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The Paraclinoid Carotid Artery: Anatomical Aspects of a Microneurosurgical Approach

Engelbert Knosp, M.D., Gerd Müller, M.D., and Axel Perneczky, M.D.

Department of Neurosurgery (EK, AP) and Department of Anatomy (GM), University of Vienna, Austria

The paraclinoid area is investigated anatomically for possible microneurosurgical approaches to the C_3 segment of the internal carotid artery and to structures in the vicinity of the anterior siphon knee. Removal of the anterior clinoid process reveals a tight connective tissue ring that fixes the internal carotid artery to the surrounding osseous structures at the point of its transdural passage. Transection of this fibrous ring opens a microsurgical pathway to the carotid C_3 segment. The artery is surrounded by a loose connective tissue layer that allows blunt preparation along the C_3 segment, without compromising the cranial nerves and without damaging venous compartments of the cavernous sinus. This approach provides neurosurgical access to paraclinoidal aneurysms, to partly intracavernous aneurysms, and to carotid-ophthalmic aneurysms, allowing control of the proximal aneurysm neck and of the parent artery itself. In cases of tumors involving the medial sphenoid ridge, the apex of the orbit, or the cavernous sinus, the pericarotid connective tissue can serve as a guide layer for access along the internal carotid artery. (*Neurosurgery* 22:896–901, 1988)

Key words: Aneurysm, Cavernous sinus, Internal carotid artery, Microneurosurgical anatomy

INTRODUCTION

The area of the anterior siphon knee is of particular neurosurgical interest as a variety of pathological processes can take place in this confined and anatomically complicated region. Primarily, it is tumors and aneurysms occurring in this area that may require surgical exposure. Aneurysms that develop in this region are referred to as paraclinoidal, infraclinoidal, or carotid-ophthalmic aneurysms according to their site of origin. Subarachnoid hemorrhage is a common symptom of such aneurysms and requires neurosurgical management, which can cause considerable technical problems. Osseous structures of the skull base may impair sufficient exposure of the aneurysm neck, and there is risk in opening venous compartments of the cavernous sinus. Although direct operation of infraclinoidal aneurysms is practicable (20), we investigate in this study the anatomical basis for neurosurgical approaches to the anterior siphon knee of the internal carotid artery.

The dural transition area of the internal carotid artery (ICA), between its intracavernous and intradural portions, is important to the neurosurgeon because of the particular anatomical relation of the ICA to adjacent structures. Several authors have described the neurovascular relations of the ICA and of the ophthalmic artery with the optic nerve, with the 3rd, 4th, 6th, and 1st divisions of the 5th cranial nerve, with the cavernous sinus, and with the osseous structures of the area (1–3, 5, 9–11, 13, 14, 18–23, 26–29). In most of these works the basal cranial dura mater is considered as the borderline between the intracranial portion of the ICA (C_2 segment) and the intracavernous portion of the ICA. Such views suggest that the ICA is surrounded by the cavernous sinus immediately below the dural level, and operation is often abandoned at this point because of the risk to venous compartments of the cavernous sinus. The present study disputes this concept.

MATERIALS AND METHODS

Microdissection was carried out on 20 formalin-fixed and nonfixed adult skulls, taking lateral (pterional) and medial approaches. Before dissection, the arteries and veins of several specimens were injected with colored latex or gelatin. Other specimens were injected with methylmethacrylate (Technovit; Kulzer & Co, Wehrheim, Germany) and immersed in 30% KOH to obtain vascular corrosion casts, which demonstrate the relationship of the ICA to the cavernous sinus venous plexus. For histological examination, the sellar region was removed en bloc, decalcified, sectioned, and stained for connective tissue (Mallory-Azan). Our study also included a number of fetal and infant skulls. Microdissection and photography were carried out with a binocular microscope (Leitz M8; Wild Leitz Col. Ltd., Willowdale, Ontario).

RESULTS

Microdissection reveals a complex arrangement of osseous and connective tissue structures in the paraclinoid region. The structures of the area exhibit a high degree of individual variation, which is important to the surgical approach as some of these structures define and limit operative pathways.

