ICA and serves as a surgical landmark for entry into the anterior cavernous sinus space.

At the point where the ICA enters intradural space, the ICA becomes surrounded by a distal dural ring that is tightly and circumferentially attached to the adventitia of the ICA. The distal dural ring represents the strict anatomic boundary between the intradural and extradural spaces. It is continuous with the dura propria of the cavernous sinus along its lateral aspect and is continuous with the diaphragma sellae along its medial aspect. The distal dural ring also serves to mark the end of the clinoid segment and the beginning of the ophthalmic (C6) segment ([4]).

The original description of the distal dural ring was presented by Perneczky et al. ([43]), who termed it the fibrous ring. Other synonyms for the distal dural ring include Perneczky's ring, the upper dural ring, the true dural ring, or simply the dural ring. We prefer to use the term distal dural ring because it is descriptive, accurate, and in widespread use.

The distal dural ring is tightly attached to the ICA; therefore, surgeons should not attempt to dissect the dura from the ICA at this level, because the ICA could be torn. Rather, the dura should be incised sharply, leaving a small ring of dura attached to the ICA.

Carotid cave

The term carotid cave was introduced by Kobayashi et al. ([27]) in 1989. The carotid cave is a redundant dural pouch that can sometimes be observed at the medial aspect of the distal dural ring. The cave is bounded laterally by the ICA and medially by the carotid sulcus, whose presence is a normal finding. In a study by Hitotsumatsu et al. ([22]), a carotid cave was identified in 68% of specimens, including 10% that were identified only microscopically. Similarly, our study identified a macroscopic carotid cave in 77% of specimens.

The cave points toward the cavernous sinus, and the apex of the cave consists of connective tissue, which, if traversed, communicates with the clinoid venous plexus. This may explain why larger carotid cave aneurysms frequently expand into the intra- and extradural spaces. It should be noted that the carotid cave always contains subarachnoid space; therefore, aneurysms in this location can be responsible for subarachnoid hemorrhage.

Clinoid space

An anterior clinoidectomy creates an anatomic space that does not exist with an intact clinoid process. This space is strictly a potential space, which is enveloped by the outer dural layer superiorly and the inner dural layer inferiorly. This interdural, extracavernous, surgically created space has been named the clinoid space ([49]). De Jesús ([7]) subdivided this space into three regions, i.e., a large space anterolateral to the ICA that was previously occupied by the body of the ACP, a small posterior space ([26,52]) that was occupied by the posteromedial projection of the clinoid tip, and a small anteromedial space that exists only in the presence of a MCP. When a true caroticoclinoid foramen is present, the posterior clinoid space communicates with the anteromedial space.

Clinoid (C5) ICA

The clinoid (C5) ICA is defined as the segment of the ICA that lies medial to the ACP and is bounded superiorly by the distal dural ring and inferiorly by the proximal dural ring ([4]). This portion of the ICA is typically surrounded on three sides by bony structures, i.e., the ACP laterally, the optic strut anteriorly, and the tuberculum sellae medially. In the presence of a caroticoclinoid foramen, the posterior surface of the ICA also abuts bone. The bony structures adjacent to the clinoid ICA are more generous anteriorly than posteriorly; therefore, the clinoid ICA is shaped more like a wedge than a cylinder.

The clinoid ICA is covered with a layer of membranous tissue wherever it is in contact with bone. This tissue is periosteum ([51]). Seoane et al. ([50]) named this membranous sleeve that surrounds the clinoid (C5) segment of the ICA the carotid collar. The superior margin of the collar is the distal dural ring, and the inferior margin is the proximal ring.

