Intracavernous Aneurysms and Carotid-Cavernous Fistulas. A Clinicopathological Study

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Summary

The location of the original sites of the lesions was studied in 22 non-traumatic and 21 traumatic intracavernous carotid aneurysms in which the neck of the aneurysm was confirmed, and also in 23 traumatic carotid-cavernous fistulas in which the location of the fistula was identified. In the cavernous sinus, common sites of non-traumatic and traumatic carotid aneurysms as well as traumatic carotid-cavernous fistulas were the C_3-segment and C_4–C_5 junction of the internal carotid artery although 27 per cent of non-traumatic carotid aneurysms originated in the C_4-segment of the carotid artery.

An anatomical study of 37 cavernous sinuses removed from 23 cadavers revealed the following findings.

The inner surface of the venous sinus was covered with endothelial cell layers. The size and shape of the venous sinuses vary considerably, but they can be divided into three major groups: 1) the broken (58 per cent) or 2) the unbroken (33 per cent) according to the amount of trabeculae and 3) the small scattered venous channel without trabeculation (9 per cent).

The third, fourth and fifth cranial nerves ran through the lateral wall without exception, but the sixth cranial nerve was found in the lateral wall in only 48 per cent of the specimens. The internal carotid artery was entirely surrounded by the venous sinus in 72 per cent of the cavernous spaces studied.

Based on the above findings, the possibility of direct surgery on aneurysms in the cavernous sinus and carotid-cavernous fistulas is discussed.

Key words: Cavernous sinus, microsurgical anatomy, direct surgery intracavernous carotid aneurysm, carotid-cavernous fistula

Introduction

The pathological nature of intracavernous carotid aneurysms is different from that of aneurysms originating in other parts of the cerebral arteries. Rupture of this aneurysm causes formation of a carotid-cavernous fistula and presents various pathological manifestations. Since Delens[37] first report in 1870, it has been known that posttraumatic intracavernous carotid aneurysms will often cause massive epistaxis. There have been numerous innovative suggestions concerning the treatment of these aneurysms and carotid-cavernous fistulas from various fields of study, reflecting the unique anatomical features of this region. However, there are a few cases which cannot be treated by these less risky maneuvers and which direct surgery is desirable. The pioneers of direct surgery of intracavernous aneurysms and carotid-cavernous fistulas were Browder[3] and Parkinson,[24,25,27,29] but no standard technique has been established so far.

On the other hand, the anatomy of the "cavernous sinus" has drawn the attention of scholars in various fields of medicine since Winslow (1732)[41] named this sinus the "cavernous sinus" comparing it to the corpus cavernosum of the penis. For neurosurgeons,

the microsurgical anatomy of the cavernous sinus has particular importance, and yet the anatomy of this region poses many unanswered questions as follows: (1) Is the cavernous sinus an unbroken venous channel or a small venous plexus? (2) Do the so-called trabeculae really exist in the cavernous sinus or not? and (3) Where is the actual location of the carotid artery and four cranial nerves?

The aims of this paper are to answer all three questions, to identify the common locations of the intracavernous aneurysms and carotid-cavernous fistulas, and also to discuss the possibility of a direct surgical approach to these lesions. To avoid confusion, the whole intradural structure will be called the "cavernous space" and the venous channel in the cavernous space will be called the "cavernous venous sinus" in this paper.

Materials and Methods

Location of the lesions was studied in 21 cases of posttraumatic intracavernous carotid aneurysms[6-8,16,21,22,34,37,38,40,42] and 23 cases of traumatic carotid-cavernous fistulas[4,6,10-13,15,35,38,40] where the aneurysm neck or fistula was confirmed, in addition to 22 cases of nontraumatic intracavernous carotid aneurysms[5,16,18,19,21,36] also with identified necks. Another study was performed on 23 cadavers whose skull bases containing bilateral cavernous sinuses were removed en bloc with the help of an electric saw. Twelve cavernous spaces of 12 cadavers were frozen at $-150°C$ with liquid nitrogen, and then they were coronally cut in the middle to inspect the inner structure macroscopically. The remaining 25 cavernous sinuses were fixed in 10 per cent formalin and the sphenoidal bones were re-

moved before serial sections were prepared and stained with Hematoxylin and Eosin to be studied microscopically.