The anterior clinoid process, as an extension of the lesser sphenoid wing, represents the lateral osseous limitation of the dural transition area of the ICA. The anterior clinoid process may embrace the ICA to varying degrees. Medial to the anterior siphon knee lies the corpus of the sphenoid bone, where the ICA produces a mild impression named the carotid sulcus. Thus, the anterior and anteromedial aspect of the artery is in direct contact with osseous structures. From within the sphenoid sinus, the carotid sulcus can be seen bulging into the sinus and is then called the carotid prominence. In the anterosuperior part of the carotid sulcus, the ethmoid air cells are occasionally found in close proximity to the carotid artery. The medial ridge of the carotid sulcus may be pronounced and then forms the middle clinoid process. In some skulls, however, a continuous osseous lamina connects the middle clinoid process with the anterior clinoid process. In such cases, bone completely surrounds the ICA and forms a caroticoclinoid foramen (6, 7, 13, 14) (Fig. 1).

Several strong connective tissue strands, also called "ligaments," originate from the anterior clinoid process. The anterior petroclinoid fold, which is the most anterior extension of the free margin of the tentorium, runs laterally from the ICA to the anterior clinoid process. A ligament that turns around the dorsal aspect of the ICA connects the anterior clinoid process with the middle clinoid process. This ligament encircles the artery and may be called the caroticoclinoid ligament (Fig. 2). The ligament sometimes ossifies to form the caroticoclinoid foramen. A third ligament, called the interclinoid ligament (14), connects the anterior and the posterior clinoid processes.

At the point of dural transition, the ICA is fixed by strong connective tissue strands (Fig. 2) that attach the artery in a radiating arrangement to the adjacent structures. These dural strands together form a fibrous ring around the ICA (Figs. 2, 3, and 8) with connections to the planum sphenoidale, to the diaphragma sellae, and to the anterior clinoid process. During operation, one must be aware that the transversal plate medial to the ICA is at a lower level than the anterior clinoid processes lateral to the ICA.

The neurosurgical approach to the C_3 segment requires, as a first step, removal of the anterior clinoid process to obtain access to extradural parts of the ICA. Before the lateral wall of the artery is exposed, the periosteum of the anterior clinoid process and the fibrous ring must be removed. Sharp transection of the fibrous ring close to the wall of the ICA (Fig. 4) unfolds a layer of loose connective tissue that extends around the artery and is also seen in histological sections (Fig. 5). This tissue layer allows further blunt dissection around the artery and along its course to deeper "intracavernous" parts of the ICA. Preparation mainly follows the anterior and lateral aspects of the artery, and care must be taken at the hollow of the anterior siphon knee to prevent disruption of the cavernous venous plexus. Additional dural transection and opening of the optic canal is necessary for further exposure of the C_3 segment (Fig. 6).

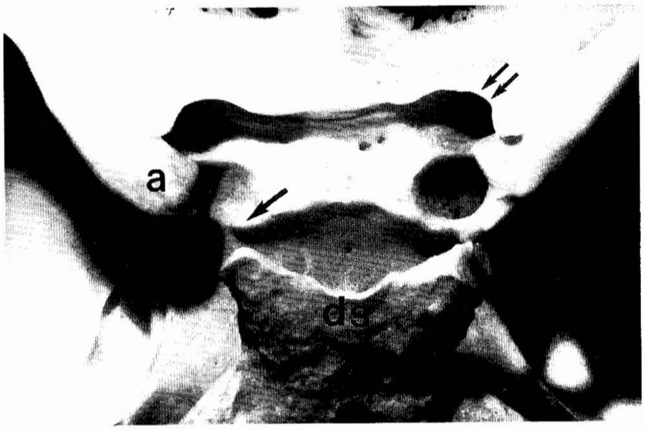

FIG. 1. Sellar area showing a caroticoclinoid foramen on the *right*. On the *left*, the osseous bridge between the anterior clinoid process (*a*) and the middle clinoid process (*arrow*) is incomplete. Dorsum sellae (*ds*), optic canal (*double arrows*).

The C_3 segment of the ICA has the form of a semicircular loop with its convexity on the anterior aspect. Depending on the tortuosity of the C_4 and C_5 segments, the shape of the anterior knee varies significantly. In the area of dural transition, the artery inclines laterally and dorsally, and thus the anteromedial circumference of the ICA represents the most medial point of the intracavernous segment. The parts of the ICA that can be reached by the approach described are shown in Figure 6 (see "Discussion").

Further preparation is limited by the cranial nerves that are situated in the lateral wall of the cavernous sinus and by the venous compartments of the cavernous sinus. In the area relevant to the particular approach described herein, the cranial nerves, which converge toward the superior orbital fissure, are confined within a tight connective tissue layer (Fig. 2*a*). It is advantageous to keep the nerves within this sheath as a common entity to prevent direct pressure on the nerves and to maintain their blood supply.

