Pterional Approach
PROCEDURE

Although Dandy noted the importance of the keyhole bur hole to approach the optic chiasm and neurosurgeons have long used the subfrontal approach, Yasargil deserves credit for developing the pterional approach. He emphasized that combining the frontotemporal approach with resection of the outer sphenoid wing provides access to the circle of Willis, with minimal retraction of the brain.

In the classic pterional approach, the temporalis muscle and its investing fascia are cut off the bone at the junction between the posterior orbital rim and the zygomatic arch, and through an incision in the temporal line, the muscle can be dissected posteriorly without injury to its nerve or blood supply, thereby minimizing muscle atrophy. However, with this intrafacial approach, there is risk of injury to the frontalis branch of the facial nerve from retraction or dissection. With the muscle-splitting flap described below (and advocated by many surgeons), approximately the front half of the temporalis muscle is dissected anteriorly in conjunction with the skin flap. In this way, there is minimal risk of injury to the facial nerve. One disadvantage of this is that the angle of the approach is altered ever so slightly, and this sometimes requires more retraction of the brain to achieve exposure.

Head Position

For the muscle-splitting flap, the head is extended slightly; this allows the frontal lobe to fall away from the skull base, thus decreasing the need for brain retraction. The head is also rotated approximately 25 to 30 degrees opposite to the side of the craniotomy. Occasionally, it is necessary to put a towel under the patient’s shoulder on the side of the craniotomy. Minimal shaving of the head is required. The incision is made 1.0 to 1.5 cm behind the hairline, so that the scar is not visible.

Skin Flap

The incision is started in front of the ear and carried to the midline, avoiding the anterior limb of the superficial temporal artery. The incision is made through both the skin and the temporalis muscle, and together, they are swept forward. The muscle fibers can be dissected off the cranium with a periosteal elevator and with bipolar coagulation of arterial feeders. This reduces the degree of atrophy of the temporalis muscle (atrophy can occur when a monopolar cutting current is used to separate the muscle from the skull). The skin flap and temporalis muscle are retracted with 3 to 4 fishhooks placed under tension.

Bone Flap

With current craniotomes, it is not necessary to place multiple bur holes. Still, it is helpful to mark on the skull surface the four bur holes that would be required if Gigli saws were used. When a craniotome is used, there is a tendency to limit the craniotomy, thereby compromising exposure. The critical keyhole bur hole is placed just behind the orbital rim, immediately superior to the frontal zygomatic suture. This keyhole provides access to both the anterior and middle cranial fossae. The second bur hole is placed just above the orbital rim, between the inner canthus and the mid-pupillary line. By placing this bur hole medial to the mid-pupillary line, the surgeon can use a more subfrontal approach, if required. The lower this bur hole, the less brain retraction required. Although it is preferable to stay out of the frontal sinus, exposure should never be sacrificed only to preserve the integrity of the sinus. If the frontal sinus is entered and the mucosa has not been violated, a piece of temporalis muscle should be placed in the opening to obliterate the communication. Alternatively, if the mucosa has been violated, it should be removed. A piece of temporalis muscle is used to plug the deep ostium. A third bur hole is placed in the parietal bone 4 cm posterior to the second bur hole in the linea temporalis near the coronal suture. A fourth bur hole is placed low in the squamous temporal bone behind the sphenoid temporal suture. When making the cut between this fourth bur hole and the keyhole bur hole, it is important that the incision swing low and anterior along the floor of the middle cranial fossa. A diamond bur can be used instead of a craniotome to create this fourth cut. This has the advantage of ensuring that the cut is low and anterior, to better expose the temporal lobe. A low and anterior bone cut becomes important when a lateral approach or line of site along the sphenoid wing is desirable for approaching difficult posterior communicating artery aneurysms.

After elevation of the bone flap, it is helpful to remove the outer one-third to one-half of the sphenoid wing down close to the superior orbital fissure. First, the dura mater is stripped off the sphenoid wing with a Penfield dissector or periosteal elevator. Next, a diamond bur is used to drill off the outer sphenoid wing for a depth of approximately 3 cm. Approximately a 1.0- to 1.5-cm width of outer sphenoid wing can be removed to improve exposure and to decrease the need for brain retraction. Occasionally, part of the orbital roof is removed inadvertently, but this is of little concern. If the patient has a thick frontal bone, it may be helpful to remove the inner one-half table of bone between the sphenoid wing and orbital bur hole to increase exposure and to minimize brain retraction.
Opening of the Dura Mater

If the dura mater is going to be closed with a graft, it is best to open the dura mater and to tack it to the bone and muscle margins. If this is done, there is no risk that the underlying cerebral cortex will be injured inadvertently by a tack suture. However, if the dura mater is going to be closed primarily, it is necessary to tack the dura before it is opened by placing the tack sutures in the outer layer of the dura mater. The dura mater is opened in a way that allows it to be reflected over the sphenoid wing and tacked to the temporalis muscle. This will decrease the amount of blood running into the wound. A small “t” is extended over the temporal lobe and tacked to the edge of the bone to facilitate exposure of the Sylvian fissure. The remaining dura mater is tucked to the bone margins but left intact to protect the brain.

Division of the Sylvian Fissure

The Sylvian fissure can be divided with either a medial to lateral or a lateral to medial approach. In most circumstances, the latter method is better. However, in young patients or in some patients with a severe subarachnoid hemorrhage, the Sylvian fissure is obliterated or not present. In this case, the surgeon must temporarily retract the frontal lobe to initially identify the carotid artery adjacent to the clinoid process and then work from medial to lateral to divide the fissure. It is for this reason—that is, to minimize the degree of brain retraction in case an initial subfrontal approach is required—that it is important to ensure that the frontal cut made during the craniotomy is low and just above the orbital ridge.

In the more standard dissection of the Sylvian fissure, the frontal lobe first is protected with hemostatic fabric (Surgicel) covered by a large cottonoid (Americot). By placing the hemostatic fabric first, it will be easier to remove the cottonoid from the brain at the end of the operation and there will be less risk of subpial hemorrhage. Gently, the frontal lobe is retracted medially and upward, which places tension on the arachnoid between the frontal and temporal lobes. Under the operating microscope, a small incision is made in the arachnoid with a #11 blade knife. Any large Sylvian veins should be kept lateral with the temporal lobe. After the initial incision is made in the arachnoid, it is enlarged with either a straight microscissors or bipolar forceps. Occasionally, small veins that bridge the Sylvian fissure must be cauterized and divided. There is wide variation in vascular anatomy among patients, and in some, the middle cerebral artery is quite superficial and prone to injury. After the outer, or superficial, Sylvian fissure has been divided, the frontal retractor is repositioned to provide new tension on the deep arachnoid. The dissection of the arachnoid along the Sylvian fissure is extended down to the carotid bifurcation.

At this point, it is best to incise the arachnoid on both sides of the carotid artery to achieve vascular control, especially in cases of cerebral aneurysm. After the carotid bifurcation has been dissected free of arachnoid, the lesion dictates the approach to dissecting the arachnoid off the anterior cerebral artery. Specifically, if the operation is for a craniopharyngioma, the arachnoid between the anterior cerebral artery and the optic chiasm should be incised. This will allow the anterior cerebral artery to be retracted, with the frontal lobe still protected by arachnoid. Alternatively, if the lesion is an anterior communicating artery aneurysm, the arachnoid on both sides of the proximal anterior cerebral artery needs to be incised for control of proximal blood vessels.

NEUROSURGICAL ANATOMY

Because the optic nerve is the anatomic landmark and serves as a reference to all other structures in this region, it should be identified early in the exposure. There is significant variation among patients regarding the diameter and length of the internal carotid artery, the location of the carotid bifurcation, the size and extent of the anterior clinoid process, and whether the optic chiasm is prefixed or postfixed. The anatomic publications of Yasargil and Rhoton and their colleagues are required reading.

Ophthalmic Artery

The ophthalmic artery originates medially from the internal carotid artery as it emerges from the cavernous sinus underneath the anterior clinoid process. The ophthalmic artery arises from the subdural portion of the internal carotid artery in 90 percent of patients and at the carotid-duval ring in 2 percent. In the other 8 percent of patients, its origin is extradural, from the cavernous carotid artery. As the ophthalmic artery leaves the internal carotid artery, it runs along the inferior surface of the optic nerve, delicately attached by loose connective tissue. The artery enters the optic canal inferiorly to the optic nerve by piercing the dural sheath of the optic nerve. As the artery runs through the optic canal, it is inferior to the optic nerve. The artery penetrates the orbit and curves medially, either above or below the optic nerve.

Superior Hypophysial Artery

Several small arteries, named the superior hypophysial arteries, usually exit from the inferior medial portion of the internal carotid artery underneath the optic nerve and
supply the pituitary stalk, anterior lobe of the pituitary, and the inferior surface of the optic nerve and chiasm. These small arteries anastomose with their counterparts from the opposite internal carotid artery and with the inferior hypophyseal arteries form a vascular plexus around the pituitary stalk.