The anatomic structure of the proximal dural ring ([36,50]) differs from that of the distal dural ring. Although it is called a dural ring, the proximal ring is actually a reflection of the inner dural layer that loosely surrounds the ICA and is incompetent. The incompetence of the proximal ring allows extension of the cavernous venous plexus around the clinoid ICA up to the distal dural ring. This plexus of veins surrounding the clinoid ICA has been termed the clinoid venous plexus ([50]), and there is great variability in the density of this plexus. In some specimens the clinoid venous plexus consists of a few small veins, whereas in other specimens the plexus is so dense that it resembles the cavernous plexus of veins. Before an anterior clinoidectomy, the clinoid venous plexus is compressed between the ICA and the surrounding bony structures, namely, the ACP, the optic strut, and the carotid sulcus of the sphenoid bone. In summary, the clinoid ICA is surrounded by the clinoid venous plexus, which is surrounded by the carotid collar, which in turn is partially surrounded by osseous structures.

The clinoid (C5) segment of the ICA was long considered intracavernous ([9,10,24,26,43,46,50,55]). However, Nutik ([39]) and Perneczky et al. ([43]) reported that removal of the ACP permitted exposure of a short segment of the ICA, proximal to the distal dural ring, without entry into the cavernous sinus. After those descriptions, many authors considered the clinoid (C5) segment to be extracavernous ([4,5,7,11,32,52]), although others continue to argue to the contrary. Inoue et al. ([24]) described the carotico-oculomotor membrane, which separates the cavernous sinus from the clinoid space, and they considered the clinoid (C5) segment a part of the intracavernous ICA. In comments on that article, Sekhar and Sen ([48]) stated that the ICA is always separated from the clinoid space by a thin membrane and that opening of that membrane results in cavernous venous bleeding. Therefore, those authors also concluded that the clinoid ICA is intracavernous. Seoane et al. ([50]) defined the clinoid (C5) segment as intracavernous because it was located within a collar of tissue in which venous tributaries from the cavernous sinus coursed.

On the basis of our anatomic studies, we think that the clinoid venous plexus is in direct communication with the cavernous venous plexus. We agree with many authors on this point. However, with respect to the issue of defining the clinoid ICA as either intracavernous or extracavernous, we contend that an unequivocal distinction cannot be made. To be considered intracavernous, the clinoid ICA should be surrounded by a profuse collection of veins that are continuous with the historically accepted collection of veins that define the cavernous plexus. This is not always the case, because in some specimens there is a definite paucity of veins surrounding the clinoid ICA. We propose to resolve the debate by stating that the clinoid ICA is sometimes intracavernous and sometimes extracavernous. The proposal by Parkinson ([42]) to rename the cavernous sinus (and its surrounding region) as the lateral sellar compartment would provide a solution to this problem, because the distinction of extracavernous or intracavernous would no longer hold semantic value.

Ultimately, we think that the question of whether the clinoid ICA is extracavernous or intracavernous is theoretical. Entering the cavernous sinus itself is not an action that is intentionally performed when the ACP is being drilled. Any bleeding from the clinoid venous plexus that is encountered during an anterior clinoidectomy can be controlled with packing, and the procedure progresses.

Ophthalmic and superior hypophyseal arteries

The ophthalmic artery generally arises on the rostromedial aspect of the ophthalmic (C6) segment of the ICA ([18,19,32,37,46]) and courses forward along the inferior surface of the optic nerve ([49]). This artery arises proximal to the distal dural ring, from either the clinoid (C5) or cavernous (C4) segment, in 2 to 16% of cases ([18,20,37,46,53]). Yaşargil ([53]) described the ophthalmic artery as arising from the cavernous sinus (7.5%). In our study, the ophthalmic artery arose at the insertion of the distal dural ring into the ICA (3%) and from the clinoid (C5) segment proximal to the distal dural ring (6%). We encountered one case (1%) of a cavernous (C4) segment origin. Discrepancies between the literature findings and our study probably result from the fact that previous descriptions disregarded the subdivision of the ICA into clinoid (C5) and cavernous (C4) segments.