The venous compartments of the cavernous sinus are not extensive in the area of the anterior siphon knee. The superior ophthalmic vein, which collects the orbital venous blood, passes between V_1 and V_2, and joins the cavernous venous plexus in its anterior, inferolateral part (11, 14). The cavernous venous plexus only rarely has significant extensions near the anteromedial, anterior, and anterolateral aspect of the C_3 segment of the ICA (Fig. 7). Along the dorsal aspect of the anterior siphon knee, however, the pericarotid tissue layer is

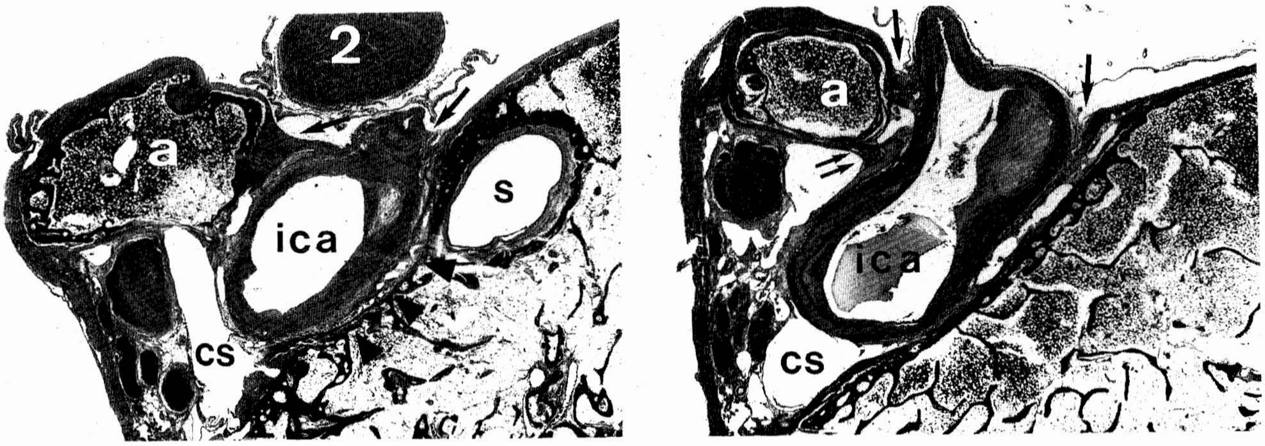

FIG. 2. Histological section through the left parasellar area.

Left: The section through the frontalmost portion of the anterior siphon knee (*ica*) shows the carotid sulcus (*arrowheads*) on the sphenoid corpus and dural strands (*arrows*) that fix the artery to the anterior clinoid process (*a*) as well as to the sphenoid bone. Note the cranial nerves that converge toward the superior orbital fissure within a common connective tissue sheath. There is pneumatization (*s*) of the sphenoid corpus in the vicinity of the ICA. Optic nerve (*2*), cavernous sinus (*cs*).

Right: Section through the anterior siphon knee. Strong connective tissue strands of the dura mater (*arrows*) are seen to fix the artery to the adjacent structures and will form together a fibrous ring around the ICA. The attachment site of the caroticoclinoid ligament (*double arrows*) at the anterior clinoid process (*a*). Cavernous sinus (*cs*).