**Posterior Communicating Artery**

The next major branch of the internal carotid artery is the posterior communicating artery. It originates from the inferior lateral wall of the supraclinoid internal carotid artery, 2 to 7 mm distal to the anterior clinoid process, and exits from the carotid cistern by penetrating the arachnoid posteriorly and inferiorly to enter the interpeduncular cistern. This portion of the posterior communicating artery is covered by arachnoid. As the artery runs posteriorly, it is adjacent to the posterior clinoid process, to which it is occasionally adherent. In approximately 60 percent of patients, the posterior communicating artery is 2 mm or less in diameter. Its diameter is larger in children than in adults. In approximately 10 percent of patients, the posterior communicating artery is hypoplastic or absent. Rarely, it can have a duplication or fenestration. After it leaves the internal carotid artery, the posterior communicating artery runs medially and, thus, is hidden from view if the surgeon uses a subfrontal approach to this region. If a more lateral or temporal approach along the axis of the sphenoid wing is used, the artery can be followed further into the interpeduncular cistern. Approximately 3 mm from its origin, the posterior communicating artery gives rise to 2 to 10 branches that run posteriorly, inferiorly, and medially into the interpeduncular cistern to supply the optic chiasm and tract, tuber cinereum, mammillary bodies, hypothalamus, and inferior thalamus. These branches are long and variable in caliber.

**Anterior Choroidal Artery**

The anterior choroidal artery arises 2 to 5 mm distal to the origin of the posterior communicating artery and runs laterally to this artery, following the optic tract posteriorly. The anterior choroidal artery varies greatly in diameter (0.5 to 1.5 mm) and may arise as more than one vessel (it is duplicated in 30 percent of patients). If it originates as a single trunk that divides into two vessels, one of them, the “uncal artery,” ramifies almost immediately to supply the uncus, part of the amygdala, and the anterior hippocampus. The main trunk of the anterior choroidal artery continues posteriorly inferior to the optic tract to the choroidal fissure, where its supplies the choroidal plexus of the temporal horn and anastomoses distally with branches of the posterior lateral choroidal artery. In its course through the carotid cistern, the anterior chorio-
dal artery gives off branches that supply the inferior surface of the optic chiasm, the posterior two-thirds of the optic tract, the medial globus pallidus, the genu of the internal capsule, the middle third of the cerebral peduncle, part of the red nucleus, the subthalamus, and thalamic nuclei. As the anterior choroidal artery enters the choroidal fissure to supply the choroidal plexus of the temporal horn, it gives off branches that supply the anterior lateral half of the lateral geniculate body, the anterior half of the posterior internal capsule, the retrolobular part of the internal capsule, and the optic radiations. Considering the territory that is irrigated by the anterior choroidal artery, it is clear that loss of this vessel has devastating neurologic consequences for the patient.

**Middle Cerebral Artery**

The middle cerebral artery is 2.5 to 4.6 mm in diameter at its origin. The part of this artery that extends from its origin to its bifurcation—approximately 15 mm in length—is referred to as the “M1,” “sphenoidal,” or “pterional segment.” The M1 segment gives off two sets of branches: the superior lateral (or temporal) and the inferior medial (or deep) perforating branches. Typically, 1 to 3 branches form the superior lateral group and are labeled the “uncal,” “polar temporal,” and “anterior temporal arteries.” Occasionally, the uncal branch originates from the posterior internal carotid artery just distal to the anterior choroidal artery. Often, the polar temporal artery is small or absent. In this case, the remaining anterior temporal artery is large. Occasionally, the polar temporal and anterior temporal arteries are both absent and are replaced by a large branch from the anterior trunk of the M2 segment of the middle cerebral artery.

The inferior medial branches of the M1 segment are the lenticulostriate arteries. There usually are 3 to 5 of these arteries, although up to 15 perforating vessels have been reported. They enter the lateral two-thirds of the anterior perforated substance and supply the anterior commissure, the putamen, the lateral globus pallidus, the superior half of the internal capsule, and the head and body of the caudate nucleus. Sometimes, there is only one large lenticulostriate artery that divides into many smaller branches that perfuse the above territory. This larger lenticulostriate artery usually originates just proximal to the bifurcation of the middle cerebral artery and runs medially. This vessel can be injured if the clip is placed too deep during repair of a middle cerebral artery aneurysm.

The part of the middle cerebral artery that is distal to its bifurcation is called the “M2 segment.” It usually consists of a superior branch and inferior branch, but in approximately 20 percent of patients, there are three branches—a trifurcation instead of a bifurcation. The proximal branches of the M2 segment include the lateral
orbitofrontal, prefrontal, frontal auricular, precentral, central sulcus, angular, and posterior temporal arteries. The branches originating from the superior trunk typically supply inferior frontal cortex, frontal auricular cortex, and parietal and central sulcus regions. Branches from the inferior trunk usually supply the temporal, temporoooccipital, angular, and posterior parietal gyri. Rarely, an accessory middle cerebral artery has been reported to originate from the anterior cerebral artery complex.

**Anterior Cerebral Artery**

The size and configuration of the anterior cerebral artery complex and its branches vary significantly. The A₁ segment of the anterior cerebral artery extends from the bifurcation of the internal carotid artery to the anterior communicating artery. Typically, one A₁ segment is dominant, with the opposite A₁ segment being either quite small in caliber or absent. The average diameter of the A₁ segment is 2.5 mm. Perforating arteries arise from the inferior posterior portion of the proximal anterior cerebral artery and supply the optic chiasm and penetrate the anterior perforated substance to supply part of the fornix, the anterior limb of the internal capsule, the anterior inferior part of the striatum, and the anterior hypothalamus. These branches of the A₁ segment may originate from one larger vessel, the medial proximal striate artery, which may have a reciprocal relationship with the lenticulostriate arteries that originate from the M₁ segment of the middle cerebral artery.

**Figure 1-1.**

The optic nerve and the supraclinoid part of the internal carotid artery serve as the landmarks or reference points for all the structures exposed during a standard pterional craniotomy. The approach to these structures is along the long axis of the sphenoid wing. The two routes of access are the trans-Sylvian and the subfrontal. Which of these two routes is used is determined primarily by whether the patient has a Sylvian fissure that can be divided easily. In young patients or those who are obese or have a subarachnoid hemorrhage, the Sylvian fissure is often obscured. In this case, a subfrontal approach can be used, and the medial aspect of Sylvian fissure can be identified and incised from medial to lateral.
The anterior communicating artery is 0.1 to 3.0 mm long. Typically, a large A₁ branch divides into two distal A₂ segments, and the anterior communicating artery is the apparent attachment or entry point of the hypoplastic contralateral A₁ segment. In 75 percent of patients, the anterior communicating artery is a single vessel, and in the other 25 percent, it has various anomalies, including fenestrations or duplications. Perforating arteries, which vary in number and diameter, arise from the posterior inferior aspect of the anterior communicating artery and the distal A₁ segment, at its junction with the anterior communicating artery. They supply the infundibulum, optic chiasm, and preoptic area of the hypothalamus. Yasargil reported that if the A₁ segments are equal in size, the perforating vessels arise from the midportion of the anterior communicating artery. However, if the A₁ segments are unequal, the perforating branches arise from the anterior communicating artery on the side of the larger A₁ segment. Because this relationship is similar to that observed for aneurysms in this location, these vessels typically are found on the anterior inferior side of the neck of the aneurysm.

Recurrent Artery of Heubner

A recurrent artery of Heubner is almost always present and usually originates from the A₁ or A₂ segment, adjacent to the origin of the anterior communicating artery. It originates from the A₂ segment in approximately 80 percent of patients and is bilateral in 95 percent. The reported diameters for the recurrent artery of Heubner range from 0.2 to 2.9 mm. It runs parallel to the anterior cerebral artery before entering the anterior perforated substance to supply the anterior part of the caudate nucleus, the anterior putamen, part of the globus pallidus, and the anterior limb of the internal capsule. During exposure of the anterior communicating artery complex, any vessel that runs laterally along the inferior frontal lobe must be presumed to be the recurrent artery of Heubner and, therefore, protected. This is particularly true if partial resection of the gyrus rectus is necessary. Of note is that the recurrent artery of Heubner occasionally originates from the frontal polar branch of the anterior cerebral artery.

Figure 1–2.

Step 1. A, The patient’s head is fixed in a pinion, extended slightly, and rotated approximately 25 to 30 degrees opposite the side of the craniotomy. With extension of the head, the frontal lobe falls away from the floor of the frontal cranial fossa, thereby lessening the degree of brain retraction.
Figure 1-3.

Step 2. Several techniques can be used to cut the bone flap, including standard bur holes and Gigli saws or newer craniotomes. It is helpful to mark the extent of the bone flap when using a craniotome to prevent minimizing the size of the craniotomy. It is important to extend the bone flap down toward the base of the middle cranial fossa. Sometimes, the optimal method is to perform two-thirds of the craniotomy with a craniotome and then use a high-speed air drill with a diamond bur to make the last one-third of the cut along the floor of the middle cranial fossa over the outer sphenoid wing up to the keyhole bur hole. With this method, the bone flap is not minimized.