The superior hypophyseal arteries are the largest perforating vessels of the ophthalmic (C6) segment of the ICA and commonly arise from the posteromedial wall of the proximal one-half of the C6 segment ([5,17,18,29]). The number of superior hypophyseal branches varied from 1 to 4 in our study (mean, 2.3) and from 1 to 5 in the literature ([17,18,29]). Hitotsumatsu et al. ([22]) observed that 38% of superior hypophyseal arteries originated near the distal dural ring, 36% were thought to arise from the carotid cave, and 16% were intracavernous in origin. In our study, 162 (67%) superior hypophyseal arteries originated from the posteromedial wall of the proximal one-half of the C6 segment of the ICA. Among 54 identified carotid caves, 43 (80%) exhibited one or two superior hypophyseal arteries originating from the ICA segment within the cave.

Radiographic localization of the distal ring

Preoperative identification of the distal dural ring remains an unsolved problem. Aneurysms located completely below the distal dural ring cannot cause subarachnoid hemorrhage and do not produce the same morbidity with rupture as do aneurysms arising from the intradural space. Determination of the relationship between aneurysms in this region and the distal dural ring is a critical clinical issue, but this assessment is currently not possible using angiography or magnetic resonance imaging.

In 1979, Punt ([45]) recognized that division of the carotid artery into supra- and infraclinoid portions was satisfactory for anatomic descriptions but the important clinical distinction was between intra- and extradural ICA segments. He proposed that the origin of the ophthalmic artery be used as the marker for the intradural ICA ([45]). That rule occasionally fails, because the origin of the ophthalmic artery is extradural in approximately 10% of cases. Taptas ([51]) proposed that the base of the ACP in lateral radiographs served as a more reliable marker for the intradural ICA. That rule also occasionally fails, because carotid cave aneurysms can be observed below the level of the ACP. More recently, Oikawa et al. ([41]) studied the orientation of the distal dural ring. They noted that the distal dural ring sloped downward in a posterolateral to anteromedial direction, so that the medial aspect of the ring was at the level of the tuberculum sellae and the lateral aspect of the ring was at the level of the clinoid process. However, those authors also concluded that a carotid cave aneurysm may even dip below the level of the tuberculum sellae.

We are currently unaware of any combination of radiographic tests that permit reliable identification of the distal dural ring. Therefore, for some aneurysms it is impossible to preoperatively determine whether the aneurysm arises from the C5 segment or the C6 segment of the ICA. Surgical exploration is the only solution in these cases. The surgeon must be prepared to abort the operation if the aneurysm is discovered to be completely extradural. It may be preferable to inspect the intradural ICA before proceeding with an anterior clinoidectomy in cases in which the intradural location of an aneurysm is in question.

Paraclinoid aneurysms

The existing nomenclature of aneurysms arising from the clinoid and ophthalmic segments of the ICA is contradictory. There are anatomic reasons for this confusion. First, the ophthalmic artery can arise from either the clinoid (C5) segment or the ophthalmic (C6) segment of the ICA. Second, aneurysms of this region do not necessarily arise in relation to a named arterial branch. Third, aneurysms of this area can be intradural, extradural, or both; it is sometimes impossible to make this determination using radiographic investigations. Fourth, recognition of the carotid cave as an entity has complicated the issue, because carotid cave aneurysms are located below the plane of the distal dural ring but are intradural.

The proposed nomenclature for aneurysms of this region originated with Drake et al. ([12]), who, in 1968, described carotid-ophthalmic aneurysms as aneurysms arising from the origin of the ophthalmic artery. Kothandaram et al. ([28]) considered carotid-ophthalmic aneurysms to be aneurysms arising between the origin of the ophthalmic artery and the posterior communicating artery. Dolenc ([10]) and Yaşargil et al. ([55]) subsequently concurred with Kothandaram et al. ([28]). More recently, Day et al. ([6]) and Batjer et al. ([3]) have reverted to the original definition of Drake et al. ([12]).

