A Surgical Approach to the Cavernous Portion of the Carotid Artery

Anatomical Studies and Case Report*

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Occasionally the neurosurgeon is confronted with a situation in which he wishes he could safely approach and leave the cavernous portion of the carotid artery. This paper records a case of traumatic carotid-cavernous fistula which was carried through many stages, including definitive surgery, and which illuminated certain related anatomical observations.

Case Report

F.H., a 29-year-old man, suffered a head injury in 1944. Following this he noticed the gradual development of a right pulsating exophthalmus and, shortly thereafter, a noise in his head synchronous with his pulse. He was examined for the first time in 1947. The pulsations and bruit could be obliterated by digital compression of the right common carotid. A carotid arteriogram revealed abnormal vasculature about the right orbit. The common carotid was ligated in April, 1947, with resulting cessation of the pulsation and the bruit. In December of the same year, the patient noticed the occasional return of a bruit.

By 1956, the bruit was continuous and the pulsations and proptosis had increased. There was marked engorgement of the vessels of the conjunctiva, lids and adjacent area of the face. Left and right carotid angiograms both demonstrated the right carotid-cavernous fistula; in the orbit as well as along the base of the frontal lobe were large tortuous veins filled with arterial blood. The right internal carotid artery was ligated under local anaesthesia. The external carotid artery and available branches on the left were double ligated. In both this neck exposure and the previous similar exposure on the right all the exposed veins were unduly large. Aside from some blanching of his nose and ears during the Winnipeg winter, there was no significant postoperative change.

In December, 1956, a right transfrontal craniotomy was performed. The bone was exceedingly hard without diploi but with multiple large channels containing blood of arterial pressure and colour. The roof of the orbit and the undersurface of the frontal lobe were covered with continuous, dilated vessels visible beneath the skin across the entire width of the upper and lower lid as well as above the eyebrow and down across the cheek.
Surgical Anatomy of Cavernous Carotid

billowing, thin-walled, looping veins up to 1 cm. in diameter. Swirling arterial blood was visible in many of these loops. These were encountered all the way down to the chiasm. The exposure resembled a proctoscopic passage through massive internal hemorrhoids. The vascular loops were easily compressed but on release instantly bulged back obscuring the vision. Eventually an internal carotid of normal size was visualized and clipped. Search for the ophthalmic artery was out of the question. The bruit was absent for about 4 hours, and in May, 1957, it was still diminished. Moreover, the exophthalmus was reduced so that he was able to wear sunglasses that had previously rubbed his right eye.

In June, 1962, he experienced a nearly fatal exsanguinating epistaxis. The exophthalmus was now as bad as ever with marked engorgement of the superficial vessels of the lids, conjunctiva and adjacent skin (Fig. 1). A retrograde brachial angiogram with films taken 6 per second revealed that the ascending arteries of the neck were unusually large and tortuous. There was no anomalous contribution from the vertebral to the carotid system but in the angiogram sequence the trapped carotid segment filled before the facial arteries or the ophthalmic artery had been visualized (Figs. 2 and 3). The trapped segment must have been fed from collateral vessels as well as from the ophthalmic system. Efforts to introduce muscle emboli into the internal carotid above the old occlusion in the neck were unsuccessful. The continuous bruit, waxing with systole and waning...
small branches within the cavernous sinus. The position and spacing of the cranial nerves as they pass the cavernous carotid varies with the modern tests used,\textsuperscript{2,3,4,8,11,15,17,18} Walsh's\textsuperscript{18} neuro-ophthalmology has an accurate photograph of the nerves as seen from the lateral aspect but it is impossible to see the relationship to the carotid or the dura in this photograph. One text states that the relationship, “is actually of little clinical importance as the nerves are grouped so closely that a lesion is apt to affect all together.”\textsuperscript{8}

Normal Anatomy. We have made over 200 cavernous carotid dissections on routine autopsy specimens and have reported the position and connections of the normal branches of the cavernous carotid as seen in these dissections.\textsuperscript{12}

A meningo-hypophyseal trunk departs from the midline of the carotid posteriorly just before the apogee of the first forward curve (Fig. 4). It immediately divides into 3 divisions and the proximal portions of these divisions lie freely in the space beneath the roof of the cavernous sinus. The first division is the artery to the tentorium which departs between the leaves of that structure. The second is the dorsal meningeal artery which remains in the extension of the cavernous sinus around the dorsum and down the clivus. The third is the inferior hypophyseal artery which passes beneath the outer layer of the dura lining the floor of the sella. The last 2 divisions form an arterial circle around the root of the dorsum sellae by anastomosing directly with their fellows from the opposite side. This meningo-hypophyseal trunk with its 3 divisions was present in all of the dissections.

