Neurovascular relationships of the sphenoid sinus

A microsurgical study

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Kiyotaka Fujii, M.D., Steven M. Chambers, Ph.D., and Albert L. Rhoton, Jr., M.D.

Department of Neurological Surgery, University of Florida Health Center, Gainesville, Florida

The increasing use of the transsphenoidal approach to sellar tumors has created a need for more detailed information about the neurovascular relationships of the sphenoid sinus. To better define this anatomy, 25 sphenoid sinuses were examined in cadavers, with attention to the neural and vascular structures in the lateral wall of the sinus. Three structures produced prominent bulges into the lateral wall of the sinus; they were 1) the optic nerves, 2) the carotid arteries, and 3) the maxillary branches of the trigeminal nerve. Over half of these structures had a bone thickness of less than 0.5 mm separating them from the sphenoid sinus, and in a few cases, they were separated by only sinus mucosa and dura.

1) The optic canals protruded into the superolateral part of the sphenoid sinus in all except one side of one specimen. In 4% of the optic nerves, only the optic sheath and sinus mucosa separated the nerves from the sinus, and in 78%, less than a 0.5-mm thickness of bone separated them. 2) The carotid arteries produced a prominent bulge into the sphenoid sinus in all but one side of one specimen. In 8% of the carotid arteries there were areas where no bone separated the artery and the sinus. 3) The maxillary branches of trigeminal nerves bulged into the inferolateral part of the sphenoid sinus in all except one side of two specimens. One side of one specimen had no bone, and 70% had less than a 0.5-mm thickness of bone separating the nerve from the sinus. The importance of these findings in transsphenoidal surgery is reviewed.

Key Words: microneurosurgery, sphenoid sinus, transsphenoidal surgery, carotid artery, trigeminal nerve, cavernous sinus, optic nerve

In the adult, the sphenoid sinus separates the cavernous sinuses, the cavernous segments of the carotid arteries, and the optic, extraocular, and trigeminal nerves. In addition, it separates the pituitary gland from the nasal cavity. The sphenoid sinus, which is contained within the body of the sphenoid bone, is present as minute cavities at birth. Its main development takes place after puberty. In early life, it extends backward into the presellar area and, subsequently, invades the area below and behind the sella turcica, reaching its full size in adolescence. As the sinus enlarges, it extends close to, or even partially encircles the optic canals. When the sinus is exceptionally large, it extends into the roots of the pterygoid processes or greater wing of the sphenoid, and may invade the basilar part of the occipital bone. As age advances, the sinus frequently undergoes a further enlargement associated with absorption of its bone walls. Occasionally, there are gaps in its bone walls and the mucous membrane may lie directly against the dura mater.

The fact that, with age, the pituitary fossa becomes separated from the sinus by only a thin layer of bone led to the transsphenoidal route being used for operations on sellar tumors as early as 1907. However, this approach fell into disfavor because of the high incidence of complications and because of the difficulty in operating through such a deep, narrow exposure. However, in 1958, Guiot reintroduced this technique using radiofluoroscopy to visualize laterally...

Fig. 1. Stepwise dissection of the lateral wall of the right half of a sellar type of sphenoid sinus and its adjacent structures. Upper Left: The sphenoid sinus and sellar area have been divided in a midsagittal plane. The optic nerve is seen proximal to the optic canal. The opticocarotid recess separates the carotid prominence and optic canal. The septum in the posterior part of the sinus is incomplete. Upper Right: The sinus mucosa and thin bone of the lateral sinus wall have been removed to expose the dura covering the carotid artery, the second trigeminal division (V₂) just distal to the trigeminal ganglion, and the optic nerve. Lower Left: The dura is opened to expose the carotid artery, the optic nerve in the optic canal, the second trigeminal division below the carotid artery, and the abducens nerve (VI) between the first trigeminal division (V₁) and the carotid artery. Lower Right: Lateral view of the specimen showing an area of cavernous sinus. The oculomotor (III) and trochlear (IV) nerves are seen above. The intracavernous portion of the carotid artery is seen medial to the trigeminal root (V) and the ophthalmic, maxillary (V₂), and mandibular divisions (V₃) of the trigeminal nerve. The petrous portion of the carotid artery is seen in cross section below the trigeminal nerve. The opening into the sphenoid sinus is located between the first and second trigeminal divisions.