Yaşargil and Fox ([54]) described ventral ICA aneurysms as originating between the ophthalmic and posterior communicating arteries and projecting inferiorly into the cavernous sinus. In this aneurysm type, the neck arises 180 degrees from the origin of the ophthalmic artery. Nutik ([38]) introduced the term paraclinoid aneurysm to describe this very specific aneurysm type. That author noted that these aneurysms exhibited a propensity to occupy both the intra- and extradural spaces. Pia ([44]) briefly described a similar aneurysm type and proposed the term infraophthalmic aneurysm. Nutik ([40]) subsequently used the term ventral paraclinoid aneurysm, because he thought it was a more descriptive alternative to paraclinoid aneurysm, which he had proposed earlier. Fox ([15]) also used the term ventral paraclinoid aneurysm.

Heros et al. ([21]) used the term paraclinoid aneurysm as an umbrella term for all aneurysms arising in proximity to the ACP. Aneurysms were broadly categorized as ophthalmic (if they arose in relation to the ophthalmic artery) or paraophthalmic (if they arose elsewhere). Carotid cave aneurysms were first described by Kobayashi et al. ([27]) as a special type of aneurysms that arose from the ventromedial ICA and occupied the carotid cave.

Day et al. ([6]) proposed the first cogent classification of proximal ICA aneurysms. The ophthalmic segment was defined as extending from the ophthalmic artery to the posterior communicating artery. Ophthalmic artery aneurysms were defined as aneurysms with a clear relation to the ophthalmic artery. Other aneurysms of the ophthalmic segment were collectively referred to as superior hypophyseal artery aneurysms. Superior hypophyseal artery aneurysms were divided into paraclinoid and suprasellar variants. The paraclinoid variant included aneurysms that burrowed into the clinoid process (equivalent to the ventral paraclinoid aneurysms described by Nutik [[40]]) or burrowed inferomedial to the ICA (equivalent to the carotid cave aneurysms described by Kobayashi et al. [[27]]). The suprasellar variant included aneurysms that burrowed under the optic chiasm.

Al-Rodhan et al. ([2]) provided comprehensive nomenclature for aneurysms of the paraclinoid region. They recognized ophthalmic artery aneurysms as arising in relation to the origin of the ophthalmic artery. Aneurysms arising distal to the origin of the ophthalmic artery but proximal to the origin of the posterior communicating artery were classified as superior hypophyseal aneurysms or ventral paraclinoid aneurysms, depending on the projection (medially or posteroinferiorly, respectively). Carotid cave aneurysms and cavernous aneurysms were labeled using the customary definitions. Aneurysms arising from the superior carotid wall with a neck in extradural space and a dome in intradural space were designated transitional aneurysms.

Batjer et al. ([3]) proposed a modification of the classification suggested by Day et al. ([6]). Batjer et al. ([3]) designated all aneurysms arising between the roof of the cavernous sinus and the origin of the posterior communicating artery as paraclinoid aneurysms. Aneurysms were grouped into three categories. Carotid-ophthalmic artery aneurysms were defined as arising just distal to the ophthalmic artery and projecting superiorly. Superior hypophyseal aneurysms were defined as arising from the medial wall of the ICA and projecting inferomedially. Posterior carotid wall aneurysms were defined as arising from the posterior carotid wall and projecting posterolaterally.

We are in greatest agreement with the classification proposed by Al-Rodhan et al. ([2]) Their classification is practical and simple to apply. However, we think that, as our understanding of the anatomic features of the paraclinoid region becomes more refined, classification schemes should reflect this knowledge. Bouthillier et al. ([4]) recently described the clinoid (C5) segment of the ICA that is situated between the proximal and distal dural rings.

Because of the great difficulty of locating the distal dural ring (and hence the clinoid segment of the ICA) using angiography, the term paraclinoid aneurysm can be used as an umbrella term to describe aneurysms of the C5 and C6 segments when the exact origins of the aneurysms are unknown. We agree with Heros et al. ([21]) and Batjer et al. ([3]) regarding the generic use of this term.