In approximately 80 per cent of the dissections an artery to the inferior cavernous sinus arises \(\frac{1}{2}\) cm. further along from the inferior lateral aspect of the carotid. It supplies primarily the contents and coverings of the inferior cavernous sinus as it runs down over the 6th nerve medial to the ophthalmic division of the 5th nerve and the Gasserian ganglion. Among other connections it makes a direct anastomosis with the middle meningeal at the foramen spinosum (Figs. 4 and 5).

McConnell's\textsuperscript{9} capsular artery departs from the inferior medial aspect of the carotid approximately \(\frac{1}{2}\) cm. beyond the nearest proximal branch and runs directly across the floor of the sella anteriorly to anastomose with the same artery of the other side (Fig. 4).

The curvature of the cavernous carotid varies considerably, but the relative positions of the meningo-hypophyseal trunk and the artery to the inferior cavernous sinus are quite constant. The carotid is free within the spaces of the cavernous sinus and not in direct contact with bone except at the point of entrance and again at the most anterior portion inferiorly. The dorsal meningeal and inferior hypophyseal arteries both approximate bone very closely as they depart from the cavernous sinus medially (Fig. 6).

The 3rd and 4th cranial nerves always enter the dural roof of the cavernous sinus as pictured in standard texts. The 3rd is in front and slightly lateral to the 4th and both are medial to and beneath the ridge of the free margin of the tentorium at their point of entry (Figs. 4, 5 and 7). The point of entry of the 3rd nerve is almost immediately above the meningo-hypophyseal trunk. The 3rd and 4th nerves then become closely approximated and run together within the dural roof of the cavernous sinus throughout their course to the superior orbital fissure. The ophthalmic division of the 5th nerve enters the cavernous sinus low down and remains in the inferior lateral dural wall of the cavernous sinus as it slopes (Fig. 4) forward and slightly upward to depart through the superior orbital fissure. The 6th nerve enters from beneath Gruber's ligament and then bends around the proximal portion of the cavernous carotid artery and runs medial to and parallel to the ophthalmic division of the 5th nerve (Figs. 4 and 5). It alone is free within the cavernous sinus; the others are always within the dural wall of the sinus. Occasionally the 6th nerve is double up to its point of entrance into the dura and often from there on throughout its course in the cavernous sinus (Fig. 8). When this is so the 2 di-
Fig. 4. Schematic drawing based on numerous photographs of two separate specimens in varying stages of dissection. Structures overlying an artery are drawn as though transparent. On the right, the dura has been removed from one-half of the hypophyseal fossa and from a portion of the dorsum sellae as well as from the cavernous sinus and the entire middle fossa. A portion of the dorsum sellae itself has also been removed leaving only the posterior clinoid and the supporting bone. A portion of the first division of the 5th nerve has been resected to show the first portions of the artery to the inferior cavernous sinus, running over the 6th nerve on the right. The first portion of the inferior hypophyseal artery is viewed through the posterior clinoid. The minute branch of the inferior hypophyseal artery that wraps around the posterior clinoid is shown up to the region where the dorsum sellae has been cut away. The strip of dura enclosing the entrance of the 3rd and 4th nerves has been preserved by the artist while the 3rd and 4th nerves are pulled laterally. The point of departure of the tentorial artery from the space of the cavernous sinus to its course between the two dural layers is immediately beneath the entrance of the 4th nerve to its dural cleft. The trifurcation of the meningo-hypophyseal trunk is uncovered just adjacent to the lateral margin of the posterior clinoid. On the left, the trifurcation of the meningo-hypophyscal trunk is seen through the strip of dura left over the roof of the cavernous sinus. On this side the nerves are all removed as well as the dura of the middle fossa in order to demonstrate the entire length of the anastomosing portion of the artery of the inferior cavernous sinus. The carotid is pulled outwards to show the origin of the capsular artery. The first portion of the inferior hypophyseal artery on the right is viewed through the posterior clinoid. The minute branch of the inferior hypophyseal that wraps around the posterior clinoid is shown up to the region where the dorsum sellae has been cut away to better visualize the intrasellar portion of the inferior hypophyseal artery. The anastomosis between the two dorsal meningeal arteries is shown across the root of the dorsum just beneath the cut-away in the bone. Note that the tentorial artery is much closer to the undersurface than the superior surface owing to the difference in thickness of the two dural layers of the tentorium. On the right, the strip of dura enclosing the entrance of the 3rd and 4th nerves has been preserved by the artist while the 3rd and 4th nerves are drawn laterally. The actual departure of the tentorial artery from the space of the cavernous sinus to its course between the two dural layers is at a point immediately beneath the entrance of the fourth nerve to its dural cleft. (Drawing used with the permission of the Canadian Journal of Surgery.)
Fig. 6a. Corrosion specimen of right cavernous carotid. D = dorsum; MH = meningo-hypophyseal trunk with the inferior hypophyseal artery descending downwards to the left and the dorsal meningeal artery (DM) descending straight downwards (the tentorial artery has fallen off with the other soft parts); ICS = artery to the inferior cavernous sinus running down into the right middle fossa. Note the cavernous carotid itself is not in contact with bone throughout the majority of its course as contrasted to some of the branches of the cavernous carotid making intimate contact with bone.