Figure 1-4.

Step 3. A. After removing the bone flap, the outer sphenoid wing is removed down to the superior orbital fissure. This increases the exposure by approximately 1.5 cm. The dura mater along the sphenoid wing is sharply dissected free with a periosteal elevator.

B. The outer sphenoid wing is removed with a small orbital rongeur.

C. A Yasargil retractor is used to displace the dura mater, and, under the microscope, a high-speed air drill with a diamond bur is used to remove the deeper portion of the sphenoid wing. In fact, removal of the sphenoid wing can be extended deep to include the clinoid process, which allows the anterior clinoid process to be removed without incising the dura mater. This is described later in the chapter. In some patients, the frontal bone is thick and the diamond bur can be used to remove the inner one-half of the frontal bone, which also increases exposure, especially if a subfrontal approach to the internal carotid artery is being used.
Step 5. The dura mater is opened and reflected over the sphenoid wing and temporalis muscle to prevent blood from running into the operative field. The frontal lobe is lined with hemostatic fabric and cottonoids and then gently retracted to place the Sylvian fissure under tension. Correct orientation of the Yasargil bar, head, and arm will increase the effectiveness of this retractor. As described by Sundt, the Yasargil arm should hang straight down and touch the drapes approximately 5 cm from the blade, forming a gentle "S" shape. With this arrangement, gravity assists the retraction and the distal arm has a fulcrum. To achieve this straight up-and-down orientation, the Yasargil head off the bar needs to be in the correct position. The surgeon can determine this by attaching the arm to the unsecured Yasargil head on the bar. The arm is held in the correct orientation, and the head is rotated around the bar until there is no torque. Next, the head is secured to the bar. A common mistake is not to insert the Yasargil bar far enough into the clamp along the side of the operating room table to prevent excessive outward looping of the arm.

Step 4. The dura mater is tacked to the bone margins. If a dural graft is going to be used, the dura mater can be opened and then tacked. In this way, there is no risk of inadvertently injuring the underlying cerebral cortex. However, if the dura mater is going to be closed primarily, it is best to tack it to the bone before opening it. In patients with a large frontal sinus, the frontal tack stitch should be sewn to the muscle to avoid a tack hole going into the frontal sinus, which can lead to rhinorrhea postoperatively.
Figure 1-7.

Step 6. With a #5 or #7 straight suction tip and small cottonoid, the frontal lobe adjacent to the lateral Sylvian fissure is retracted gently to place the arachnoid under tension. In the process of dividing the Sylvian fissure, both the suction tip and cottonoid are "walked down" the fissure, placing under tension the next part of the arachnoid to be cut. Under the operating microscope, an incision is made in the arachnoid with a #11 blade knife.

Figure 1-8.

This incision in the arachnoid is extended downward or medially along the Sylvian fissure by separating the arachnoid with bipolar forceps. Alternatively, the arachnoid can be lifted and cut with a straight microscissors. Large Sylvian veins should be left intact and displaced laterally with the temporal lobe. Small bridging veins across the Sylvian fissure can be safely cauterized and divided.
Figure 1-9.

As the Sylvian fissure becomes more broadly split, the frontal lobe is increasingly retracted upward to place the deep arachnoid under tension. If a lumbar drain has been placed, it is best not to remove cerebrospinal fluid until the Sylvian fissure has been divided. Removal of cerebrospinal fluid through the drain will decompress the Sylvian fissure and, thus, make it more difficult to dissect the arachnoid. The arachnoid incision is carried down on top of the internal carotid artery.
Figure 1–10.

With a straight or angled dissector, the arachnoid is teased off the internal carotid artery both medially and laterally, especially in cases of aneurysm. Accordingly, immediate proximal control has been obtained. Next, the arachnoid is incised medially between the anterior cerebral artery and the optic chiasm. This incision is carried over to the opposite optic nerve. By cutting the arachnoid between the anterior cerebral artery and the optic chiasm, the A1 segment and its perforating vessels are lifted with the frontal lobe and, therefore, moved out of harm’s way. If an anterior cerebral artery–anterior communicating artery aneurysm is being treated, both sides of the proximal A1 segment need to be dissected to provide proximal arterial control. After the Sylvian fissure is divided, the temporal lobe can be retracted laterally if necessary. There often are bridging veins off the tip of the temporal lobe that are under tension. These can be supported and protected with a piece of absorbable gelatin sponge (Gelfoam). If required, these bridging veins can safely be cauterized and divided.
POSTERIOR COMMUNICATING ARTERY ANEURYSM

Aneurysms in this location are best exposed by first identifying the medial surface of the internal carotid artery adjacent to the optic nerve. This is called the “optic-carotid triangle.” In most instances, these aneurysms project laterally toward the tentorium cerebelli and the oculomotor nerve. Not unexpectedly, they often are associated with hemorrhage into the temporal lobe. Occasionally, these aneurysms are located proximally, necessitating resection of the anterior clinoid process.

After the medial surface of the internal carotid artery is identified, a dissector is used to incise the arachnoid over the lateral aspect of the artery. This allows proximal arterial control to be achieved and, if necessary, a temporary clip to be placed. Typically, the aneurysms arise from the axilla of the posterior communicating artery, at its origin from the internal carotid artery. The base of the aneurysm usually projects at a 45-degree angle away from the origin of the posterior communicating artery. It is important to dissect the origin of the posterior communicating artery from the anterior wall of the aneurysm so that the artery can be preserved when a clip is placed across the base. After the posterior communicating artery is identified and the arachnoid that tethers the aneurysm to the artery is incised, a piece of absorbable gelatin sponge (Gelfoam) can be placed to displace this artery. A dissector is then used to identify the origins of the anterior choroidal artery. A piece of absorbable gelatin sponge is also placed between this artery and the neck of the aneurysm. Placement of small bits of absorbable gelatin sponge keep the important arteries out of harm’s way when an aneurysm clip is placed. In rare instances, the posterior communicating artery originates from the neck of the aneurysm in such a way that the posterior communica-

ting artery has to be occluded at its origin from the internal carotid artery before the aneurysm can be obliterated. Before concluding that this is indeed the case, it is mandatory that the surgeon ensure that there is no plane between the artery and neck of the aneurysm and that the posterior communicating artery has a small diameter. Furthermore, the preoperative angiogram should show retrograde filling of the posterior communicating artery on the vertebral study. In this rare case, it is acceptable to place the aneurysm clip in a way that both the neck of the aneurysm and the origin of the posterior communicating artery are occluded. This will be tolerated by the patient because the posterior communicating artery fills retrogradely.

For all aneurysms, it is necessary to ensure that after the clip has been placed, the aneurysm has been obliterated completely and no vessels are trapped by the jaws of the clip. It is useful to aspirate the aneurysm, especially large lesions, to collapse the structure. After this is done, the dome of the aneurysm can be manipulated with a #5 or #7 straight suction tip, and the underside of the neck of the aneurysm and the clip can be inspected. After a posterior communicating artery aneurysm is clipped, the anterior choroidal artery is viewed from a lateral perspective to make sure that it has not been compromised. The same is true for the posterior communicating artery. Depending on the location of the aneurysm clip, it may be difficult to visualize the posterior communicating artery. If this is so, the artery and its branches can be viewed from a medial perspective between the optic nerve and the internal carotid artery by gently displacing the medial wall of the internal carotid artery laterally. After these vessels have been inspected, papaverine can be applied topically with a cottonoid to relieve mechanically induced vasospasms.
Typical operative exposure used for aneurysms of the posterior communicating artery, anterior choroidal artery, or bifurcation of the internal carotid artery. Depending on the location and projection of the aneurysm, a retractor placed on the temporal lobe can be useful.

Figure 1-12.
Step 1. Under the operating microscope, it is mandatory to dissect the neck of the aneurysm of the posterior communicating artery off both the anterior choroidal artery and the posterior communicating artery.
Figure 1–13.

Step 2. A useful step in all aneurysm surgery is to displace dissected vessels from the neck of the aneurysm by using small pieces of absorbable gelatin sponge (Gelfoam).

Figure 1–14.

Step 3. A. Usually a straight, bayonet, or 45-degree-angled aneurysm clip is best for aneurysms of the posterior communicating artery or anterior choroidal artery. When placing the clip, it is important to ensure that neither the perforating vessels nor the internal carotid artery is compromised or constricted.

B. After the aneurysm is clipped, its dome is aspirated if the surgeon believes that the neck has been occluded completely with the clip. Aspirating the dome of the aneurysm enhances the exposure, thus allowing better inspection of the underlying perforating vessels.
Figure 1–15.