Results

I. Common locations of aneurysms and carotid-cavernous fistulas

1. Non-traumatic intracavernous carotid aneurysms

Eight cases (36 per cent) were located in the C_3 segment of the carotid artery (Fischer). Two cases (9 per cent) were found at the junction of the ophthalmic artery and two other cases (9 per cent) at the junction of the meningo-hypophyseal artery. Four cases (19 per cent) were found at the C_4-C_5 junction (Fig. 1).
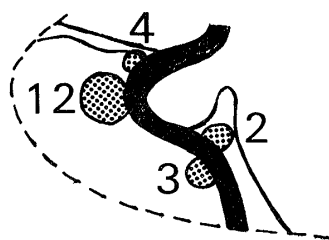
2. Traumatic intracavernous carotid aneurysms

Traumatic aneurysms were found in the C_3-segment of the carotid artery in 12 out of 21 cases (57 per cent). Four cases (19 per cent) were located at the border between the cavernous space and the intradural space, three cases (14 per cent) at the portion between the C_4-C_5 junction and C_5-segment of the carotid artery shortly after entering the cavernous space,
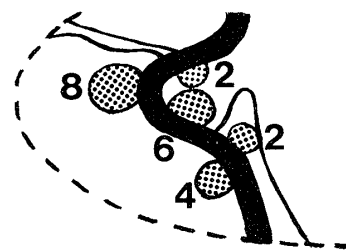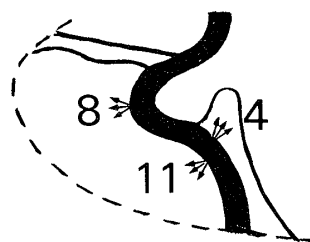

Non-traumatic Aneurysms

Fig. 1   Location of 22 non-traumatic intracavernous carotid aneurysms.

Traumatic Aneurysms

Traumatic C-C Fistulas

Fig. 2   Location of traumatic intracavernous carotid aneurysms and traumatic carotid-cavernous fistulas.
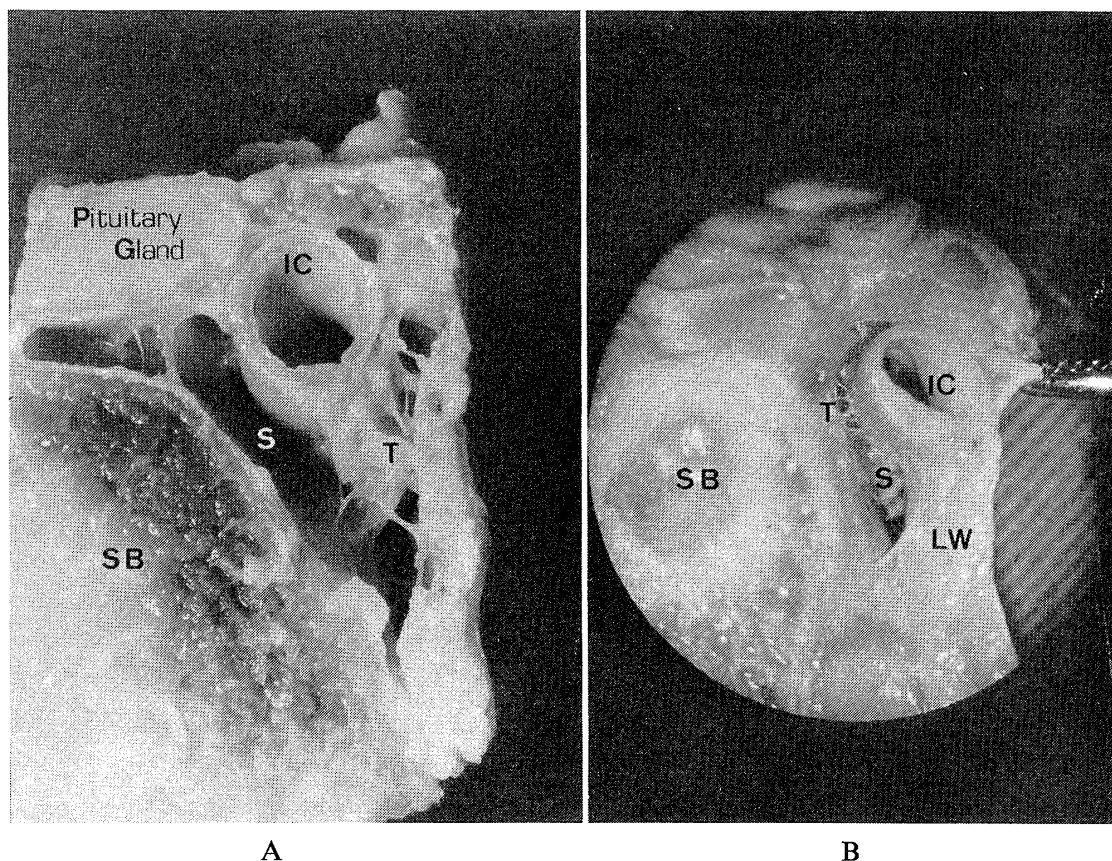
A   B