Fig. 6b. Corrosion specimen left cavernous carotid lateral view. White arrow = meningo-hypophyseal trunk. Black arrows = artery to inferior cavernous sinus. Again note that the cavernous carotid itself is not in direct contact with bone except in its most anterior portion.

anterior portion. When the relatively thick walled cavernous carotid is torn there is probably but one fistulous opening although it could flow from either direction (Fig. 10). On the other hand, if one of the thin walled branches were torn as it approximates bone there would be in effect two fistulous sources, and no amount of packing or trapping of the carotid would control the distal source (Fig. 10).

A spontaneous cavernous carotid fistula is presumably due to an aneurysmal rupture. Again, presumably, the aneurysm probably

visions remain adjacent in the normal position of a single 6th nerve. There is a considerable triangular space between the 3rd and 4th nerves above and the 6th nerve and ophthalmic division of the 5th nerve below, with a wide base posteriorly represented by the slope of the dorsum and clivus (Figs. 4, 5 and 9). This space has been present in over 200 cavernous sinus dissections including all ages.

Pathological Anatomy. In the few instances in which we have been able to visualize a traumatic fistula it has always been in the
develops at the junction of one of these constant branches from the cavernous carotid. In the presence of an established fistula the cavernous carotid must obtain its collateral supply from branches already present. We have no evidence that a major artery such as the carotid can grow any new branches from its lumen. Hayes prepared a diagram of the course of anastomotic channels in the presence of a cavernous carotid fistula.

Surgical Anatomy. A surgical approach to this region must provide safe entrance and exit through the cavernous sinus without damage to the cranial nerves. It must give adequate exposure of the cavernous carotid and its main branches. Our dissections suggested 2 possible routes both utilizing the triangular space. The space could be entered extradurally as in a Gasserian ganglion approach dissecting above the ganglion and the ophthalmic division and then opening through the dura propria posteriorly. After numerous trial approaches on cadavers, this route was abandoned since the exposure was tight and there was no certainty of a safe dural closure.