After surgical exploration has been performed, the anatomic features of the aneurysms can be clearly defined and the aneurysms should be characterized as arising primarily from either the ophthalmic or clinoid segment of the ICA. This terminology better communicates the important relationship between the aneurysms and the distal dural ring. Ophthalmic artery aneurysms arise in relation to the ophthalmic artery and usually originate from the dorsal surface of the ophthalmic segment. Ophthalmic artery aneurysms can infrequently arise from the clinoid segment. Superior hypophyseal artery aneurysms arise from the medial aspect of the ophthalmic segment. Carotid cave aneurysms can be viewed as a special class of superior hypophyseal artery aneurysms.

The term posterior carotid wall aneurysm, which was proposed by Batjer et al. ([3]), refers to aneurysms that arise from the posterior aspect of the ophthalmic segment. Although for these aneurysms the neck is intradural, the dome is often extradural. These aneurysms essentially straddle the distal dural ring. Other names for this aneurysm type include the paraclinoid variant ([6]), ventral paraclinoid aneurysms ([40]), infraophthalmic aneurysms ([44]), and ventral proximal ICA aneurysms ([54]).

Transitional cavernous aneurysm is a term proposed by Al-Rodhan et al. ([2]); it refers to the rare cavernous aneurysms that reach such a large size that the dome enters the intradural space. Like some posterior carotid wall aneurysms, these aneurysms straddle the distal dural ring. For example, Horowitz et al. ([23]) described an aneurysm that extended above and below the distal dural ring. We present a similar case of an aneurysm (Fig. 5) that was both above and below the distal dural ring.

We do not propose a new nomenclature for paraclinoid region aneurysms. In Table 2 and Figure 6, we do attempt to clarify the anatomic features of previously described aneurysms in this region, especially their relationships to the dura. The practical significance of such information is that each aneurysm type requires a different surgical strategy. For example, aneurysms identified as being completely extradural may not require treatment. Aneurysms identified as being completely intradural may require only an anterior clinoidectomy. On the other hand, aneurysms that straddle intra- and extradural space may require broad opening of the distal ring for adequate control and clipping.

FIGURE 5.

Angiogram in which an aneurysmal sac was circumscribed by the distal dural ring (**arrow**). Although the angiogram suggests two separate aneurysms, intraoperative inspection revealed a single aneurysm that straddled the distal dural ring.

TABLE 2.

Dural Relationships of Paraclinoid Aneurysms

TABLE 2. Dural Relationships of Paraclinoid Aneurysms

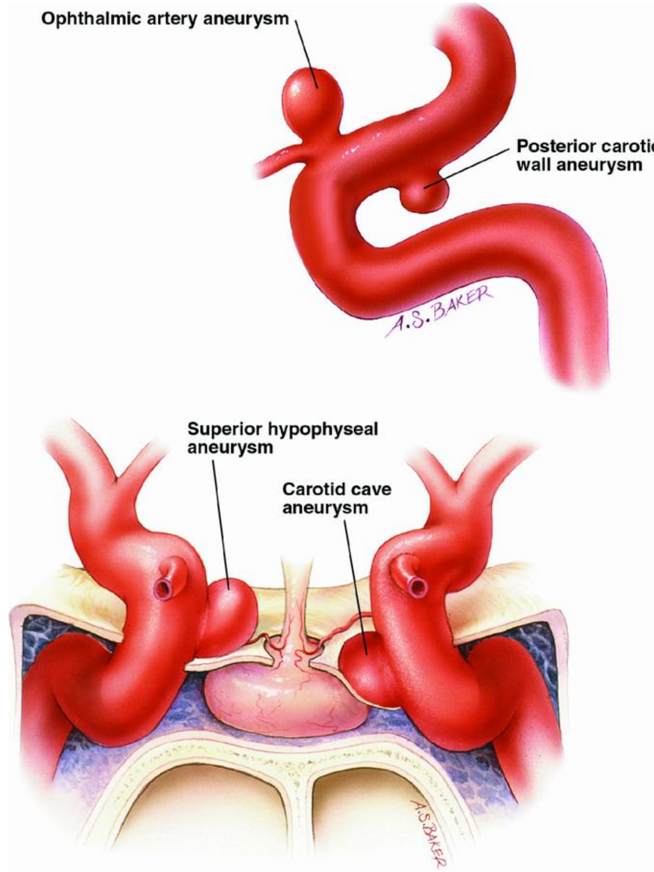
	Neck	Dome	Projection
Cavernous (C4) segment aneurysms			
Intracavernous aneurysms	Extradural	Extradural	Variable
Transitional cavernous aneurysms	Extradural	Intradural	Superior
Clinoid (C5) segment aneurysms			
Clinoid segment aneurysms	Extradural	Extradural	Variable
Ophthalmic artery aneurysms (infrequent)	Extradural	Extradural	Superior
Ophthalmic (C6) segment aneurysms			
Ophthalmic artery aneurysms	Intradural	Intradural	Superior
Superior hypophyseal aneurysms	Intradural	Intradural	Medial
Carotid cave aneurysms	Intradural	Intra- or extradural	Inferomedial
Posterior carotid wall aneurysms	Intradural	Intra- or extradural	Inferoposterior