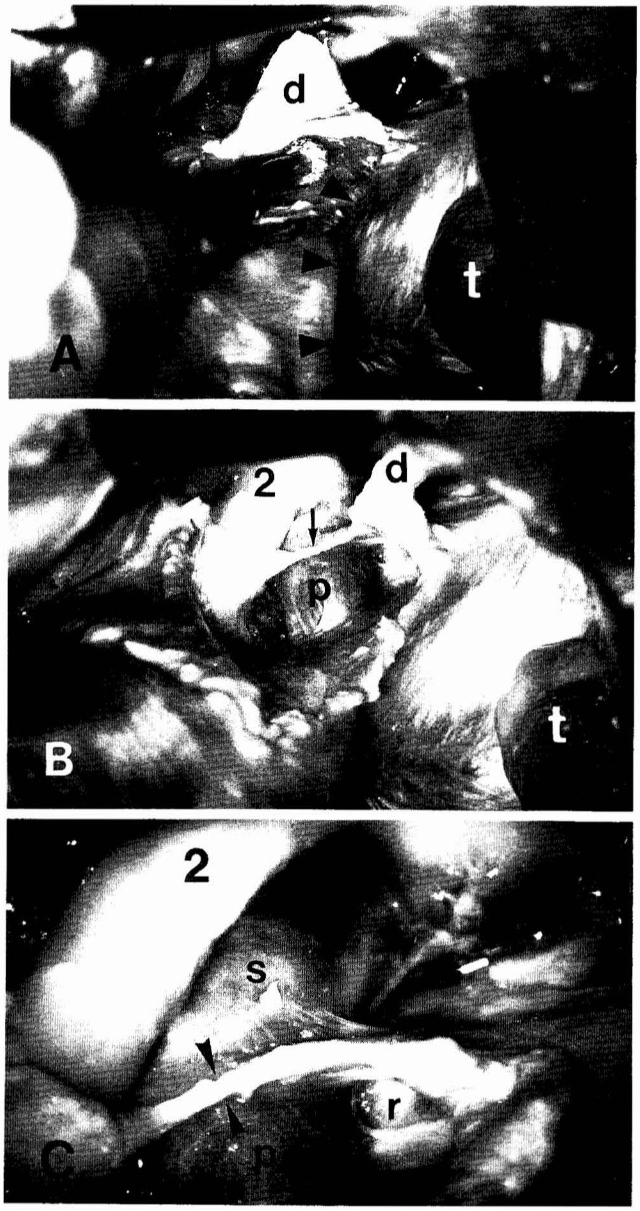

FIG. 3. Left pterional approach to the paraclinoid carotid artery.

A: A dural flap (*d*) is created by incision along the lesser sphenoid wing reaching anterior to the optic canal. While the anterior clinoid process is drilled with a high speed diamond drill, the optic nerve and the ICA are protected by this dural flap. Sphenoid ridge (*arrowheads*), temporal lobe (*t*).

B: After removal of the anterior clinoid process and opening of the optic canal, the paraclinoid carotid artery (*p*) is dissected. The dural flap (*d*) is resected, leaving a fibrous ring (*arrow*) around the ICA. Optic nerve (*2*), temporal lobe (*t*).

C: Higher magnification of the basal cranial dural attachment around the ICA, showing a fibrous ring (*arrowheads*), paraclinoid (*p*) and supraclinoid (*s*) portions of the ICA, and the optic nerve (*2*). Note the recess (*r*), which is created by removal of the apex of the anterior clinoid process without opening of the cavernous sinus.

thin and fragile, and in the majority of cases large compartments of the cavernous venous plexus are found in this area. These anatomical conditions constrain further exposure of the ICA.

The anatomical condition in fetal and infant skulls differs from the adult condition in several ways. The course of the ICA is almost straight and the anterior knee is much less pronounced. The fibrous ring at the dural transition point of the ICA is not yet clearly formed. Dissection was carried out easily along the ICA, which is richly surrounded by connective tissue, thus being clearly separated from the cavernous venous plexus (11). This suggests that the pericarotid tissue layer of the adult may be regarded as a remnant or the abundant connective tissue in fetal cavernous sinuses.

DISCUSSION

Aneurysms located in the paraclinoid and infraclinoid area represent 1.3 to 5% of all intracranial aneurysms (8, 12, 30). In patients with subarachnoid hemorrhage or severe neurological symptoms, neurosurgical management is mandatory. One of the main problems in aneurysm surgery is to obtain proximal control of the parent artery. In our experience, many of the so-called carotid-ophthalmic aneurysms show the aneurysm neck extending partly extradurally (21), which is especially true with infraclinoidal aneurysms; these may also cause subarachnoid hemorrhage (20).

There are several differing approaches to the management of carotid-ophthalmic and paraclinoidal aneurysms. Removal of the anterior clinoid process, with additional opening of the optic canal, has been advocated to reach carotid-ophthalmic aneurysms (15, 30). Other authors favor more extensive opening of the optic canal and subsequent mobilization of the optic nerve instead of removal of the anterior clinoid process (25). Operation of paraclinoid aneurysms, however, has not given reassuring results (15).