The depth and position of the surgical instruments, and this, in combination with the intense illumination and magnification provided by the operating microscope, afforded the possibility of a safer operation and more accurate visualization of normal and pathological tissues. These innovations caused the transsphenoidal approach to be used with increasing frequency. In approaching the sphenoid sinus surgically, there may be a tendency to forget that the carotid arteries and optic nerves may project into the sinus and be covered by a thin or incomplete shell of bone. In a previous study, Renn and Rhoton found that in a small percentage of cases the carotid arteries and optic nerves were separated from the sinus cavity by only a layer of sinus mucosa and dura, and in many cases there was only a thin shell of bone separating these structures and the sinus. The purpose of this study was to further investigate the relationships between the sphenoid sinus and the adjacent intracranial neural and vascular structures.

Material and Methods

Twenty-five sphenoid sinuses and adjacent structures including the optic nerves and cavernous sinuses of both sides were removed from the cranial base of
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Fig. 2. Stepwise dissection of the lateral wall of the right half of a presellar type of sphenoid sinus and its adjacent structures. Upper Left: The sphenoid sinus and sellar area have been divided in a midsagittal plane. The sinus air cavity does not extend posteriorly below the sellar floor. The optic nerve is visible above the pituitary gland. The oculomotor (III), trigeminal (V), and abducens (VI) nerves lie posterior to the clivus. A large dural venous sinus (basilar sinus) is seen posterior to the clivus. Upper Right: The sinus mucosa and thin bone of lateral wall have been removed to expose the carotid artery, the second trigeminal division (V₂), the optic nerve in the optic canal, and the dura. Lower Left: Lateral view of the same specimen with the lateral dural wall of the cavernous sinus removed. The structures within the cavernous sinus or its dural wall include the oculomotor, trochlear (IV), abducens, and trigeminal (V) nerves and the ophthalmic (V₁), maxillary, and mandibular divisions (V₂). The carotid artery lies medial to the nerves. Lower Right: The trigeminal nerve has been reflected forward to expose the abducens nerve, sphenoid sinus, trigeminal impression, and the artery of the inferior cavernous sinus (Art. Inf. Cav. Sinus).

adult cadavers and divided sagittally in the midline to yield 50 specimens in which the lateral wall could be examined and opened to identify the intracranial structures lateral to the sphenoid sinus. The specimens were examined and dissected under ×3 to ×40 magnification provided by the operating microscope.

Results

Sphenoid Sinus

Hamberger, et al., classified the sphenoid sinus into three types, conchal, presellar, and sellar, depending on the extent to which the sphenoid bone was pneumatized (Figs. 1 and 2). In the conchal type the area below the sella is a solid block of bone without an air cavity. In the presellar type the air cavity does not penetrate beyond a plane perpendicular to the sellar wall. The sellar type is most common and in this type the air cavity extends into the body of the sphenoid below the sella and may extend as far posteriorly as the clivus. No conchal types were encountered in this study of adults; the conchal type is most common in children before the age of 12 years, at which time pneumatization begins within the sphenoid sinus. In this study, the presellar type of sinus was found in 24% and the sellar type in 76% of our specimens. In
TABLE 1

<table>
<thead>
<tr>
<th>Site of Measurement</th>
<th>Sellar Type Sinus (19 Cases)</th>
<th>Presellar Type Sinus (6 Cases)</th>
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<tbody>
<tr>
<td></td>
<td>Range</td>
<td>Mean</td>
</tr>
<tr>
<td>planum sphenoidale</td>
<td>0.2-1.4</td>
<td>0.6</td>
</tr>
<tr>
<td>tuberculum sellae</td>
<td>0.2-4.3</td>
<td>1.0</td>
</tr>
<tr>
<td>anterior wall of sella</td>
<td>0.1-0.7</td>
<td>0.4</td>
</tr>
<tr>
<td>floor of sella (only sellar type)</td>
<td>0.1-3.0</td>
<td>0.7</td>
</tr>
<tr>
<td>clivus</td>
<td>0.2-10.0</td>
<td>2.7</td>
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TABLE 2