CONCLUSIONS

We have detailed the anatomic features of the paraclinoid region. Knowledge of the surgical anatomic features of this region is important for the surgical management of paraclinoid aneurysms and neoplasms. Two dural rings surround the clinoid segment of the ICA. The distal ring separates the extradural clinoid ICA from the intradural ophthalmic ICA. This distal ring cannot be observed with radiographic tests. The proximal ring separates the clinoid ICA from the cavernous ICA. The proximal ring is incompetent and allows the passage of veins continuous with the cavernous sinus. Because of the plethora of terms describing structures in this region, we have attempted to standardize the anatomic features and nomenclature of this region.

FIGURE 6.

Diagrammatic clarification of aneurysms of the ophthalmic segment (reprinted with permission from the Mayfield Clinic).



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COMMENTS

The authors have performed an anatomic study with the aim of better defining the microsurgical anatomic features of the paraclinoid region, with particular emphasis on the con- nective tissue and neural relationships to the subclinoid segment of the internal carotid artery (ICA). There has recently been some controversy in the literature regarding this region, and I think that this study clarifies some of the contentious points.

One point of recent debate has involved whether the subclinoid segment of the ICA is an intracavernous or extracavernous segment of the vessel. I think that the authors have demonstrated that it is correct to label this segment as neither intracavernous nor extracavernous. The key point is that the amount of venous plexus that surrounds that segment of the artery is highly variable. I have observed great variability of this segment of the vessel in both anatomic preparations and clinical exposures. Because of this observed variability, I consider it is correct to describe the subclinoid segment as extradural but variably intra- or extracavernous. We cannot be dogmatic in our descriptions of this segment of the vessel.

I agree with the description of the region provided by the authors, except for a minor point. The authors describe the splitting of the dura propria and periosteal layers by the anterior clinoid process (ACP), and it is not clear from their description whether the superior surface of the ACP is covered by periosteum. I think that the entire ACP is covered by a periosteal layer. I think it is clear that the dura propria layer lies adjacent to the superior aspect of the ACP. However, there is an intervening layer of periosteum between the dura propria and the bone of the ACP on this superior aspect. If the description of the authors were correct, one would have to imagine a portion of the ACP that is devoid of periosteal covering. This would amount to a periosteal "bare spot" that I do not think exists, and the authors do not present convincing evidence to the contrary.