This anatomical study demonstrates the possibility of a more extensive approach, especially to the paraclinoid carotid artery. Although our ipsilateral approach also starts by drilling of the anterior clinoid process and by partial opening of the osseous optic canal, thus providing additional space, mobilization of the carotid C_3 segment is still inhibited by the strong radial attachment of dural fibers that form a fibrous tissue ring around the artery. Sharp transection of this ring allows more extensive mobilization of the carotid artery by blunt preparation along the loose connective tissue layer that surrounds the artery. This preparation can be performed under direct vision to the point where the cranial nerves, which pass through the superior orbital fissure, hinder further dissection. By this procedure, 4 to 8 mm are gained along the C_3 segment, which corresponds to the height of the anterior clinoid process (13). An additional 2 to 4 mm can be gained by blunt preparation without direct vision. This results accessibility to and control of nearly the entire C_3 segment of the ICA (Fig. 6).

Problems with this approach may arise from extensive pneumatization of the sphenoid bone, which can also include the anterior clinoid process and which can occasionally cause visual disturbances (24) or may lead to pneumocephalus after removal of the anterior clinoid process (30). Care must also be taken when the roof of the superior orbital fissure is opened, as the 3rd, 4th, 6th, and 1st divisions of the 5th cranial nerve are in close proximity and even small lesions may cause a superior orbital fissure syndrome (28). Therefore we recommend that this group of cranial nerves be maintained within their common connective tissue sheath (Fig. 2*a*), which also contains the blood supply of the nerves (10).

The risk of disruption of the venous compartments of the cavernous sinus is minimal along the anterior aspect of the C_3 segment, where we rarely observed veins (Fig. 7), but is increased in the hollow of the anterior siphon knee (Fig. 8). Here the caroticoclinoid ligament surrounds the ICA, making

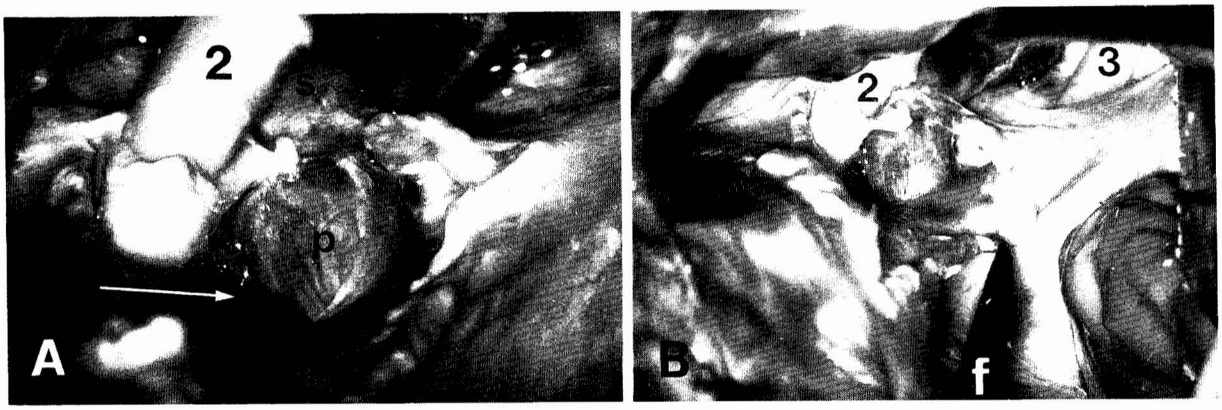

FIG. 4. Left pterional approach to the paraclinoid carotid artery.

A: The fibrous ring has been split; a loose connective tissue layer allows blunt preparation around the paraclinoid carotid artery (*p*), optic nerve (*2*), and supraclinoid carotid artery (*s*). Note that further preparation along the proximal segment of the ICA is possible with blunt instruments (*arrow*) (see also Fig. 6).

B: Further preparation along the ICA under direct vision is limited by the oculomotor nerve (*3*) running through the superior orbital fissure. The forceps (*f*) demonstrates the course of the oculomotor nerve. Optic nerve (*2*).