Fig. 3 Inner structure of the cavernous space cut in the middle.
   A: A broken venous channel with many trabeculae. The internal carotid artery is totally surrounded by venous sinuses.
   B: An unbroken venous channel with few trabeculae. The internal carotid artery and cranial nerves are located in the lateral wall.
   IC: Internal carotid artery,   LW: Lateral wall,   S: Venous sinus,   SB: Sphenoid bone,   T: Trabeculae.

and two cases (10 per cent) at the junction of the meningohypophyseal artery (Fig. 2).

3. Traumatic carotid-cavernous fistulas

Eleven of 23 cases (48 per cent) of traumatic carotid-cavernous fistulas were located at the C_4-C_5 junction. Eight cases (35 per cent) were in the C_3-segment, and four others (17 per cent) were at the junction of the meningo-hypophyseal artery (Fig. 2).

II. Macroscopic study of the cavernous space

The cavernous space can be divided into three major types according to the shape of the cavernous venous sinus. In the first type, the cavernous venous sinus itself forms a non-branching tube and there are irregularly-placed multiple trabeculae. This type is the so-called "broken venous channel" (Fig. 3A). In the second type, the cavernous venous sinus is also a large non-branching tube (Fig. 3B).

It is an "unbroken venous channel", because there are only a few trabeculae interlacing between the channel and the sinus wall.

In the third type, most of the cavernous space is occupied by reticulated tissues unrelated to the venous sinus. Small venous channels are scattered here and there within the tissue, which has no trabeculae or thier equivalents (Fig. 5). Of 12 macroscopically studied cavernous spaces, seven belonged to Type I (58 per cent), four belonged to Type II (33 per cent), and only one belonged to Type III (9 per cent). No venous plexus type was found.