<table>
<thead>
<tr>
<th>Location</th>
<th>Length of Prominence in Sphenoid Sinus</th>
<th>Thickness of Bone Over Prominence</th>
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<tbody>
<tr>
<td></td>
<td>Range</td>
<td>Mean</td>
</tr>
<tr>
<td>optic canals</td>
<td></td>
<td></td>
</tr>
<tr>
<td>maxillary nerve</td>
<td></td>
<td></td>
</tr>
<tr>
<td>prominence</td>
<td></td>
<td></td>
</tr>
<tr>
<td>carotid prominence:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>presellar segment</td>
<td></td>
<td></td>
</tr>
<tr>
<td>infrasellar segment</td>
<td></td>
<td></td>
</tr>
<tr>
<td>retrosellar segment</td>
<td></td>
<td></td>
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<tr>
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TABLE 3

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<thead>
<tr>
<th>Level of Measurement</th>
<th>Diameter of Carotid Artery</th>
<th>Width of Carotid Prominence</th>
<th>Thickness of Bone Over Carotid Prominence</th>
<th>Distance Between Carotid Prominences of Two Sides</th>
<th>Distance Between Carotid Arteries of Two Sides</th>
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</thead>
<tbody>
<tr>
<td></td>
<td>Range</td>
<td>Mean</td>
<td>Range</td>
<td>Mean</td>
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<tr>
<td>tuberculum sellae</td>
<td>4.3-5.6</td>
<td>5.0</td>
<td>3.0-6.5</td>
<td>4.6</td>
<td>0-0.6</td>
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<tr>
<td>anterior sellar wall</td>
<td>4.4-5.7</td>
<td>5.1</td>
<td>2.0-6.0</td>
<td>3.9</td>
<td>0.1-1.0</td>
</tr>
<tr>
<td>sellar floor</td>
<td>4.5-5.6</td>
<td>5.2</td>
<td>1.0-7.0</td>
<td>3.5</td>
<td>0.1-1.5</td>
</tr>
<tr>
<td>dorsum sellae</td>
<td>4.6-5.8</td>
<td>5.2</td>
<td>2.0-8.0</td>
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<td>0.1-1.5</td>
</tr>
<tr>
<td>clivus</td>
<td>4.6-6.0</td>
<td>5.2</td>
<td>2.0-8.0</td>
<td>5.2</td>
<td>0-10.0</td>
</tr>
</tbody>
</table>

Hamberger and associates' study, a presellar type was found in 11% and a sellar type in 86%. Renn and Rhoton found sellar and presellar types in 80% and 20% of adults, respectively.

The depth of the sphenoid sinus is defined as the distance from the ostium of the sphenoid sinus to the closest part of the sella. This measurement approximates the length of the path within the sinus through which instruments must pass in transsphenoidal surgery to reach the anterior sellar wall. Sellar depth ranged from 12.0 to 23.0 mm (mean 17.1 mm) in our study. Another measurement important in transsphenoidal surgery is the thickness of the anterior sellar wall and sellar floor. In the sellar type of sinus, the thickness of the anterior sellar wall ranged from 0.1 to 0.7 mm (mean 0.4 mm) as compared to 0.3 to 1.5 mm (mean 0.7 mm) for the presellar type. The thickness of bone covering the sinus was defined at the planum sphenoidale, tuberculum sellae, anterior sellar wall, sellar floor, and the clivus. The thickest bone was found at the clivus and tuberculum sellae and the thinnest along the anterior sellar wall (Table 1).