A direct transdural approach through the lateral wall of the cavernous sinus was mapped out. The important landmark is the entrance of the 3rd and 4th cranial nerves as they are seen above the free margin of the tentorium. An incision placed 4 mm. beneath the point of disappearance of the 3rd nerve may be extended anteriorly approximately 2 cm., parallel to the slope of the 3rd and 4th nerves (Fig. 7). When the margins are retracted there is good exposure of the cavernous carotid and 2 of its branches, the meningohypophyseal trunk and the artery to
Fig. 8. Autopsy dissection of left cavernous sinus viewed from above. Forcep retracting pons severed at junction with midbrain putting the bilaterally duplicated 6th nerves on stretch as they go forward to enter the dura. C=arrow pointing to left cavernous carotid just above the doubled 6th nerve on the left; V=right 5th nerve departing from pons going across to enter the dura; II=the 2 severed optic nerves; P=pituitary stalk. The threads have gently separated the two 6th nerves as they pass through the left cavernous sinus. Although they are separate structures they occupy the same horizontal plane as the normal 6th nerve and hence are both safe from the incision described and do not alter the triangular space.

Meckel's cave. Retraction of these margins is safe because the 3rd and 4th nerves are imbedded in the dura below. The 6th nerve is free well below in the cavernous sinus and comes into sight at the bottom edge of the exposure. The most forward aspect of the cavernous carotid as it turns upward cannot be

Fig. 9. Diagrammatic sketch of the triangular space outlined in dotted lines. The 3rd and 4th nerves are above with the 5th and 6th below. It is seen that an incision placed within this triangular space will afford access to the cavernous carotid and its two largest branches.

Fig. 10a. Diagram of intact collateral circulation connecting the 2 cavernous carotids. Collateral, "balanced," as indicated by opposing black arrows.

Fig. 10b. Diagram with fistula in left cavernous carotid. A single opening of arteriovenous shunting. Both carotids will feed this fistula with the collateral flowing from right to left as indicated by the double black arrows.

Fig. 10c. Diagrammatic representation of tear of an anastomotic artery within the cavernous sinus. There are 2 arteriovenous shunts as both the proximal and distal torn arterial ends are fistulous (white arrows). Trapping of the left carotid would never control the distal fistula. The collateral is again from right to left (black arrows).
seen through this exposure unless the artery is grasped and pulled backwards. However, utilizing this method the entire circumference of the artery can be incorporated in a clip placed from behind if this becomes necessary. It will be found that the cavernous carotid is firmly adherent anteriorly and is of course immobile where it goes up to pierce the dura and become supraclinoid. Closing sutures must be placed near the margin of the dural incision in order to avoid incorporating one of the cranial nerves, particularly in the anterior portion of the incision.

### Operation in Present Case

**Operation.** The lateral transdural approach was used in the case we have described. It was conducted under hypothermia with the heart exposed. The great vessels from the arch of the aorta were occluded and an incision made in the cavernous sinus. There was voluminous hemorrhagic flooding. It was obvious that there was an arterial supply from the intercostal arteries to those of the head and thence into the carotid segment by way of the collaterals described. Cardiac arrest was provided and the hemorrhage was immediately controlled. Retractors were placed and an excellent view of the cavernous portion of the carotid and its branches was obtained (Fig. 7). Surprisingly these collateral branches appeared no larger than those in normal cadavers. It was possible to pass ligatures around the carotid to elevate it, incise it and pack it with muscle; the artery was then clipped and ligated. The dura was sutured and the heart restarted. There was no leakage and no bruit. The patient awakened with no evidence of any neurological deficit other than the mechanical limitation of right eye movement which he had previously. There was ocular movement in the field of action of all three nerves. Corneal sensation was normal. He maintained a normal level of consciousness although there was considerable respiratory difficulty. The neurological picture remained normal. Tragically, he died rather rapidly on the 3rd postoperative day from some poorly understood and even less appreciated cardio-pulmonary complications.

At autopsy the meningo-hypophyseal trunk and its proximal branches were only slightly enlarged. The ophthalmic artery was of normal size. There were no additional collateral branches of the cavernous carotid artery, either gross or microscopic, although it had participated in an arteriovenous fistula for over 18 years. The draining veins of the orbit and head were huge.