Step 4. In all aneurysm repairs, it is mandatory to ensure that both the parent vessel and adjacent perforators are structurally intact. The takeoff of the anterior choroidal artery can be visualized best from a lateral view. Often, this is true also for the posterior communicating artery. Occasionally, the clip prevents the posterior communicating artery from being visualized. In that case, it can be viewed from a medial to lateral perspective, looking between the optic nerve and internal carotid artery through the optic-carotid triangle.
ANTERIOR COMMUNICATING ARTERY ANEURYSM

It is easiest to expose an aneurysm of the anterior communicating artery from a more subfrontal than sphenoidal approach through a pterional craniotomy. Therefore, the head should not be rotated more than 30 degrees opposite the side of the craniotomy. It usually is best to approach the aneurysm from the side of the dominant feeding artery, unless there has been severe hemorrhage into the opposite gyrus rectus. Because it occasionally is necessary to remove part of the gyrus rectus to expose the aneurysm, it is preferable to remove tissue that has already been damaged by a hemorrhage.

After the Sylvian fissure is divided, the carotid bifurcation is identified. A hemostatic fabric and cottonoids are placed over the frontal lobe, which is then retracted upward and posteriorly. This increases tension on the arachnoid over the anterior cerebral artery. The arachnoid between the anterior cerebral artery and the chiasmatic cistern is opened and the proximal A1 segment is identified in case a temporary clip has to be placed should the aneurysm rupture. The arachnoid is dissected free between the anterior cerebral artery and the optic chiasm. It is not necessary to separate the arachnoid completely between the frontal lobe and the anterior cerebral artery, because this might increase the risk of injury to the perforating arteries that originate from the A1 segment. To prevent inadvertent rupture during exposure, the surgeon must bear in mind the direction of the dome of the aneurysm.

The incision in the arachnoid is extended medially over the optic chiasm so that the opposite A1 segment can be visualized. With a #11 blade knife, the cistern of the lamina terminalis in the interhemispheric fissure is incised between the two gyri recti. If the lamina terminalis can be identified clearly, it may be useful to incise it to drain cerebrospinal fluid from the third ventricle to increase brain relaxation. If a lumbar spinal drain is being used, this maneuver is not required. If necessary, a small portion of the gyrus rectus can be removed with a bipolar cautery and suction. It is important not to coagulate or to divide any perforating vessels in this area. Furthermore, the frontal polar artery must not be mistaken for the recurrent artery of Huebner. After the gyrus rectus is removed, the ipsilateral A2 segment is identified. Therefore, at this point in the operation, three of the four major trunks have been visualized except for the opposite A2 segment. With a typical posteriorly pointing aneurysm, it is best to start dissecting the aneurysm at the junction between the ipsilateral A2 segment and the anterior communicating artery. This dissection usually starts posteriorly behind the aneurysm, with the aneurysm being elevated with a #5 or #7 straight suction tip and small cottonoid. Typically, perforating vessels are enmeshed in their own arachnoid and can be dissected off the back wall of the aneurysm as a single sheet or layer. As the aneurysm is gently rotated anteriorly, the opposite A2 segment usually can be identified and dissected free. Thereafter, a small piece of absorbable gelatin sponge is placed between the opposite A2 segment, arachnoid and perforating vessels, and the ipsilateral A2 segment and the neck of the aneurysm. After clipping, it is important to decompress the aneurysm to allow manipulation of the dome to verify that the anterior communicating artery complex and its perforating vessels are intact and not entrapped by the jaws of the clip.

In large aneurysms, it may be necessary to perform a thrombectomy in order to place a clip and to preserve the surrounding vasculature. In this case, the dominant feeding A1 segment is temporarily occluded. If perforating vessels originate from the A1 segment, it is preferable to place the temporary clip distal to their takeoff, without compromising exposure of the neck of the aneurysm. An incision is made in the dome far distal to the neck. If an incision is made too close to the neck, then subsequent placement of an aneurysm clip may be compromised. Thrombectomy is performed with curets. If back bleeding is significant, it may be necessary to occlude the contralateral A1 segment.
Figure 1–16.

Step 1. The approach to an anterior communicating artery aneurysm is more subfrontal than sphenoidal. After the Sylvian fissure is divided, the frontal lobe retractor is repositioned to lift the frontal lobe up and posteriorly to expose the carotid bifurcation. The arachnoid over the A₁ segment is incised to allow access in case a temporary clip has to be placed because of intraoperative rupture of the aneurysm. The arachnoid between the anterior cerebral artery and the optic chiasm is incised to identify the opposite A₁ segment.
**Step 2.** Despite the Sylvian fissure being divided and despite cerebrospinal fluid being aspirated from the supracerebral cistern and drained through a lumbar drain or an incision in the lamina terminalis, exposure of the aneurysm can still be difficult. If exposure is a problem, part of the ipsilateral gyrus rectus may be removed with bipolar cautery and delicate suction. Any artery that runs lateral and horizontal to the A₁ segment should be protected and presumed to be the recurrent artery of Heubner.

**Figure 1-18.**

Step 3. The frontal retractor is placed deeper to allow additional retraction of the frontal lobe and gyrus rectus. It is important to be sure that the interhemispheric arachnoid has been incised to decrease tension on the opposite frontal lobe. Before the aneurysm is dissected, it is mandatory to ensure good access to the dominant A₁ segment in case temporary clipping is necessary.
Figure 1–19.

Step 4. A. The neck of the aneurysm is carefully dissected free from the underlying perforating vessels and the adjacent A₁ and A₂ segments. It is best first to isolate the dominant A₁ segment and then the opposite A₁ for good proximal control. A spatula or dissector is used to dissect free the ipsilateral A₂ segment. The contralateral A₂ segment is the last structure identified. The perforating vessels originating from the anterior communicating artery usually are sheathed in arachnoid and can be separated in a plane en bloc. This is similar to dissecting perforating vessels off the basilar caput. The perforating vessels adjacent to the ipsilateral A₂ segment are identified first. The plane between these perforators and the neck of the aneurysm is developed and extended around the backside of the lesion.

B. A piece of absorbable gelatin sponge is used to displace these vessels before the aneurysm is clipped.

C. After placement of the clip, the dome is aspirated and manipulated to allow inspection of the clip and its relationship to all adjacent vascular structures.

Figure 1–20.

Illustrated here is repair of a giant partially thrombosed aneurysm of the anterior communicating artery complex. With these lesions, thrombectomy must be performed. A temporary clip is placed on the dominant A₁ segment distal to any perforating vessels. The dome of the aneurysm is incised, and ring curets are used to remove the thrombus. It is important to make sure that the incision in the dome of the aneurysm is as far from the neck as possible. If there is significant back bleeding, it may be necessary to occlude temporarily the opposite anterior cerebral artery adjacent to the opposite optic nerve.
SUPRACLINOID INTERNAL CAROTID ARTERY ANEURYSM

As emphasized by Sundt, giant aneurysms of the supraclinoid internal carotid artery can be divided by the direction of their projection, including superior, posterior, medial, and lateral. In nearly all instances, it is necessary to resect the anterior clinoid process. This resection can be performed through either an intradural or an extradural approach. If the intradural approach is chosen, the dura mater overlying the anterior clinoid process is cauterized for a distance of 5 to 10 mm. The bone is then removed with a high-speed diamond air bit. When using the high-speed air drill, it is critical to remove all cottonoids from the wound, because the suction vacuum created by the drill can quickly wrap these cottonoids around the drill and create an “egg beater” in the wound. The extradural approach to removing the anterior clinoid process is described later in this chapter.

Posteriorly projecting aneurysms, as illustrated in this case, are typically the most treacherous because it often is difficult to reconstruct the parent internal carotid artery. Therefore, the surgeon must be prepared to perform a bypass graft either from the cervical carotid or petrous carotid artery, using a saphenous vein harvested from the leg. In this regard, it is useful to know preoperatively the potential for collateral blood flow by performing a trial balloon occlusion during the initial angiography, perhaps in combination with a xenon blood flow or a single photon emission computed tomographic (SPECT) blood flow study. Alternatively, the surgeon can expose the cervical carotid artery and perform a temporary occlusion in conjunction with intraoperative electroencephalographic or cerebral blood flow monitoring. If on inspection of the aneurysm it appears that it is not technically feasible to reconstruct the internal carotid artery and the patient does not tolerate the temporary occlusion, a reasonable option is to perform a saphenous vein bypass graft.

After the Sylvian fissure is divided, the internal carotid artery and optic nerve are first identified. The relationship between the internal carotid artery between the anterior clinoid process and the carotid bifurcation is inspected to determine whether primary clipping will be feasible technically. If the anterior clinoid process has not been removed through an extradural approach, it is removed through an intradural approach. This allows identification of the proximal neck of the aneurysm, which typically originates immediately under the anterior clinoid process.

After the proximal neck of the aneurysm is identified, attention is turned to the distal neck to establish the relationship between it and the anterior choroidal artery. The posterior communicating artery is often absent in posteriorly projecting aneurysms of the internal carotid artery. However, the anterior choroidal artery is often stretched just underneath the carotid bifurcation and must be dissected free. After the anterior choroidal artery is identified, a piece of absorbable gelatin sponge is placed between it and the neck of the aneurysm.