**Carotid Arteries**

The carotid artery is the most medial structure within the cavernous sinus. It rests directly against the lateral surface of the body of the sphenoid bone and its course is marked by a groove in the bone, the carotid sulcus, which defines the course of the intracavernous portion of the carotid artery. As the sphenoid sinus expands and its walls resorb, the carotid sulcus produces a prominence within the sphenoid sinus. Of the 50 carotid arteries examined, 49 produced a prominence in the lateral wall of the sphenoid sinus (Figs. 1 to 4). This prominence was most pronounced in those specimens with maximal pneumatization of the sphenoid. It varied in size from a small focal bulge to a serpigenous elevation marking the full course of the carotid artery along the lateral wall of the sphenoid sinus. This carotid prominence can be divided into three parts: the retroinsellar, infrasellar, and presellar segments. The first part, the retroinsellar segment, was located in the posterolateral part of the sinus. This segment of the prominence is present only in well pneumatized sellar type sinuses in which the air cavity extends laterally in the area below the dorsum. The second part, the infrasellar segment, is located below the sellar floor. The third part, the presellar segment, is located beside the anterior sellar wall. Out of 50 specimens, 98% had presellar, 80% had infrasellar, and 78% had retroinsellar prominences. Any part of the prominence may be present and the others
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Fig. 3. Anterior views of sellar type sphenoid sinus. Upper Left: The anterior wall of the sella has been removed to expose the pituitary gland. The specimen has been split in the midline. The air cavity is wider below than above, as is typical in a well pneumatized specimen. The optic canals lie above; the carotid prominences are lateral to the sella, and the trigeminal prominence lies below the carotid prominence. Upper Right: The specimen is opened slightly to provide a better view of the lateral wall and the carotid and trigeminal prominences. Lower Left: Mucosa, dura, and bone of the lateral wall of the sinus have been removed to expose parasphenoidal segments of the carotid artery. The sympathetic nerves (Symp. N.) lie anterior to the left carotid artery, and the orbital contents are seen laterally. Lower Right: The specimen is spread slightly to show the abducens (VI) nerve and the ophthalmic (V₁), maxillary (V₂), and mandibular (V₃) divisions of the trigeminal nerve (V).

absent. If all three parts are present and connected, they form a serpigenous bulge marking the full course of the carotid artery (Fig. 3).

Only the presellar part of the carotid prominence is present in a presellar type of sphenoid sinus, and it was this part which was also most frequently present in the sellar type of sinus. The length of these segments is listed in Table 2. The corresponding arterial segments are slightly longer than the segments of the prominence because of tortuosity of the artery. This tortuosity, although present, is limited by the dural walls of the cavernous sinus, particularly if the artery is encircled by a ring of bone formed by the union of the anterior and middle clinoid processes. Serial coronal sections through the cavernous sinus show that the artery does not always nestle into the bony carotid sulcus on the intracranial surface of the sphenoid bone, but is separated from it by an extension of the cavernous sinus.

The bone separating the artery and the sphenoid sinus was thinner over the anterior than the posterior parts of the carotid prominence and was thinnest over the part of the artery just below the tuberculum sellae (Table 3). A layer of bone less than 0.5 mm thick separated the artery and sinus in 88% of cases and areas of absence of bone between the artery and the sinus were present in 8% (Table 4). One specimen had bilateral defects in the bone separating the sphenoid sinus and carotid arteries. There was only one of 50 specimens in which the bone separating the artery and the sinus was as thick as 1.0 mm. The bone over the carotid arteries was frequently as thin or thinner than...
FIG. 4. Paintings of the sphenoid sinus. 

Upper Left: Anterior view of the sinus with the anterior and right lateral walls cut away to show the relationship of the sinus to the carotid artery, optic nerve and chiasm, pituitary gland, anterior (A.C.A.) and middle cerebral (M.C.A.), anterior communicating (A.Co.A.), recurrent (Rec. A.) and ophthalmic (Ophth. A.) arteries, and the oculomotor (III), trochlear (IV), abducens (VI), and trigeminal (V) nerves, and the ophthalmic (V1), maxillary (V2), and mandibular (V3) divisions of the latter. Note the prominence over the carotid artery.

Upper Right: View through the sinus with the right lateral wall removed to expose the optic nerve, carotid artery, ophthalmic and maxillary trigeminal divisions, and abducens nerve just lateral to the wall of the sphenoid sinus.