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The authors have presented an excellent review of the anatomic features of the paraclinoid region, the clinoid segment of the ICA, and the dural rings, as well as the surgical implications of these anatomic features. Their findings on the dural rings agree with ours, in that the distal ring defining the upper margin of the clinoid segment is more tightly bound to the ICA than is the proximal ring ([2]). The authors noted that the clinoid segment of the ICA is surrounded by a dural cuff (which we designated the carotid collar) and that the clinoid venous plexus, which is formed by venous tributaries from the ACP, the optic strut, and the orbital roof, passes inside the collar to reach the cavernous sinus. The observation that the clinoid venous plexus extends inside the collar and through the lower ring to the level of the upper ring has led us to conclude that the clinoid segment of the ICA is intracavernous rather than extracavernous. The authors also refer to the dural sheath, which extends across the oculomotor nerve and forms the lower dural ring, as the carotico-oculomotor membrane, as we reported previously ([1]). The authors have provided an excellent review of the various terms used to describe differ- ent aspects of the anatomic features of this area, including the carotid cave, clinoid space, clinoid segment, carotid collar, and carotico-oculomotor membrane.

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Kim et al. have provided a detailed description of the ACP, the clinoid space, and the clinoid segment of the ICA. Although no new information is presented in this article, several important anatomic points are reemphasized. The clinoid segment of the ICA is very important during exposure of cranial base tumors and paraclinoid aneurysms ([2]). In contrast to the opinions originally expressed by Day ([1]), we have always thought that the clinoid space is intracavernous to varying extents, a finding confirmed by these authors. Clinoid segment aneurysms are of great clinical interest, and they may be medial, lateral, or anterosuperior in their projection. The ophthalmic artery may occasionally originate from the clinoid segment, and exposure of this segment is a key element of the superior approach to the cavernous sinus.

During extradural or intradural exposure of the clinoid space, neurosurgeons must be alert for extension of the sphenoid sinus into the optic strut and occasionally into the ACP. This extension must always be searched for and, if present, treated with fascia and fat occlusion and dural closure. Despite these measures, cerebrospinal fluid leakage through this space may occasionally occur.

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The authors have described the microsurgical anatomic features of the clinoid segment of the ICA and its surrounding structures and have provided a thorough literature review of the commonly used but often confusing terms describing the anatomic features of the paraclinoid region. The segment of the ICA under discussion has become very important with the recent introduction of cranial base surgery to directly treat lesions involving the parasellar, paraclinoid, and cavernous sinus regions. It is quite important to understand the detailed anatomic features of the surgical field. Therefore, this article is timely and worthwhile for those interested in surgery in this region.

Anatomic features in this region are clearest for small aneurysms, because pathological conditions such as tumors may distort or destroy the normal anatomic features. Intracavernous aneurysms are usually not approached directly; ICA aneurysms in the juxta-dural ring region can be approached directly, although some of them can be treated endovascularly. The nomenclature for structures in this region (especially segmentation of the ICA) was initially introduced for angiographic orientation, and it is not detailed and practical enough for use during surgery. Cadaveric anatomic features are the basis for understanding the anatomic features of living subjects. We present the following observations from our surgical experience with approximately 100 cases involving small aneurysms in this region.

First, the clinoid segment of the ICA is enveloped by the inner layer of the cavernous sinus wall (periosteum of the ACP), as the authors describe. We agree with the authors that there is a potential space between the adventitia of the ICA and the covering periosteum, which contains variable dural venous channels; when the ACP is removed, the venous channels can be observed through the periosteum, with various degrees of bluish coloration.

When the venous channel is poorly developed, the clinoid segment appears whitish; when the venous channel is well developed, the channel appears as a venous pool and can even be observed from within the carotid cave. It is then difficult to determine whether the channel represents the venous sinus channel or a fused venous channel. It can be an extension of the cavernous sinus or venous channels outside the cavernous sinus bordered by the loose proximal ring, and it may be termed the carotid groove sinus ([3]). As the authors state, the bordering membrane between the cavernous sinus and the venous channel of the clinoid segment is incompetent and often loose, appearing to be bordered by trabeculae of connective tissue; the competency of the proximal ring also depends on anatomic variations of the ICA in this region, as well as on variations of the surrounding structures. Whether the venous channel of the clinoid segment is intracavernous or extracavernous should also be discussed from the perspective of embryological development. Currently, it can only be stated that the clinoid segment of the ICA is extradural.