For most giant aneurysms in this location, temporary vessel occlusion and thrombectomy are necessary to facilitate clip placement. The internal carotid artery is occluded either in the neck just distal to the carotid bifurcation or intracranially as the carotid artery exits the cavernous sinus. In that regard, it is best to incise the distal carotid dural ring, which allows a temporary clip to be placed more proximally, thus increasing the amount of space along the proximal neck of the aneurysm. The second temporary clip is placed on the distal internal carotid artery if there is sufficient room. Otherwise, it may be necessary to occlude the proximal A1 segment if back bleeding is sufficient after the aneurysm has been opened and decompressed. The patient’s blood pressure is increased to a systolic pressure of 150 to 160 mm Hg to increase collateral blood flow. Intraoperative electroencephalography can be helpful in determining whether collateral cerebral blood flow is sufficient. If, during preparative planning, the surgeon anticipates that occlusion of the internal carotid artery will be longer than 20 minutes because of the complexity of the aneurysm and trial balloon occlusion was not tolerated, serious consideration should be given to performing the operation under profound hypothermia or constructing a preclosure hypothermia or constructing a preclosure bypass graft to the distal middle cerebral artery complex.

After the aneurysm is temporarily trapped, an incision is made in the dome as distal to the parent artery as possible. Thrombectomy is performed with ring curets. After the aneurysm is collapsed, a clip is placed across its neck in one of two directions. Placement of an angled clip underneath the internal carotid artery from lateral to medial is technically easier than using a cutout clip placed parallel to the internal carotid artery. Although it often is written that a cutout clip is less likely to stenose or to occlude the internal carotid artery, it is difficult to place the clip in a position in which the neck of the aneurysm is obliterated but the origin of the anterior choroidal artery is not compromised. For this reason, it is best to start out using an angled clip placed lateral to medial to determine whether the aneurysm can be obliterated without stenosing the carotid artery. After the clip is placed, blood flow through the carotid artery is confirmed with intraoperative Doppler, ultrasonography, or angiography. The anterior choroidal artery is inspected visually to make sure that it is patent.
Figure 1-21.

Step 1. It is necessary to remove the anterior clinoid process and to expose the proximal internal carotid artery to obtain proximal control of the vessel and to identify the neck of the aneurysm. Some of these aneurysms can be transitional in that the neck originates from the clinoid segment and the dome of the aneurysm extends intradurally. Typically, the posterior communicating artery is not present. However, invariably, the anterior choroidal artery is intimately associated with the distal neck of the aneurysm and must be dissected free. It is necessary to separate widely the Sylvian fissure to identify the carotid bifurcation. It may be useful to place a retractor on the temporal lobe. However, depending on the angle of the clip to be placed, the temporal lobe retractor may be in the way and may need to be removed. With giant aneurysms in this location, exposure of the cervical carotid artery provides a safety net in case the aneurysm ruptures before proximal control of the carotid artery is achieved.
Step 2. There are two ways to remove the anterior clinoid process. As illustrated here, it can be removed through an intradural approach. A small spatula is used to cauterize and to peel the dura mater off the anterior clinoid process. A small diamond bur is used to gently drill the clinoid process and expose the supraclinoid carotid artery. When the anterior clinoid process is thin, a small bone rongeur is used to bite off the rest of the bone. During removal of the anterior clinoid process, it is important to remove the bar of bone between the anterior clinoid process and the superior orbital fissure. Also, it is best to remove the optic strut bone just lateral to the optic nerve. This removal of bone medial and lateral to the anterior clinoid process creates more room, thereby increasing the options for placing and manipulating the clip. The other way to remove the anterior clinoid process is through an extradural approach, as pioneered by Dolenc. The advantage of the extradural approach is that there is dura mater between the bony removal and the aneurysm.

Also, the surgeon can be more aggressive about the degree of bony removal of the medial sphenoid wing, which increases exposure of the intracavernous carotid artery. With the extradural approach, the outer sphenoid wing is removed with a small orbital rongeur. Under the operating microscope, the medial sphenoid wing is drilled off with a diamond bur, first identifying the superior orbital fissure. Next, the diamond bur is used to thin the bony bridge between the superior orbital fissure and the anterior clinoid process. The drill is also used to thin and to remove the orbital strut of bone between the optic canal and the anterior clinoid process. After these medial and lateral bony bridges have been thinned, small bone cups or forceps are used to bite bone and to wiggle the anterior clinoid process free. These same bony cups can be used to remove additional thin bone over the optic nerve medially and the superior orbital fissure laterally.
**Figure 1-23.**

**Step 3.** *A.* After the anterior clinoid process is removed, the internal carotid artery is mobilized by incising the distal dural ring. This distal dural ring is continuous with the dura mater that surrounds the optic nerve medially and the falciform ligament laterally.

*B.* A ball-tip dissector can be used to dissect the plane between the internal carotid artery and the dural ring.

*C.* When this plane is established, a microscissors such as a micro Potts can be used to incise the dural ring. It is best to stay on top of the internal carotid artery during this incision. After the outer dural ring is cut, a small spatula can be used to sweep the dural reflections medially and laterally. In most transitional carotid aneurysms, the origin of the ophthalmic artery defines the medial extent of the neck of the aneurysm. Often, the ophthalmic artery originates from the extradural carotid artery. Therefore, it is necessary to carry the dissection proximal to the anterior genu of the internal carotid artery. Often, the very lateral and medial attachments of the carotid dural rings are adherent to the neck of the aneurysm and must be sharply dissected free with a spatula or, occasionally, a #11 blade knife.
Figure 1-24.

**Step 4.** For most giant aneurysms, it is necessary to temporarily occlude some of the major arteries and to perform thrombectomy. In this example, removal of the anterior clinoid process is not sufficient to expose the proximal internal carotid artery to temporarily place a clip. Therefore, the cervical internal carotid artery is occluded. A temporary clip is also placed on the A1 segment. Occasionally, it is possible to place a temporary clip proximal to the anterior choroidal artery, in which case there is continued perfusion of the anterior choroidal artery and the middle cerebral artery complex through the anterior communicating artery. More typically, as illustrated here, there is not enough room to place temporary clips proximal to the bifurcation. When incising the dome of the aneurysm, it is important to make the incision as distal to the neck as possible so that placement of the permanent clip will not be compromised.
Step 5. There are two ways to place the aneurysm clip—the one illustrated here and the one shown in Figure 1-26. Placing the clip perpendicular to the internal carotid artery is technically easier in terms of preserving the anterior choroidal artery. However, it may also cause kinking of the carotid artery and lead to stenosis or occlusion.

Figure 1-26.

An alternative clip placement is a cutout that runs parallel with the internal carotid artery. There is less risk of stenosis of the artery if the cutout has sufficient caliber. Regardless of the way the clip is placed, the more aggressive the thrombectomy, the easier the placement of the clip and the less risk of stenosis of the parent internal carotid artery. After the clip is placed in these complex cases, it is mandatory to determine that the internal carotid artery is patent. Although intraoperative micro Doppler or ultrasonography can be used to demonstrate patency, intraoperative angiography is superior because it reveals whether there is significant stenosis adjacent to the clip. If the ipsilateral cervical carotid artery has already been exposed, intraoperative angiography can be performed through a direct common carotid artery puncture.
CRANIOPHARYNGIOMA

There are several good exposures for removal of suprasellar craniopharyngiomas, including a frontotemporal orbital craniotomy and a standard pterional craniotomy. The true subfrontal approach, with removal of one orbital roof, can be advantageous when there is a large extension of the craniopharyngioma into the third ventricle (described in Chapter 3). However, a large extension into the third ventricle can also be removed through a standard pterional craniotomy by vigorous internal decompression of the tumor, often in combination with an incision in the lamina terminalis posterior to the optic chiasm. With a pterional craniotomy, the expanded optic-carotid triangle can be used to the surgeon’s advantage. Sectioning the lamina terminalis during a pterional approach is often more difficult than expected, because the posterior margin of the optic chiasm may not be visible. In this case, it is best to perform an aggressive debulking of the tumor through the optic-carotid triangle and to collapse the third ventricular extension of the tumor into the subchiasmatic cistern. Occasionally, the infundibulum can be preserved, especially if the craniopharyngioma is largely cystic. However, if the tumor is more calcified and grumous, the infundibulum typically enters the tumor capsule and cannot be preserved.

After the Sylvian fissure is divided and the retractors are placed, the optic-carotid triangle is identified. Typically, the ipsilateral carotid artery is displaced laterally, the anterior cerebral artery and its perforating branches are pushed upward, and the optic chiasm is bowed medially and upward. The arachnoid is first incised between the tumor capsule and medial surface of the internal carotid artery. This incision is then carried distally between the anterior cerebral artery and the tumor capsule. Finally, the arachnoid between the optic nerve and chiasm and the tumor is incised. The arachnoid between the anterior cerebral artery and the frontal lobe is left intact. A Yasargil retractor is placed deeper along the inferior aspect of the frontal lobe, which helps to move the anterior cerebral artery out of harm’s way.