III. Microscopic study of the cavernous space

1. Cavernous wall

According to a microscopic study of the sections of the cavernous wall, the lateral wall consisted of an outer layer of dense connective tissues and an inner layer of loose connective tissues. The lateral wall contained a network
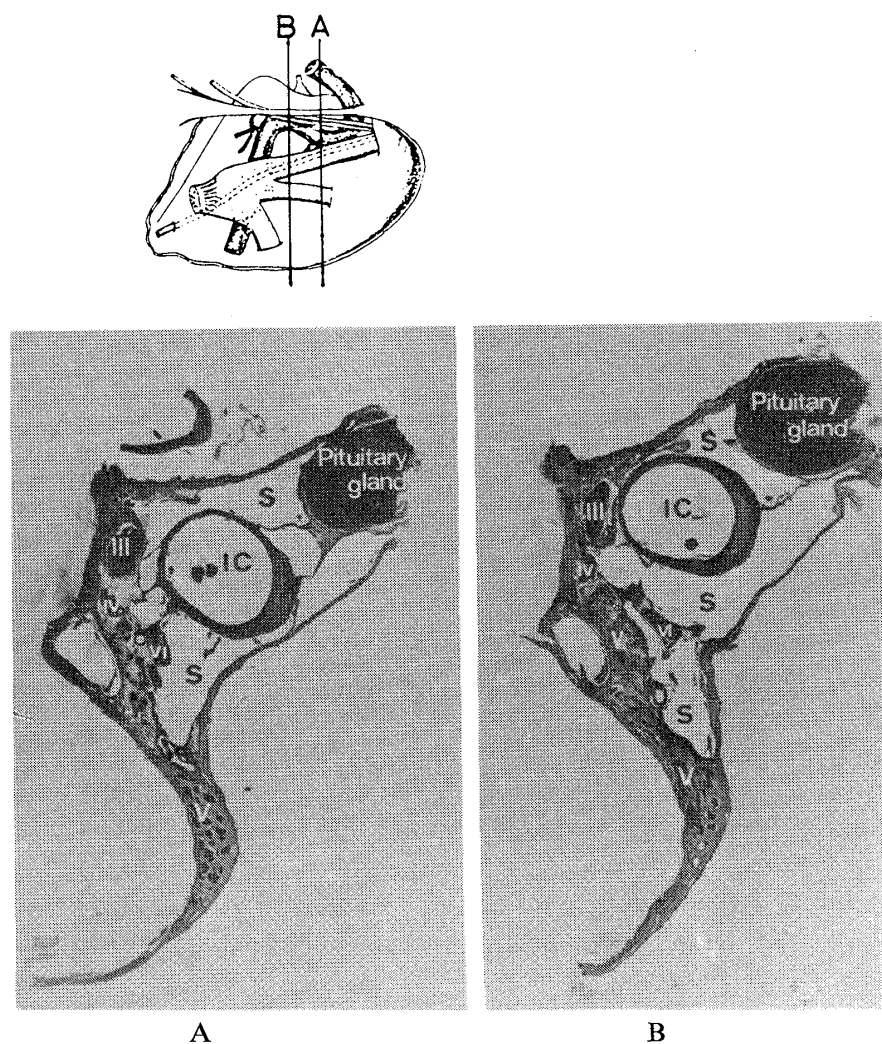
Fig. 4 A and B: Serial sections of the cavernous space cut coronally. The venous
sinus is large, and the internal carotid artery is totally surrounded by the venous
sinus. The sixth cranial nerve is in the lateral wall in Section A, but it is totally
surrounded by the venous sinus in Section B. The 5th and 6th cranial nerves are
split into multiple rootlets instead of being single trunks.
IC: Internal carotid artery,   III: Third cranial nerve,   IV: Fourth cranial
nerve,   V: Fifth cranial nerve,   VI: Sixth cranial nerve,   S: Venous sinus.

of sympathetic nerves, arterioles, a considerable amount of adipose tissues and so on. The third, fourth and fifth cranial nerves ran through the lateral wall in all cases, but the sixth nerve was located in the lateral wall only in 48 per cent of the specimens in the middle of the cavernous space. Within the lateral wall the fifth and sixth cranial nerves were frequently split into multiple rootles instead of the usual single trunk formation. The ophthalmic nerve has 13 to 46 rootlets, 33 on the average, the maxillary nerve 8 to 30 rootlets, 19 on the average, and the sixth nerve only one to seven rootlets, two on the average. A large part of the lateral wall was often occupied by these rootlets. The internal carotid artery was surrounded by the venous sinus in 72 per cent of the specimens, but was located in the lateral wall in only 28 per cent. The medial cavernous wall consisted of thin connective tissues, whereas the upper roof consisted of thick connective tissues similar to those in the lateral wall. Adipose tissues were often found in the cavernous roof and in the lateral wall, and less frequently in other parts of the cavernous space (Fig. 4).