Lower Left: Superior view of the sellar region with openings cut into the sphenoid sinus through the clivus, the planum sphenoidale, and between the first and second trigeminal divisions on left. Lower Right: Left lateral view of an area of sphenoid sinus and its adjacent structures. The trigeminal nerve is pulled inferiorly to expose an abducens nerve which has two rootlets. The opening into the sphenoid sinus is located between the first and second trigeminal divisions. The meningohypophyseal artery and the artery of the inferior cavernous sinus (Art.Inf.Cav. Sinus) arise from the intracavernous portion of the carotid artery. The anterior, middle, and posterior cerebral (P.C.A.), anterior choroidal (A.Ch.A.), basilar (B.A.), superior cerebellar (S.C.A.), and anterior and posterior communicating (P.Co.A.) arteries are seen above or behind the sella.
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that separating the anterior surface of the pituitary gland and the sphenoid sinus. According to Hardy, a blunt instrument introduced laterally allows one to recognize the prominence formed by the carotid artery bulging from within the carotid canal on either side of the sella. Seftel, et al. reported that the carotid arteries produced an elevation in the sphenoid sinus in 65 of 100 specimens. In 53, the bulge was pronounced, and in 14 of the 53, the carotid artery could be traced throughout its entire serpentine course along the sphenoid sinus wall. Renn and Rhoton found 71% of the carotid arteries in their series bulging into the sphenoid sinus. The arterial bulges were usually covered by bone; however, 4% had no bone and 66% had less than a 1-mm thickness of bone separating the artery and the sphenoid sinus. The intracranial surface of the sphenoid bone was covered by periosteum, sometimes referred to as the outer layer of the dura mater, and this and the sinus mucosa separated the air cavity and carotid arteries if no bone was present.

The transverse separation between the carotid prominences of each side was measured at the level of the tuberculum sellae, anterior sellar wall, sellar floor, dorsum sellae, and clivus. The shortest distance between both carotid bulges into the sphenoid sinus was usually located at the level of the tuberculum sellae in our specimens (Table 3). The proximity of the carotid arteries to the midline is important in pituitary surgery. The shortest distance between both carotid prominences of each side was located just below the tuberculum in 72%, at the level of the floor of the sella in 20%, and at the clivus in 8% of our specimens.

**Optic Canals**

The optic canals protruded into the superolateral part of the sphenoid sinus bilaterally in all except one side of a sellar type of sphenoid sinus (Figs. 1 to 4). Two of the 50 specimens had areas where no bone separated the optic sheath and sinus mucosa. In 78% of the optic nerves less than a 0.5-mm thickness of bone separated the optic nerve and sheath from the sinus (Tables 2 and 4). Care must be taken to protect the nerves in the transsphenoidal approach if a defective bone covering exposes them in the sinus. Injury to nerves exposed in the sinus wall may explain some of the cases of unexpected visual loss following transsphenoidal surgery.  

**Trigeminal Nerves**

The segment of the maxillary branch of the trigeminal nerve just peripheral to the ganglion frequently produced prominent bulges into the lateral sinus wall below the sellae, especially if the sinus was well pneumatized (Figs. 1 to 4). Two maxillary nerves of the 50 examined did not produce a bulge into the sinus; these were from specimens with a presellar type of sinus. One of 50 nerves examined had areas where no bone separated the nerve from the sinus mucosa, and 60% had less than a 0.5-mm thickness of bone separating the nerve from the sinus (Table 4). The length of maxillary division bulging into the sinus ranged from 7.0 to 15.0 mm (mean 10.9 mm) (Table 2). An inferior extension of the cavernous sinuses may extend between the maxillary fibers and the sphenoid bone. The trigeminal ganglion and the first and third trigeminal divisions were separated from the lateral wall of the sphenoid sinus by the carotid artery. The abducens nerve courses between the first trigeminal division laterally, and the carotid artery medially (Figs. 1 to 4).

**Discussion**

Arterial hemorrhage, visual loss, and extraocular palsies occurring in the course of transsphenoidal pituitary surgery have commonly been attributed to carotid artery and cranial nerve injury in the para- and suprasellar areas. Injury to the lateral walls of the sphenoid sinus also offers the potential for neural and arterial damage. The optic canals bulge into the superior, the carotid arteries into the midportion, and the trigeminal nerves into the inferior part of the lateral wall of the sinus. More than half of the carotid arteries and optic and trigeminal nerves had areas where a layer of bone less than 0.5 mm thick separated them from the sphenoid sinus, and in a few cases there were areas of absence of bone between them and the sphenoid sinus. Injury to the lateral wall of the sphenoid sinus offers the potential for causing blindness, extraocular muscle palsies, or facial numbness. Forced opening of a transsphenoidal speculum against the lateral walls of the sphenoid sinus could cause injury to the optic, trigeminal, and extraocular nerves. Extreme care should be taken to make certain that the tips of the speculum used for transsphenoidal pituitary operations are not forcefully opened within the sinus, but rather are opened anterior to the sphenoid bone. Forced opening of the speculum within the sinus could
crush the thin bone over the maxillary and optic nerves. Vigorous curetting of the walls of the sphenoid sinus could also cause damage to exposed neural structures.