The next step is to make a linear incision, 5 to 10 mm, in the tumor capsule. An internal decompression is then performed with ring curets. After the tumor has been partially decompressed, the lateral aspect of the tumor capsule is dissected off the medial aspect of the internal carotid artery. Typically, the posterior communicating artery and its branches are enmeshed in arachnoid, which facilitates dissection and separation from the lateral aspect of the tumor capsule. After this has been achieved, cottonoids are placed between the outer tumor capsule and the inner aspect of the internal carotid artery, the posterior communicating artery, and the anterior choroidal artery.

With a #5 or #7 straight suction tip and a cottonoid, the tumor is gently retracted medially and dissection is performed behind the tumor capsule, with preservation of the arachnoid overlying the basilar artery and its perforating vessels. The tumor is further decompressed internally to facilitate manipulation of the capsule wall. After the basilar artery, the basilar caput, and, possibly, the posterior cerebral arteries have been identified, cottonoids are placed deep to protect them.

Next, attention is directed to dissecting the tumor off the opposite anterior clinoid process and internal carotid artery. Typically, the arachnoid covers the internal carotid artery and posterior communicating artery, and if it is left intact, it will protect these structures. The tumor capsule is retracted toward the surgeon with a #5 or #7 straight suction tip, which stretches the adhesions between the capsule and the internal carotid artery, making it easier to divide the adhesions.

After the tumor has been dissected off the opposite internal carotid artery, the angle of the microscope is repositioned to allow a more direct view underneath the optic chiasm. It usually is necessary, once again, to debulk the tumor to facilitate retraction of the capsule. The tumor capsule is again retracted toward the ipsilateral internal carotid artery with the use of a #5 or #7 straight suction tip and cottonoid, which stretches the adhesions between the tumor capsule and the optic chiasm and the hypothalamus. They can be dissected free more easily, after which cottonoids are placed to protect the underside of the chiasm and the hypothalamic region.

It is important to emphasize that the residual tumor capsule should be removed through the optic-carotid triangle with gentle force. While the capsule is being removed, all aspects are inspected to make sure that no residual adhesions remain between the tumor capsule and the surrounding vascular and parenchymal structures. After the tumor is removed, the surgical bed is inspected. A malleable fiberoptic probe or mirrors are useful in inspecting the underside of the optic chiasm and the third ventricle for possible residual tumor.
Step 1. The Sylvian fissure is divided to identify the bifurcation of the internal carotid artery. The frontal lobe is lined with hemostatic fabric and cottonoids and retracted. The arachnoid between the tumor and medial aspect of the internal carotid artery and anterior cerebral artery is incised. The arachnoid between the anterior cerebral artery and the frontal lobe is left intact, so that when the frontal lobe is retracted the anterior cerebral artery is gently displaced. During the operation, most of the work is performed through the expanded optic-carotid triangle. Tumor debulking can also be performed between the two optic nerves if the chiasm is postfixed.
**Step 2.** After the lateral aspect of the tumor capsule has been defined, a 5- to 10-mm incision is made in the tumor. Various ring curettes are used to begin debulking the tumor. During this process, it is important to make sure that traction is kept to a minimum on the optic apparatus.
Step 3. After the tumor is partially debulked, the surgeon dissects the lateral margin of the tumor off the ipsilateral internal carotid artery. There typically is a layer of arachnoid between the tumor capsule and the posterior communicating and anterior choroidal arteries and their perforating arteries. Respecting this arachnoid barrier will protect these vascular structures. The tumor capsule is gently displaced medially with a #5 or #7 straight suction tip and cottonoid. After the perforating arteries that come off the internal carotid artery are identified, they are protected with cottonoids.
Step 4. The dissection is carried deeper to identify the basilar artery. The arachnoid that invests the posterior communicating artery extends deep between the tumor capsule and basilar artery. This arachnoid should not be violated. The tumor is retracted medially with a #5 or #7 straight suction tip and a cottonoid. After the posterior component of the tumor capsule has been identified, cottonoids are placed over the basilar artery.

Step 5. Next, the tumor capsule is dissected off the contralateral internal carotid artery and the anterior clinoid process. In this case, there is a postfixed chiasm; thus, the dissection is performed between the two optic nerves. The arachnoid plane between the carotid artery and its branches and the tumor capsule should be respected.
Step 6. The tumor is further decompressed internally with ring curets. To work across the middle cranial fossa, the operating microscope is repositioned to provide a more lateral or horizontal view of the ipsilateral optic nerve. This permits dissection of the interface between the tumor and the optic nerve and chiasm. There is no arachnoid plane between these structures. The tumor capsule should be retracted downward; oftentimes, this retraction peels the tumor capsule off the underside of the chiasm. It is important to recognize that the primary blood supply to the chiasm is from the underside, and, therefore, all minute blood vessels must be preserved. In patients with a large extension of craniopharyngioma into the third ventricle or a prefixed optic chiasm, it is useful to remove this ventricular component through the lamina terminalis. This is described in Chapter 3.

Step 7. After the tumor has been dissected off the chiasm and extracted from the third ventricle, it is removed through the optic-carotid triangle with a forceps. After the tumor has been removed, the underside of the chiasm and the third ventricle are inspected with either mirrors or a malleable fiberoptic probe to make sure that the tumor has been resected completely.
SPHENOID WING MENINGIOMA

Meningiomas located along the medial two-thirds of the sphenoid wing are best approached through a standard pterional craniotomy, whereas those located on the lateral one-third should be approached through a larger fronto-temporal craniotomy. It is important to recognize that often one or two perforating arteries off the middle cerebral artery enter the deep aspect of the tumor capsule. Thus, to prevent evulsing these branches, the tumor must not be pulled out before the underside or deep component of the tumor is dissected.

After the bone flap is removed, the outer sphenoid wing is removed with a high-speed air drill, under the operating microscope. This is useful in increasing exposure and devascularizing part of the tumor. The dura mater is opened widely, and any branches off the middle meningeal artery that were exposed when the outer sphenoid wing was removed are cauterized and divided because they typically feed the tumor. The brain is lined with hemostatic fabric and cottonoids, and the tumor capsule is separated from the overlying frontal and temporal lobes.

Separating the tumor from the overlying parenchyma is made easier by placing the brain under slight tension with a Yasargil retractor and providing countertraction on the tumor capsule with a #5 or #7 straight suction tip. This places tension on the adhesions between the tumor capsule and the arachnoid, easing separation. First, the lateral margin of the tumor is dissected free from the temporal lobe. Second, the distal Sylvian fissure is divided, identifying the interface between the tumor and the middle cerebral artery. After the middle cerebral artery is identified, cottonoids are placed over it for protection. The interface between the frontal lobe and the tumor is then identified and dissected free, and cottonoids are placed to protect the frontal and temporal lobes.

After an initial dissection has been performed between the tumor and the frontal and temporal lobes, the tumor capsule is cauterized and the tumor is decompressed internally with curets and an ultrasonic aspirator. The greater the internal decompression of the tumor, the easier it is to retract the tumor capsule from the neurovascular structures.

Typically, the blood supply of these tumors is from the dura mater of the sphenoid wing. Therefore, after debulking some of the tumor and clearly distinguishing the borders of the tumor from the frontal and temporal lobes, the tumor attachments to the sphenoid wing are cauterized. The tumor capsule is retracted with a #5 or #7 straight suction tip and cottonoids, thereby allowing better definition of the interface between the tumor and sphenoid wing. Bipolar cautery with irrigation is used to obtain hemostasis of the dura mater, which often is quite vascular.

The critical component in tumor resection is the deep aspect of the tumor and its relationship to the suprachiasmatic carotid artery, the middle cerebral artery, and the optic nerve. Occasionally, one can work from lateral to medial along the Sylvian fissure, identifying the middle cerebral artery and following it proximal to the carotid bifurcation. When this is achieved, much of the tumor can be removed. This leaves a small piece of tumor along the anterior clinoid process.

Underneath the anterior clinoid process, the internal carotid artery and optic nerve usually are separated from the tumor by overlying arachnoid. It is important to preserve this arachnoid (if possible) because it protects these structures. The residual bit of tumor is rolled outward along the sphenoid wing to identify the internal carotid artery and its bifurcation. Although the tumor may wrap itself around the internal carotid artery, the arachnoid plane between this artery and the tumor often allows removal of the tumor between the internal carotid artery and its branches laterally and the tentorial edge medially.
The meningioma illustrated involves much of the sphenoid wing, both medially and laterally.
Figure 1-35.

Step 1. The interface between the tumor and the temporal lobe and, then, the frontal lobe is identified and separated. Typically, a Yasargil retractor is used to retract the brain and a #5 or #7 straight suction tip and cottonoid are used to place countertraction on the tumor capsule. This places the arachnoid adhesions under tension, allowing easier separation of the tumor from the brain.