2. Trabeculae

Trabeculae existed in 92 per cent of the cavernous spaces, either densely or sparsely. In two specimens (8 per cent) small venous sinuses were scattered about, and a large portion of
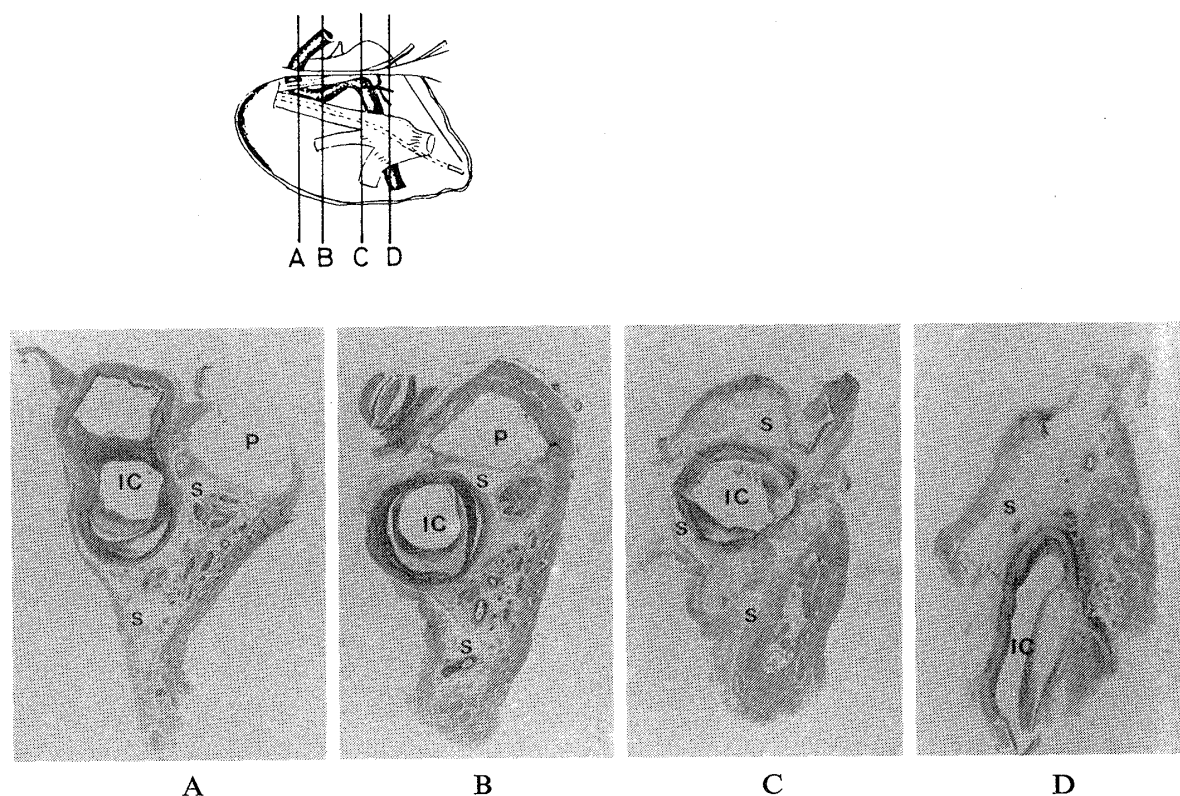
Fig. 5 A, B, C and D: Serial sections of the cavernous space cut coronally. The cavernous venous sinus is small and scattered. A major part of the cavernous space is occupied by the internal carotid artery, cranial nerves, arterioles, and abundant adipose and connective tissues. There is nothing corresponding to trabeculae.

IC: Internal carotid artery, S: Venous sinus, P: Lumen after the anterior clinoid process was removed.

the cavernous space was occupied by the internal carotid artery, four cranial nerves (III, IV, V, and VI), arterioles, and abundant adipose and connective tissues, but no trabeculae were found (Fig. 5). When trabeculae were present, they were entirely covered with endothelial cell linings. Some were as thin as filaments and others were so thick that bands would be the proper term. All of them consisted mainly of collagenous fibers but some contained arterioles and nerves (Fig. 6).