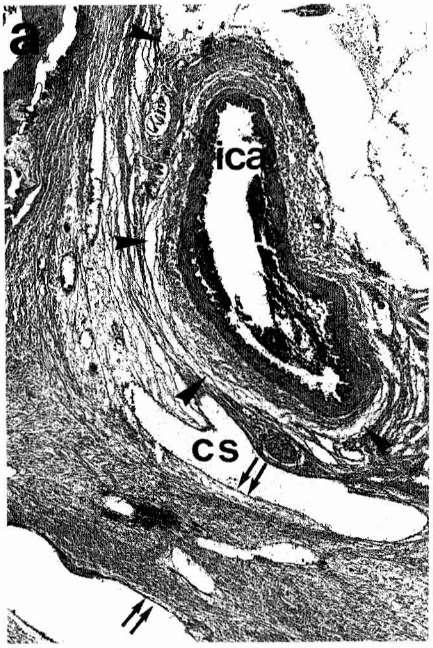

FIG. 5. Horizontal section through a left-sided ICA at the level of dural transition. Abundant connective tissue surrounds the artery, and large venous compartments (*cs*) are present at the hollow of the siphon knee. *Arrowheads* indicate the cleavage plane for preparation. Anterior clinoid process (*a*), caroticoclinoid ligament (*between double arrows*), internal carotid artery (*ica*).

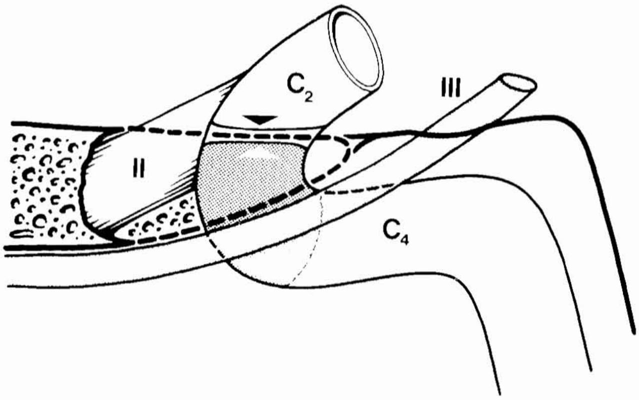

FIG. 6. Schema demonstrating the parts of the C_3 segment of the ICA that are accessible by the proposed approach (*dotted areas* of the ICA). The segment that can be reached under direct vision is shown as the *densely dotted area*. Further preparation is limited by the extraocular motor nerves, whereas blunt preparation without direct vision allows access to more caudal parts of the artery (*sparsely dotted area*). The anterior clinoid process is removed, and the osseous optic canal is opened. *Arrowheads* point at the location of the fibrous dural ring that becomes apparent after removal of the anterior clinoid process. Optic nerve (*II*), oculomotor nerve (*III*), supraclinoid carotid artery (*C2*), anterior siphon knee (*dotted area*), horizontal part of the ICA (C_4). The 4th, 6th, and 1st divisions of the 5th cranial nerve are omitted for clarity.

dissection more difficult, and the venous compartment sometimes is separated from the ICA only by a thin connective tissue layer. In about 6% of skull bases (13, 14), however, a bony connection between the anterior and middle clinoid processes may be seen to form an osseous ring around the ICA (Fig. 1) in the hollow of the anterior siphon knee. This condition, when present, proves advantageous for the surgical approach as the removal of the bone exposes the entire C_3 segment of the ICA without compromising the cavernous sinus.

In fetal and infant specimens, the ICA is richly surrounded by connective tissue, not only in its C_3 segment but all along the "intracavernous" section (11). The ICA is clearly separated from individual veins that form the cavernous venous plexus. This supports the concept that the ICA does not course inside a large, single venous sinus (11, 17–19, 26, 27).

Certain conditions, such as cases of medially pointing infraclinoidal aneurysms of smaller size, favor a contralateral approach instead of the ipsilateral one (20). In this approach, the tuberculum sellae must be drilled away, which leads in most cases to an opening of the sphenoid sinus. The medial wall of the optic canal and the bone next to the carotid artery must be removed. This part of the sphenoid corpus is usually thin and sometimes even missing (5). With this contralateral approach, the radial fibrous ring must be opened on the medial side of the ICA (Fig. 8) to give access to the pericarotid tissue layer. This approach requires special care of the ophthalmic artery. The ophthalmic artery usually arises from the anteromedial aspect of the intracranial ICA, close to the