Figure 1-36.

Step 2. After the tumor is separated from the frontal and temporal lobes, it is decompressed with curets, laser, or an ultrasonic aspirator.
Figure 1–37.

Step 3. The outer or lateral Sylvian fissure is divided, and the relationship between the tumor and the middle cerebral artery is dissected free. Often, one or two branches off the middle cerebral artery are incorporated into the tumor capsule. Because of this, the underside of the tumor must be separated completely from the middle cerebral artery before the tumor is removed. Otherwise, some of the perforating branches of the middle cerebral artery may be evulsed. Also, the tumor may parasitize several of these vessels. Branches of the middle cerebral artery that clearly supply the tumor may be safely cauterized and divided.

Figure 1–38.

Step 4. With increasing exposure, further internal decompression of large tumors is performed. This internal decompression facilitates the manipulation of the tumor capsule off the deeper neurovascular structures.
Step 5. After extensive debulking of the tumor and dissection of its lateral and medial margins, the attachments of the tumor to the dura mater of the sphenoid wing are further cauterized and divided down to the anterior clinoid process.

Step 6. Typically, there is a layer of arachnoid between the deepest part of the tumor capsule and the underlying internal carotid artery and optic nerve. This arachnoid prevents injury to these structures during dissection of the tumor. The attachment of the tumor to the anterior clinoid process and the planum sphenoidal is cauterized and divided. Countertraction is provided by a #5 or #7 straight suction tip placed on the tumor capsule.
Step 7. The residual piece of tumor is rotated medially and laterally as the tumor is dissected off the internal carotid artery and its branches. Often the tumor encircles part of the internal carotid artery, but it usually can be removed from the artery with gentle suction, fine spatulas, and bipolar cautery. Occasionally, one can visualize the tumor invading the adventitia of the internal carotid artery. Fine spatulas should be used to scrape the tumor off the artery. Any bleeding should be controlled with an absorbable gelatin sponge instead of bipolar cautery. Cauterizing small bleeders on the internal carotid artery can lead to arterial dissection and thrombosis.
TRANSITIONAL CAVERNOUS CAROTID ANEURYSM

Anatomy

It is mandatory for surgeons to understand exactly the three-dimensional anatomic relationships of the cavernous sinus before operating on a transitional cavernous carotid aneurysm. The important features are the course of the internal carotid artery through the cavernous sinus, the relationship of the cranial nerves to the internal carotid artery, and the enveloping and tethering reflections of the dura mater. When considering the anatomy and surgery of the cavernous sinus, neurosurgeons are indebted to the pioneering work of Parkinson and Dolenc. The following discussion of the anatomy of the cavernous sinus should be considered a bare minimum, or cursory, and relevant primarily to transitional cavernous carotid aneurysms.

The internal carotid artery enters the cavernous sinus through the foramen lacerum and runs superiorly and curves anteriorly toward the superior orbital fissure (Figure 1–42). The meningeal hypophysial trunk usually arises from the superior medial aspect of the internal carotid artery just distal to this curve. The three branches of the meningeal hypophysial trunk include the tentorial artery of Bernasconi and Cassinari, the dural meningeal artery, and the inferior hypophysial artery. There also may be an artery of the inferior cavernous sinus, which originates from the lateral side of the internal carotid artery and runs anteriorly to cross the abducens nerve and eventually anastomose with branches of the maxillary artery. Some of the anastomoses include the artery of the foramen rotundum, the recurrent meningeal artery along the superior orbital fissure, the accessory meningeal artery at the foramen ovale, and the middle meningeal artery at the foramen spinosum. Approximately 10 percent of patients have McConnell’s capsular arteries, which originate from the medial side of the internal carotid artery and supply part of the pituitary gland.

Within the cavernous sinus, a dense venous plexus connects the ophthalmic vein, the superior and inferior petrosal sinuses, the pterygoid plexus, and the basilar venous plexus. This venous plexus surrounds the internal carotid artery. The oculomotor, trochlear, and trigeminal nerves run in the lateral wall of the cavernous sinus. The dura mater of the cavernous sinus is continuous with the connective tissue that tethers these cranial nerves to the wall of the sinus. The abducens nerve runs within the cavernous sinus and enters the superior orbital fissure under the ophthalmic division of the trigeminal nerve.

Several nomenclatures have been proposed for divisions of the internal carotid artery. The first was that of Fisher in 1938, subsequently modified by Fukushima in 1988. In this classic nomenclature, the C1 segment begins at the carotid bifurcation and extends to the origin of the posterior communicating artery. The C2 segment extends from the posterior communicating artery to the distal dural ring. This has also been described by Day as the “ophthalmic segment.” The C3 segment is the extradural extracavernous part of the artery and lies underneath the anterior clinoid process. The C4 segment is the intracavernous segment, which extends to the origin of the meningeal hypophysial trunk. The C5 segment extends from the meningeal hypophysial trunk to underneath the trigeminal nerve. The C6 segment, the last segment, is the intratrusive portion of the internal carotid artery, from where it crosses underneath the mandibular division of the trigeminal nerve to its entrance at the foramen lacerum. More recently, van Loveren and colleagues introduced a nomenclature that essentially reverses and modifies the numbering sequence to reflect the direction of blood flow. To avoid confusion, terms such as “horizontal segment” and “anterior genu” are used in this book.

There are two so-called carotid dural rings, and they are important anatomic landmarks (Figure 1–43). The proximal ring denotes where the internal carotid artery exits from the cavernous sinus to become the clinoid segment of the internal carotid artery. The distal ring is the point where the internal carotid artery becomes intradural. Accordingly, these two rings delineate the clinoid segment of the internal carotid artery. The distal dural ring surrounds the internal carotid artery and is continuous with the dura mater of the falx cerebri, the anterior clinoid process, and the cavernous sinus. It is attached to the adventitia of the internal carotid artery. The proximal dural ring, which incompletely surrounds the internal carotid artery, is made up of periosteum arising from the anterior clinoid process. The membrane between the internal carotid artery and the oculomotor nerve is sometimes called the “caroticooculomotor membrane.”

The nine triangles of the cavernous sinus region need to be considered (Figure 1–44).

1. Anterior Medial Triangle

The anterior medial triangle is defined by the medial border of the optic nerve medially and the oculomotor nerve laterally. The base of the triangle is the dural edge
Superior orbital fissure
Middle meningeal artery
Oculomotor nerve
Trochlear nerve
Abducens nerve

Figure 1-42.
of the tentorium cerebelli. The anterior loop of the internal carotid artery lies in the floor of the triangle, along with trabeculated venous channels. This is called the “clinoid segment” of the internal carotid artery, and it is neither intradural nor intracavernous. Most transitional cavernous carotid aneurysms arise from this clinoid segment and penetrate through the distal dural ring to enter the subarachnoid space. Fibrous connective tissue in the apex of the triangle forms the proximal ring that en-sheaths the internal carotid artery and delineates the anteromedial border of the cavernous sinus.

2. Paramedial Triangle

The two sides of the paramedial triangle are defined medially by the medial border of the oculomotor nerve and laterally by the lateral border of the trochlear nerve. The base of the triangle is the dural edge of the tentorium cerebelli. The anterior loop and part of the horizontal segment of the cavernous carotid artery can be visualized through this aperture. Some surgeons have extended the paramedial triangle to a “medial triangle” that has the above-mentioned margins but a base that extends along the dura mater from the anterior to the posterior clinoid process, “the oculomotor trigone.” Incising the dura mater along this oculomotor trigone and then extending the incision into the paramedial triangle increases the exposure of the horizontal segment of the cavernous carotid artery.

3. Parkinson’s Triangle

Parkinson’s triangle is defined medially by the trochlear nerve and laterally by the first division of the trigeminal nerve. The base of this triangle is also the dural edge of the tentorium cerebelli. Access through this triangle provides visualization of the horizontal segment of the cavernous carotid artery.

4. Anterior Lateral Triangle

The anterior lateral triangle is defined medially by the ophthalmic division of the trigeminal nerve and laterally by the maxillary division of the trigeminal nerve. The base of the triangle is formed by a line running anteriorly between the superior orbital fissure and the foramen ovale. This triangle can be used to expose the superior orbital vein and to gain access to the anterior portion of the cavernous sinus.

5. Lateral Triangle

The lateral triangle is defined medially by the maxillary division of the trigeminal nerve and laterally by the mandibular division of the trigeminal nerve. The base is formed by a line extending from the foramen rotundum to the foramen ovale. The lateral triangle can be used when exposure of the anterior lateral part of the cavernous sinus is necessary for tumor excision.