Discussion

According to our study of the coronal sections of the middle of the cavernous space, which was removed en bloc with the base of the skull and then frozen at $-150°C$ with liquid nitrogen, 58 per cent of these cavernous spaces were broken venous channels with dense trabeculae, 33 per cent were unbroken venous channels with a few trabeculae, and the remaining nine per cent were small scattered venous channels without trabeculae. On the other hand, a microscopic study revealed that 72 per cent of the internal carotid arteries were surrounded by venous channels in their course. Fourty-eight per cent of the 6th cranial nerves ran through the lateral wall, and the remaining 52 per cent of the 6th cranial nerves were surrounded by venous channels. Based on surgical observations and a corrosion study, Parkinson[23-27] came to the conclusion that the "cavernous sinus" is a venous plexus incompletely surrounding the internal carotid artery with various sizes of veins dividing and anastomosing with each other. Bennot[2] rejected the ordinary concept of the cavernous sinus, and insisted that the cavernous sinus is filled with nerves and the internal carotid artery surrounded by a plexus of veins. He regarded the so-called "trabecula" as nothing but the cut surface of the small vessel wall. From microsurgical dissection of 34 cavernous sinuses, Bedford[1] stated that the cavernous sinus is an unbroken venous channel and that there is no plexus of veins. Rhoton and his coworkers[9] reached the same conclusion from
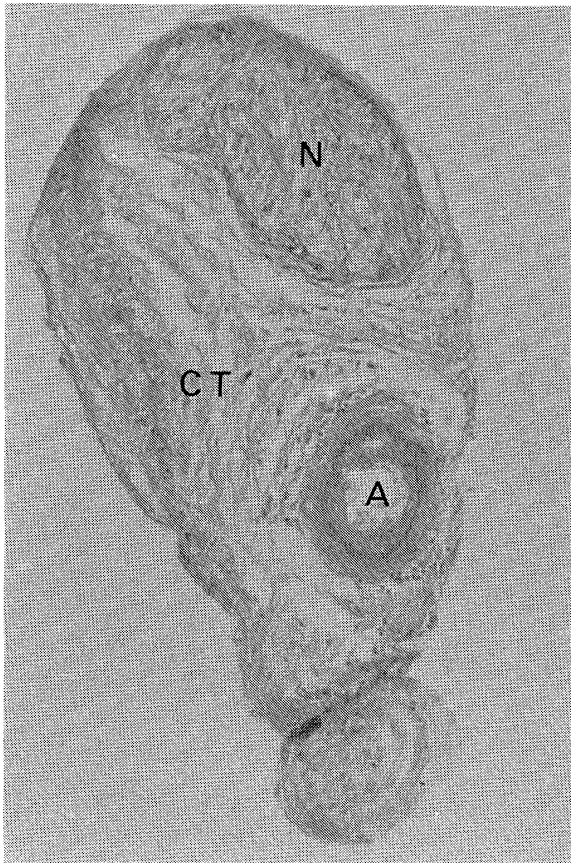
Fig. 6 Transverse sections of the trabeculae, containing the nerve and arterioles, surrounded by endothelial cells. Supporting tissues consist of collagenous fibers.   N: Nerve,   A: Arteriole, CT: Collagenous fibers.

their findings in microsurgical dissections.

Why did scholars reach such diverse opinions? The answer is that they looked into this unique region called the cavernous sinus using different methods of study. The cavernous venous sinus is surrounded by endothelial cells, but has no vascular wall of its own. In the authors' experience with microsurgical dissection of 15 cavernous spaces, it was often difficult to identify the wall of the venous sinus during dissection. Abundant adipose tissues in the lateral wall or hemorrhages during dissection make the dissection very difficult. It is impossible to observe the intact original state by dissection.

This is not surprising since the cavernous space is not a simple structure. The cavernous sinus is usually a large non-branching venous channel, forming either a broken venous channel with dense trabeculae or an unbroken venous channel with few trabeculae. The internal carotid artery is surrounded by the venous channel in 72 per cent of the cases.

As to the location of intracavernous carotid aneurysms and carotid cavernous fistulas, non-traumatic aneurysms, traumatic aneurysms and traumatic carotid-cavernous fistulas tend to appear in the C_3-segment and at the C_4-C_5 junction, although 27 per cent of the non-traumatic aneurysms were found in the middle portion of the cavernous space or in the C_4-segment of the internal carotid artery. The first direct surgery for such a traumatic carotid-cavernous fistula and aneurysm was performed by Browder (1937)[3] who opened the cavernous wall of a traumatic carotid-cavernous fistula and packed the cavernous sinus with muscle pieces, which led to successful healing. Since then, 12 cases of direct surgery have been reported in the literature (Table 1). In addition to his reported four cases, Parkinson[28,29] referred to his experience with direct surgery performed on a large number of intracavernous aneurysm cases.