### Discussion

In spite of marked variation in curvature of the carotid siphon, dissection of over 200 routine autopsy cavernous sinuses has revealed several constant features. The meningo-hypophyseal trunk always originates just before the apogee of the first forward curve, and the proximal portion of its divisions are always near the roof of the cavernous sinus. The 3rd and 4th nerves are always imbedded in the dural roof of the cavernous sinus, entering just above and slightly behind the trifurcation of the meningo-hypophyseal trunk. Their point of entry is not visible from a lateral approach over the free margin of the tentorium. If one were to roll the free margin down in order to see forward to the small triangular indentation where the 3rd nerve actually enters the dura, the incision should be centered below this point. No one should attempt this approach without having verified the landmarks in a cadaver.

The artery of the inferior cavernous sinus, when present, always departs over the 6th cranial nerve and runs down medial to the first division of the 5th cranial nerve. The subsequent branchings are inconstant and are frequently taken over by secondary branchings from the tentorial artery or the inferior hypophyseal artery.

The triangular space between the nerves has been present in every one of the 200 cases dissected and affords adequate access to this region of the cavernous sinus. The posterior margin of the cavernous sinus is represented by the slope of the dorsum and clivus, although the cavernous sinus actually continues around into the sinus extending down the clivus.

The most anterior surface of the carotid siphon is not entirely accessible through the direct trans-dural approach unless one wishes to risk damaging the cranial nerves as they converge toward their point of exit at the superior orbital fissure. This segment of carotid is fairly immobile, adherent anteriorly and superiorly where it pierces the dura to become supraclinoid. If the artery cannot
be drawn into the field, a fistula in this area can only be controlled by opening the carotid and packing it. If both the supraclinoid carotid and the ophthalmic arteries could be controlled first, it would only be necessary to clip or ligate in front of the last normal branch of the cavernous carotid. In some individuals this would be the artery to Meckel’s cave, but to be absolutely safe the ligature or clip should be placed ½ cm. or more anterior to the artery of Meckel’s cave so that it includes McConnell’s artery as the latter departs from the medial aspect and out of sight. Since this exposure through the triangular space provides an adequate access to the 2 main collateral branches, the \textit{meningo-hypophyseal trunk} and the artery to Meckel’s cave, it should provide access to most spontaneous fistulae. This is assuming that spontaneous fistulae are due to a ruptured berry aneurysm developing at one of these bifurcations. An aneurysm developing at the point of departure of McConnell’s artery would be accessible from this approach unless the carotid were rolled from its bed.

We found no evidence that the cavernous carotid develops any new branches in the presence of an arteriovenous fistula, although every pre-existing normal collateral source through the meninges, bone, scalp and neck enlarges to provide a greater flow. It must be remembered that the trapped segment involved in carotid cavernous fistulae includes also the carotico-tympanic arteries as available collateral. Our own observations indicate that none of these collaterals enlarge appreciably at or near the points of junction with the carotid. Quite possibly the rate of flow accelerates through these small short channels as they empty into the much larger channel of significantly lower resistance. If this is true, the volume per unit of time is greatly increased. The \textit{meningo-hypophyseal trunk} in most individuals is of a calibre nearly equal to the ophthalmic artery in the same person. The volume available through these normal collateral channels to the cavernous carotid is amazing. Failures in trapping procedures for carotid saccular aneurysms may be due to this collateral system.

Traumatic carotid cavernous fistulae may be of two types (Fig. 10). The first has a single fistula resulting from a tear in the wall of the carotid. The second type has 2 fistulous sources resulting from a tear across one of the small branches within the cavernous sinus. Failure of trapping operations for the traumatic type of carotid cavernous fistula may well indicate that the second type of fistula is present or that the collateral supply is too voluminous.

\textbf{Summary}

Observations concerning some constant relationships of the cavernous carotid artery have been presented. These include the normal branches and their connections and their relationship to the adjacent bone, cranial nerves and dura. Two types of traumatic carotid cavernous fistulae have been considered, a single source from a tear in the carotid wall, and a double source from a tear of a collateral branch. A surgical approach to the cavernous carotid has been described utilizing these anatomic constants. The approach has been successful in a human case which has been reported here.

\textbf{References}

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Surgical Anatomy of Cavernous Carotid

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* The author's work was completed and the paper had been presented prior to the publication of the excellent article by Schnürer and Stattin. The anatomical findings in the main are similar to theirs.