Second, the ophthalmic segment of the ICA is the segment of the ICA between the origins of the ophthalmic artery and the posterior communicating artery, as many authors, including these authors, have described. However, there are two factors that make the classification of aneurysms in this region difficult to standardize. The first factor is the variation in the origins of the ophthalmic artery and the second is the complexity of the anatomic features of the juxta-dural ring region.

The origin of the ophthalmic artery is variable, and as many as 10% of these arteries originate proximal to the distal dural ring (i.e., extradural origin). The origin of the ophthalmic artery is sometimes difficult to clearly identify in cadaveric specimens. We have intraoperatively identified a few cases in which the ophthalmic artery originated from the distal dural ring (interdural origin), which might have been difficult to ascertain during cadaveric dissection. These cases may correspond to the two cases in which the authors identified the origin of the artery at the dural attachment. The variations in the origin of the ophthalmic artery make it difficult to name ICA aneurysms in this region with reference to the ophthalmic artery.

The second factor, namely, the anatomic complexity, includes the relationship between the ICA and the distal dural ring. The clinoid segment of the ICA penetrates the dura (distal dural ring) to become the ophthalmic segment of the ICA. It should be noted that the ICA curves at that point and the distal dural ring obliquely traverses the ICA and merges with the optic sheath. Because of this complexity, there is a segment of the ICA that cannot be designated as either the clinoid or ophthalmic segment. This small segment of the ICA is located ventromedially at its dural penetration. This region is not always present, because of the variations in the regional structures, but, interestingly, aneurysms are often observed here. Carotid cave aneurysms ([2]) occur in this region, and some superior hypophyseal artery aneurysms ([1]) and ventral paraclinoid aneurysms ([4]) are also located here.

Third, the number of superior hypophyseal arteries is usually more than one, as the authors describe. In our series of carotid cave aneurysms, we observed that aneurysms were occasionally associated with this artery. However, we do not think it is correct to designate carotid cave aneurysms as a type of superior hypophyseal artery aneurysms. We would like to limit the term hypophyseal artery aneurysms to aneurysms that definitely originate from the ICA at the branching point of the hypophyseal artery, which should be relatively large, as observed for ICA-posterior communicating artery aneurysms. Carotid cave aneurysms are likely to develop at the curve of the ICA, where the hemodynamic stress is great. The ventral paraclinoid aneurysms reported by Nutik ([4]) are aneurysms that project ventrally in the surgical field; they may or may not be associated with this artery but, as defined by that author, they originate from the ICA opposite the origin of the ophthalmic artery.

Fourth, recognition of what the authors term the anterolateral and anteromedial spaces is important for surgical treatment of aneurysms in this location. The anterolateral and anteromedial clinoid spaces may roughly correspond to the areas termed genu and axilla, respectively, in surgical fields for carotid cave aneurysm clipping; securing these spaces permits the exact placement of clips on these aneurysms. Observation of the middle clinoid process in as many as 75% of cases seems too high, on the basis of our surgical experience, but the existence of this process does not affect surgical tactics because the genu and axilla of the ICA are secured before clipping; in a few cases, we drilled the underlying bone to prevent stenosis of the parent artery by a ring clip. Both spaces should probably be considered potential spaces. If the spaces are widely opened, it is likely that the created space is in the cavernous sinus.

Finally, we note that the term clinoid is a noun and not an adjective (as in processus clinoideus anterior, Paris Nomina Anatomica), so the correct terminology should be clinoidal space rather than clinoid space. However, like the use of sphenoid ridge (as in crista sphenoidalis, Paris Nomina Anatomica), rather than sphenoidal ridge, we may refer to this as the clinoid space.

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