The following three points must be considered before undertaking direct surgery inside the cavernous sinus: (1) Which part of the cavernous wall should be approached first? (2) How should the aneurysm and carotid-cavernous fistula be treated? (3) How can bleeding from the cavernous sinus be prevented?

Parkinson[23-26,29]   recommended the triangular space surrounded by the lower margin of the 4th cranial nerve, the upper margin of the 5th nerve, and the slope of the dorsum sellae and clivus, as the ideal route of direct surgery. According to Rhoton and his coworkers,[9,30-33] the upper line of this triangular space is 8 to 20 mm long, 13 mm on the average, the base line is 5 to 24 mm long, 14 mm on the average, and the slope of the dorsum and clivus is 3 to 14 mm long, 6 mm on the average. By this approach through the triangular space, direct surgery on the aneurysms and carotid-cavernous fistulas located in the posterior half of the C_4-segment to the C_4-C_5 junction of the internal carotid artery becomes possible. On the other hand, Laws[17] described their direct surgery through the medial antero-inferior wall of the cavernous sinus using the contralateral transethmoidal or transsphenoidal route, a "cross court" approach. The authors' study on the serial

Table 1   Review of direct surgery in the cavernous sinus.

Author & Year	Sex	Age	Diagnosis	Approach	Treatment
Browder 1937	M	33	CCF (Traumatic)	Intracranial transdural	Packing with muscles
Parkinson 1965	M	29	CCF (Traumatic)	Intracranial transdural	The carotid artery was packed with muscle, then clipped and ligated
1967	M	38	CCF (Traumatic)	Intracranial transdural	The intervening fistulous segment of the carotid artery was resected
1973	M	26	CCF (Traumatic)	Intracranial transdural	Clipping of fistula and closure of the opening in the arterial wall
	W	20	CCF (Spontaneous)	Intracranial transdural	Coagulation and division of abnormal vessels
Laws 1979	M	25	CCF (Traumatic)	Transspenoidal	Packing with muscles
Mullan 1979	3 cases		CCF	Intracranial transdural	Packing with muscles
Johnston 1979	M	3	Aneurysms (both sides)	Intracranial transdural	Coating of aneurysms
Van Dellen 1980	M	62	Aneurysm (Traumatic)	Intracranial transdural	Trapping of the carotid artery in the cavernous sinus
	W	22	Aneurysm (Traumatic)	Intracranial transdural	A large amount of clot was removed from the aneurysm

sections of the cavernous sinus indicated that in the majority of the normal cases there is sufficient distance between the C_3-segment of the internal carotid artery and the antero-medial surface of the cavernous wall with the venous sinus between them (Fig. 7). This means that a safe approach into the cavernous sinus is possible through the cavernous wall of this portion. Direct surgery seems possible on the C_3-segment and the anterior portion of C_4-segment through this approach, as stated by Laws and others.[17]

The first choice in the treatment of carotid-cavernous fistula is suturing and closure of the fistula, as done by Parkinson[27] in his case. If this is not possible, the second best method may be to pack the whole cavernous side of the fistula with homograft muscles, gelform or glues, as carried out by Browder[3], Laws[17] and Mullan.[20] For aneurysms, neck-clipping or coating may be performed, although it is possible to close the opened neck after resecting the aneurysm sac, as done in the treatment of carotid-cavernous fistulas.

The biggest problem to be faced in the direct surgery is how to handle bleeding from the cavernous sinus. In his first case of direct surgery, Parkinson[24] opened the cavernous sinus after temporarily occluding the great vessels from the aortic arch under hypothermia, but voluminous hemorrhagic flooding from the incision necessitated temporary cardiac arrest. He also applied profound hypothermia and cardiac arrest in his subsequent cases. Such a formidable procedure reduces the opportunity of direct surgery on lesions of this area to a minimum.