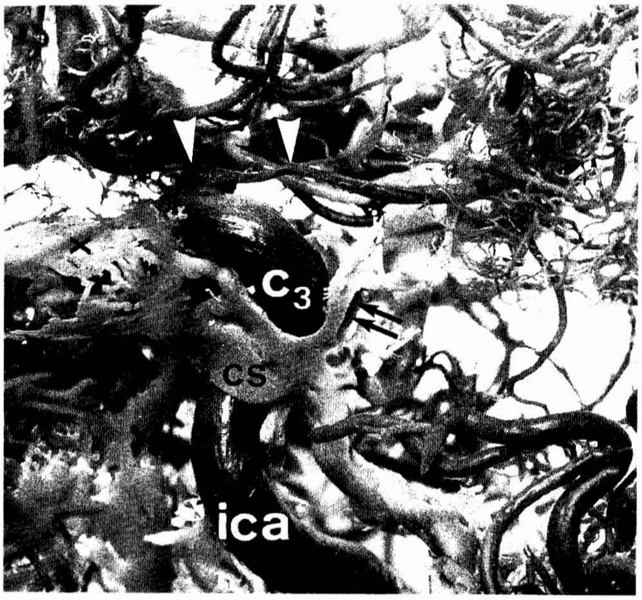

FIG. 7. Anterior view of a corrosion cast of methylmethacrylate-injected venous (*light*) and arterial (*dark*) vessels in the sellar area. The entire anterior aspect of the siphon knee (C_3) is free of venous compartments. Left internal carotid artery (*ica*), ophthalmic artery (*arrowheads*), cavernous sinus (*cs*), superior ophthalmic vein (*double arrows*), anterior and inferior intercavernous connections (×).

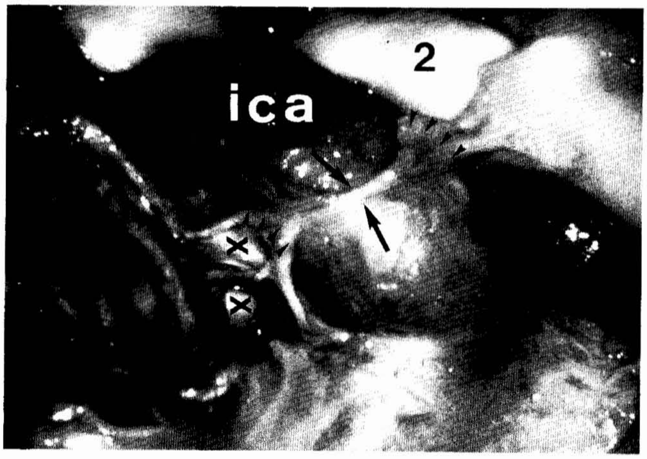

FIG. 8. Left parasellar area, medial view. Gelatin-injected internal carotid artery (*ica*) after removal of the lateral wall of the sphenoid sinus, exposing the fibrous ring (*arrows*) from medially. The artery is clearly separated from a compartment of the cavernous sinus (×) and shows a connective tissue cover caudal to the fibrous ring. The proposed incision site (*arrowheads*) of the connective tissue layer for further preparation of the C_3 segment. Optic nerve (*2*).

dural transition point. The site of its origin varies from medial to lateral with decreasing frequency. The origin of the ophthalmic artery may also be woven into the dura mater, or it may arise completely extradurally (5, 14). This was, however, never seen in our material. When working underneath the contralateral optic nerve, one can approach the whole anterior siphon knee of ICA in its anterior and anteromedial aspect.

The present anatomical study, together with neurosurgical experience (20, 21), suggests a more generous indication for operation and a more extensive surgical approach in the direct management of paraclinoidal aneurysms and of those carotid-ophthalmic aneurysms that extend into the extradural space. In cases of tumors that involve the medial sphenoid ridge, the lateral wall of the cavernous sinus, or the apex of the orbit, the ICA may be encased by tumor tissue. In such cases, the pericarotid tissue can serve as a guide layer that facilitates tumor removal from the wall of the ICA.

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Reprint requests: Engelbert Knosp, Department of Neurosurgery, Medical School, University of Vienna, Währingergürtel 18-20, A-1090 Vienna, Austria.

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COMMENT

The authors are to be congratulated on identifying the part of the C_3 segment of the internal carotid artery that is situated outside the intracranial surface of the dura mater and the venous structures forming the cavernous sinus. There are numerous lesions whose treatment would be helped by exposure of the paraclinoidal segment of the artery by unroofing of the optic canal and removal of the anterior clinoid process. This information will prove especially helpful in dealing with aneurysms that involve the dural folds at the level of the anterior clinoid process. The review of the anatomy on the medial side of the paraclinoidal segment of the artery in the region of the sphenoid sinus also will prove helpful in dealing with carotid-cavernous fistulas, as reported by Laws (1).

Albert L. Rhoton, Jr.
Gainesville, Florida

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