One of us (A.L.R.) has placed the sellar opening directly over a carotid artery twice during transsphenoidal operations. In each case the artery was recognized and not injured. In one, the carotid prominence was mistakenly thought to represent a prominence over a pituitary microadenoma. The bone is often thicker over the anterior margin of the pituitary gland than over the carotid arteries. The second incident occurred as a result of following what was mistakenly assumed to be a midline septum in the sphenoid sinus to the floor of the sella. The septa within the sphenoid sinus were found in a previous study by Renn and Rhoton to vary greatly in their size, shape, thickness, location, and completeness. The cavities within the sinus were seldom symmetrical from side to side and were often subdivided by irregular minor septa. The septa were often located off the midline as they crossed the floor of the sella. A single major septum separated the sinus into two large cavities in only 48% of specimens and even in these cases the septa were often deflected to one side. Anteroposterior tomograms of the sella are essential to define the relationship of the septa to the floor of the sella for transsphenoidal surgery. Major septa may be found as far as 8 mm off the midline.

In approaching the intrasellar contents by the transsphenoidal route, the sella floor is opened first in the midline and then resected piecemeal to form a window approximately 1 cm square. In some personal clinical cases, the carotid arteries have bulged into this opening even when it has been well placed in the midline. There are reports of massive hemorrhage during surgery, presumably due to injury of carotid arteries. The proximity of the carotid arteries to the midline is extremely important in pituitary surgery. In a previous study, the shortest distance between the two carotid arteries was found in the supraclinoid area in 82% of the cases, in the cavernous sinus along the side of the sella in 14%, and in the sphenoid sinus in 4%. In the shortest distance between the carotid arteries, they approached within 4 mm of each other within the sella turcica and compressed the pituitary from the side. Arterial injury during surgery may be followed by aneurysm formation. Internal carotid aneurysms bulging into the sphenoidal sinus may rupture, causing severe or fatal epistaxis.

In this study, sellar depth (the distance between the ostia of the sphenoid sinus and the anterior sellar wall) averaged 1.5 cm, with a range of 1.2 to 2.3 cm. This measurement defines the length of the path within the sinus through which instruments must pass to reach the sellar wall and is important when selecting instruments for transsphenoidal surgery. The speculum most commonly used for transsphenoidal pituitary surgery is 9 cm in length and its tips should be placed anterior to the sphenoid sinus. In reaching the anterior sellar wall, the depth of the sphenoid sinus (2 cm or more) is added to the 9-cm length of the speculum. Thus, after transversing a distance of 11 to 12 cm, the dissecting instruments must then enter the sella and, if a suprasellar tumor is present, be able to reach above the sella. These distances may be greater in the presence of acromegaly. Therefore, it is important that transsphenoidal instruments have shafts at least 12.0 cm in length. Some transsphenoidal instruments have shafts 9.5 cm in length, barely long enough to reach through the speculum into the sphenoid sinus.

The fact that the carotid arteries, trigeminal nerves, and optic nerves may be exposed by removing the thin wall of the sphenoid sinus offers the possibility of another surgical approach to these structures; optic sheath meningiomas located below and medial to the optic nerve within the optic canal could be approached from this direction; fractures through the optic canal compressing the optic nerve might be decompressed through the sphenoid sinus, and the second trigeminal division might be approached from this direction. The length of carotid artery exposed in the wall of the sphenoid sinus offers the possibility that the intracavernous segment might be exposed by the transsphenoidal approach for trapping procedures, inserting catheters for obliteration of fistulas, or for specialized contrast studies. The close proximity of the cavernous sinus to the lateral wall of the sphenoid sinus offers the possibility that the cavernous sinus might be entered through the thin sphenoidal wall for insertion of wire or other materials used to thrombose arteriovenous fistulas within the cavernous sinus.

References
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Address reprint requests to: Albert L. Rhoton, Jr., M.D., Neurological Surgery, Box J-265, University of Florida Health Center, Gainesville, Florida 32610.