Laws et al.[17] have reported in their recent papers that they have operated directly on bilateral traumatic carotid-cavernous fistulas without relying on profound hypothermia and cardiac arrest. They have temporarily occluded the fistula on the operated side by simply using the Pralo balloon occlusion catheter, and also temporarily occluding the contralateral common carotid artery with a Rommel tourniquet. These procedures successfully controlled bleeding from the cavernous sinus.

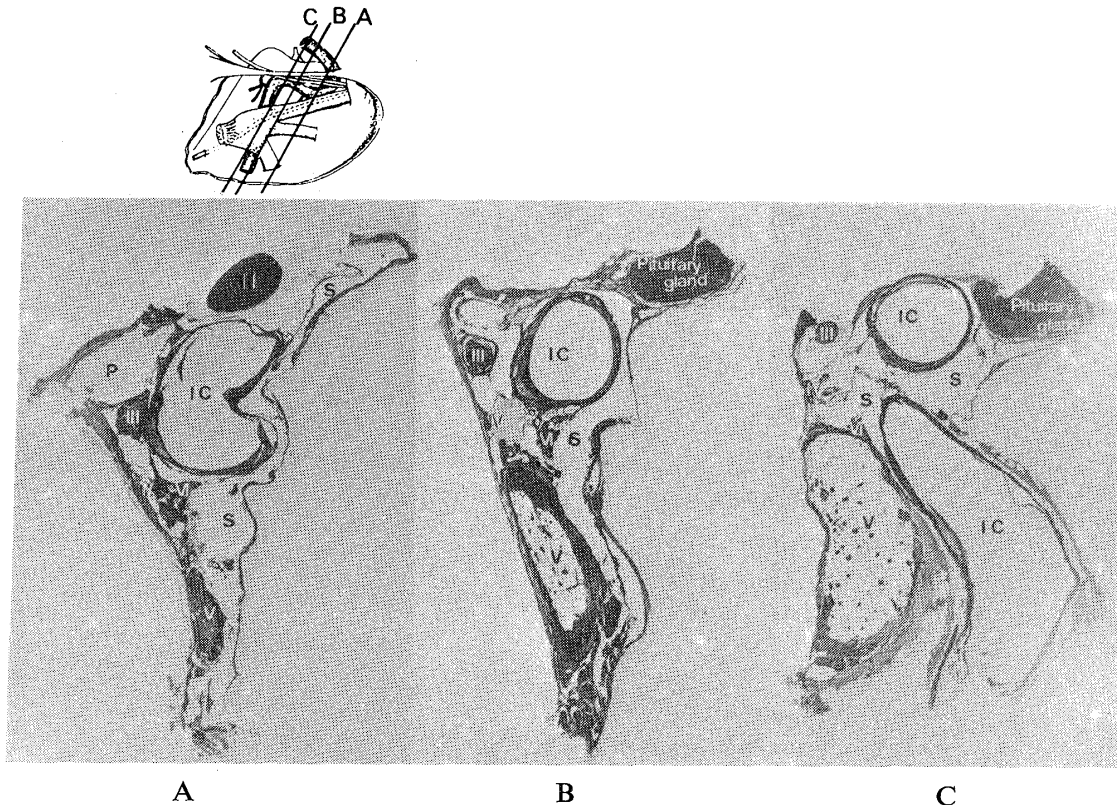Once direct surgery has been technically

Fig. 7 A, B and C: Serial sections of the cavernous space. A certain distance between the C₃-segment of the carotid artery and the medial wall of the sinus is filled with venous sinuses in specimen A. In specimen B, showing the middle section of the cavernous space, the internal carotid artery and the 6th cranial nerve are both surrounded by venous sinuses.

   IC: Internal carotid artery, III: Third nerve, IV: Fourth nerve, V: Fifth nerve, VI: Sixth nerve, S: Venous sinus, P: Lumen after the anterior clinoid process was removed.

improved and simplified by the introduction of more and more refined and innovative procedures, it is hoped that direct surgery will be used more aggressively on those cases which do not yield to safer and simpler management.

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