6. Posterior Lateral Triangle (Glasscock’s Triangle)

The posterior lateral triangle is defined by the posterior rim of the foramen ovale, the foramen spinosum, the posterior border of the mandibular division of the trigeminal nerve, and the cochlear apex (greater petrosal nerve). This triangle is important for obtaining proximal control of the horizontal segment of the intrapetrous internal carotid artery for temporary occlusion or bypass procedures. This space is approached extradurally. Often, the internal carotid artery can be seen or palpated because it is covered only by a fibrous membrane instead of bone. Exposure of this triangle is achieved by using a diamond bur. After control of the middle meningeal artery is achieved, drilling commences just medial to the foramen spinosum and progresses along the posterior border of the mandibular branch of the trigeminal nerve. The greater petrosal nerve must be sectioned to prevent traction on the geniculate ganglion.

7. Posterior Medial Triangle (Kawase’s Triangle)

The posterior medial triangle is defined laterally by the greater superior petrosal nerve and medially by the petrosal sinus. The base is the trigeminal nerve. No pertinent neurovascular structures occur in this triangle. This ridge of petrous bone within Kawase’s triangle may safely be removed to provide greater access to the posterior cranial fossa when performing a transtentorial approach. The posterior medial triangle also provides greater exposure of the trigeminal nerve.

8. Inferior Medial Triangle

The inferior medial triangle is defined medially by a line between the posterior clinoid process and the abducens nerve at Dorello’s canal and laterally by a line running between Dorello’s canal and the trochlear nerve at the edge of the tentorium. The base of the triangle is the petrous apex.

9. Inferior Lateral Triangle

The inferior lateral triangle is defined medially by a line running between Dorello’s canal and the trochlear nerve at the edge of the tentorium cerebelli and laterally by a line between Dorello’s canal and the petrosal vein at the petrosal sinus. The base is the tentorium cerebelli.
Proximal dural ring

Distal dural ring

Figure 1-43

Oculomotor nerve
Trochlear nerve
Abducens nerve
Greater petrosal nerve
Middle meningeal artery

Figure 1-44.
Operation

Most transitional carotid cavernous aneurysms can be approached through a modified pterional craniotomy that requires more removal of temporal bone. Some surgeons prefer to approach these aneurysms through a frontotemporal zygomatic craniotomy. If the aneurysm extends proximally to the proximal carotid ring, removal of the zygoma will allow better exposure of the lateral cavernous sinus.

In most larger cavernous carotid aneurysms, proximal control of the internal carotid artery is desirable. This can be achieved through an extradural exposure of the petrous carotid artery. Alternatively, the cervical carotid artery can be exposed through a linear incision anterior to the sternocleidomastoid muscle. Exposure of the cervical carotid artery has the advantages of being easier technically and providing a route to perform intraoperative angiography if so needed. Exposure of either the cervical or petrous carotid offers the surgeon some degree of safety should the aneurysm inadvertently rupture intraoperatively.

Figure 1-45.

Step 1. Most transitional cavernous carotid aneurysms can be explored through an enlarged pterional craniotomy that has some extension into the middle cranial fossa. As illustrated here, the cervical carotid artery is exposed to provide proximal blood vessel control should an inadvertent rupture occur intraoperatively. An alternative to this is a frontotemporal zygomatic craniotomy, with extradural exposure of the petrous carotid artery. Exposure of the cervical carotid artery is technically easier and quicker, and it provides an easier route for performing intraoperative angiography if needed. Note that the position of the patient’s head is slightly more lateral than for a true pterional craniotomy to facilitate dissection of the cavernous sinus.
Step 2. After the bone flap is elevated, the frontal and temporal dura mater are dissected off the sphenoid wing and protected with malleable retractors. The outer sphenoid wing is removed with a high-speed diamond air drill. Approximately 2 to 3 cm deep to the outer sphenoid wing, the drill is used to make a hole into the orbital roof.

Step 3. The hole created in the orbital roof is extended by using a small bone forceps or punch. Both small spatulas and ball-tip dissectors can be used to dissect the inner sphenoid wing and anterior clinoid process off both the orbital fascia and the frontal and temporal dura mater. As the dissection is extended deeper, two struts of bone tether the anterior clinoid process. Both of these struts, the optic strut and the lateral rim over the superior orbital fissure, can be removed with small bone forceps. After these two bony struts are removed, a fine spatula is used to dissect the anterior clinoid process off the dura mater. The dura mater is then grabbed with the bone forceps, gently rocked, and rotated medially and laterally until it is loose, and then it is pulled out of the junction between the frontal dura mater, temporal dura mater, and orbital fascia.
Figure 1-48.

Step 4. This figure illustrates the location of the aneurysm in relation to the removed part of the medial sphenoid wing and the anterior clinoid process. This extradural removal is advantageous because dura mater overlies the aneurysm, the internal carotid artery, and the optic nerve. The relationship of the optic nerve to the medial bony optic strut indicates why removal of this bone with bone forceps decreases the risk of thermal injury to the optic nerve, which might occur with a high-speed air drill.

The dura mater is opened in a curved fashion and tacked to the overlying temporalis muscle. This dural flap prevents blood from running into the wound. At the end of the operation, the dura mater can be closed either primarily or with a graft. In this way, the only dural defect that remains is the one in the cavernous sinus region, and the risk of postoperative leakage of cerebrospinal fluid and wound complications is minimized.
Figure 1–49.

Step 5. As in a standard pterional craniotomy, the next step is to separate the Sylvian fissure. In this illustration, the fissure is being divided from lateral to medial. However, as mentioned above, in some situations it may be necessary to divide the fissure from medial to lateral, especially in young patients or after a significant subarachnoid hemorrhage in which blood is packed in the Sylvian fissure. Although small bridging veins overlying the Sylvian fissure may safely be cauterized and divided, it is best to preserve the temporal veins by displacing them laterally with the temporal lobe. This will help decrease the risk of postoperative seizures and contusions of the temporal lobe.
**Step 6.** The Sylvian fissure is divided, and after the brain is protected with hemostatic fabric and cottonoids, the frontal lobe retractor is again repositioned deeper. The arachnoid over the supraclinoid carotid artery is divided to identify the bifurcation of the internal carotid artery. Typically, the rostral portion of the aneurysm is immediately apparent. Most often, the optic nerve is displaced medially by the medial projection of the dome of the aneurysm.

Exposure of the cavernous portion of the aneurysm is first accomplished by incising the dura mater linearly along the presumed axis of the internal carotid artery over the site where the extradural bone was removed. Before this incision is made, a small spatula is used to gently depress the dura mater intended to be cut to make sure that no part of the aneurysm dome lies immediately beneath the site.
Figure 1-51.

Step 7. A small ball-tip dissector is used to separate the distal dural ring from the underlying aneurysmal dome. The ball-tip dissector is swept medially to laterally. The freed dural ring is then incised with either a scalpel, micro Potts scissors, or standard straight microscissors. The advantage of either the micro Potts or microscissors is that the dural ring can be lifted off the dome of the aneurysm and cut more easily than with a scalpel.

After the distal dural ring is incised, it is necessary to dissect the medial and lateral portions of the aneurysm. Most often, the dome of the aneurysm is adherent to the lateral portion of the wall of the cavernous sinus. A small spatula can be used to sharply dissect the dome off this wall. It is important to recognize that cranial nerves run in this lateral cavernous wall. At this level, the primary nerve at risk for injury is the oculomotor nerve.

Medially, it is necessary to identify the origin of the ophthalmic artery. Most often, the origin of this artery marks the junction between the aneurysm and the parent carotid artery along the medial border. This is an important landmark because it may be difficult to identify this transition zone. Sometimes, it is not enough to remove the bony optic strut. If so, a small punch can be used to remove more bone to allow a better line of site to identify the junction between the aneurysm and the parent artery.

It also is important to identify the proximal margin of the aneurysm and its point of takeoff from the parent carotid artery. Usually, this proximal neck occurs at the anterior genu of the internal carotid artery, as it starts to curve laterally and deep.
Step 8. The dome of the aneurysm is displaced with a #5 or #7 straight suction tip and cottonoid to allow exact identification of the junction of the ophthalmic artery, parent carotid artery, and medial neck of the aneurysm. The best clip to use for most of the aneurysms is a forward-angled straight clip passed along the long axis of the artery. Helpful visual and tactile guides to use for the initial placement of the clip are the ophthalmic artery medially and the anterior wall of the cavernous sinus. If the clip is placed just above the ophthalmic artery and inserted until there is resistance when the tips of the clip hit the anterior bony wall of the cavernous sinus, it is likely that this initial clip placement will successfully obliterate the neck without compromising the internal carotid artery.

After the location of the jaws of the aneurysm clip have been inspected visually, the dome is aspirated for decompression of the aneurysm. Thereafter, correct placement of the aneurysm clip is reconfirmed. At this point, it is useful to have objective documentation that the aneurysm has been obliterated and that the parent internal carotid artery is not stenosed or occluded. Intraoperative Doppler or ultrasonography of the internal carotid-middle cerebral artery complex is useful. However, currently, intraoperative angiography is the best method of documentation. Therefore, if available, a radiolucent headholder and table should be used. Intraoperative angiography can be performed through either a direct cervical carotid puncture or by femoral artery catheterization.