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Surgical approaches to suprasellar and parasellar tumors

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Most pituitary tumors, even large lesions, are treated quite effectively via the transsphenoidal approach to the sella. At times, however, pituitary tumors grow outside the bounds of the sella and invade the cavernous sinus and adjacent parasellar region. Significant lateral extensions within the cavernous sinus may be extremely difficult if not impossible to resect from below, even with adjuncts like endoscopy. Larger tumors may be unresectable via the transsphenoidal approach because of a significant suprasellar component, especially when the tumor consistency is extremely firm. As a consequence, the tumor does not "drop down" during the course of transsphenoidal resection as inferior portions of tumor are cleared away. In such cases, a transcranial approach is indicated for total removal of the tumor.

Transcranial strategies for supra- and parasellar lesions have recently been influenced tremendously by the development of sophisticated cranial base approach techniques. Utilization of complex cranial base strategies has rested on several central tenets. Primary is the concept of extradural removal of bone in lieu of brain retraction. A byproduct of optimizing bone removal is creating mobility of cranial nerve and arterial structures by unroofing them at the canals through which they traverse the cranial base. Another basic tenet of cranial base strategies is the preservation of venous drainage routes. A specific example of this is the preservation of the temporal tip bridging veins practiced as a part of the extradural temporopolar approach [1]. This article focuses on the specific methods that possess the greatest utility for most pituitary lesions occupying the central cranial base and having extensions within the suprasellar and parasellar regions.

Frontotemporal transcavernous approaches

Pterional, transzygomatic, and orbitozygomatic approaches

Development and indications

The frontotemporal transcavernous approach [1–3] to the supra- and parasellar regions takes its origin from the pterional approach popularized by Yasargil and Fox [4]. This standard technique was further modified by Dolenc et al [3] to include the necessary maneuvers to gain access to the cavernous sinus. The craniotomy technique may employ any of three basic strategies: pterional, transzygomatic, and orbitozygomatic. The choice of craniotomy depends on the particular exposure needs for treatment of the individual lesion. Beyond the initial craniotomy, the special maneuvers to gain access to the cavernous sinus constitute the essence of the approach and are detailed below. For many less extensive lesions, the standard pterional approach proves adequate in terms of the external cranial opening. Lesions with significant extensions to the middle fossa and those that extend far above the level of the dorsum sellae may benefit from a more extensive cranial opening, however, such as the transzygomatic or orbitozygomatic method.

Mobilization of the zygoma and lateral orbital rim has been used by head and neck surgeons for

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years as a means to expose the infratemporal fossa [5,6]. Zygomatic osteotomy combined with a frontotemporal craniotomy is a maneuver that has yielded benefits in exposure of the lateral and central cranial base and has been reported by several groups [7–11]. The exposure benefits of zygomatic arch osteotomy are twofold. Access to the lateral aspect of the middle cranial base is effected with decreased retraction of the temporal lobe. Removal of the zygoma also results in an increased ability to radically deviate the surgical microscope, enhancing inferior-to-superior viewing trajectories. This concept is the basis of the approach's utility within the context of central cranial base lesions that extend far superior to involve the third ventricular region.

The approach is indicated for lesions occupying the parasellar and suprasellar regions that have either significant lateral extension to the middle fossa or moderate superior extension toward the third ventricle. The superior extent of exposure is limited to no more than 2 to 3 cm above the level of the tuberculum sellae. Visualization above this level is not possible without an untenable degree of retraction of the frontal lobe.

As with the zygomatic approach, orbitozygomatic osteotomy has been used for years by head and neck surgeons as well as by ophthalmologists as a means of exposing the orbit and infratemporal fossa regions [12]. This technique has also been helpful to cranial base surgeons for exposure of intradural pathologic findings at the central cranial base [13–17]. The obvious benefit of such an approach is the lesser degree of brain retraction required for adequate exposure in the depth of the operative field. As applied to central cranial base lesions, this approach is indicated for those with more dramatic superior extensions compared with the zygomatic approach. Lesions that extend to the third ventricle and above the level of the optic chiasm may be well exposed with this strategy. Lesions with lateral extensions to the cavernous sinus and those involving the parasellar and interpeduncular regions are also provided wide exposure. The added benefits of the orbitozygomatic technique rest on a widened angle of attack. The angle of approach is inclusive of the subfrontal, frontotemporal, and anterior subtemporal trajectories. Second, exposure and skeletonization of the superolateral orbit results in the ability to apply gentle retraction in the inferior direction. The result is more radical deviation of the microscope in the inferior direction, allowing an increased inferior-to-superior viewing trajectory.

Technique

After induction of general endotracheal anesthesia, the head is secured in position via three-pin fixation. The optimum position is with the head rotated approximately 45° toward the opposite side, with the malar eminence the highest point. The appropriate electrodes are then placed for intraoperative monitoring of selected cranial nerves, electroencephalography (EEG), and somatosensory evoked potentials (SSEPs) as necessary.

Pterional and transzygomatic craniotomy. The surface landmarks critical to proper positioning of the scalp incision are the tragus of the ear, the zygomatic arch, and the midline. The same incision is used for the pterional and transzygomatic methods. The skin is incised beginning 1 cm below the level of the zygomatic root and 5 mm anterior to the tragus. The incision continues superiorly, incising through the galea and curving gently within the hairline to end at the midline. For the pterional approach, the scalp and temporalis muscle are usually elevated as a single layer, holding the flap anterior with blunt scalp hooks. The transzygomatic method requires elevating the scalp separate from the fascia and muscle, however. This is done using the method of Yasargil and Fox [4], performing an interfascial dissection. The galea is separated from pericranium medial to the superior temporal line. Over the temporalis fascia, the interfascial dissection is performed to protect the frontalis branches of the facial nerve. The flap is elevated to expose the lateral orbital rim and zygomatic arch. The periosteum over these structures is incised and reflected subperiosteally. The anterior and inferior limit of the dissection is signaled by exposure of the zygomaticofacial foramen.

Osteotomies are then performed for removal of the zygoma (Fig. 1). An anterior osteotomy is made incorporating the posterior portion of the lateral orbital rim, effectively removing the bone overhanging the frontozygomatic recess. The posterior osteotomy is oriented parallel with the temporal squama. Performing this posterior osteotomy in a perpendicular orientation to the temporal squama may result in a hindrance to complete temporalis muscle reflection inferiorly. The temporalis muscle and fascia are then elevated to clear the frontozygomatic recess and the temporal squama. The muscle is held posteriorly and inferiorly with large hooks.

A frontotemporal craniotomy is performed, the dimensions of which depend on the necessary amount of frontal exposure. After removal of the

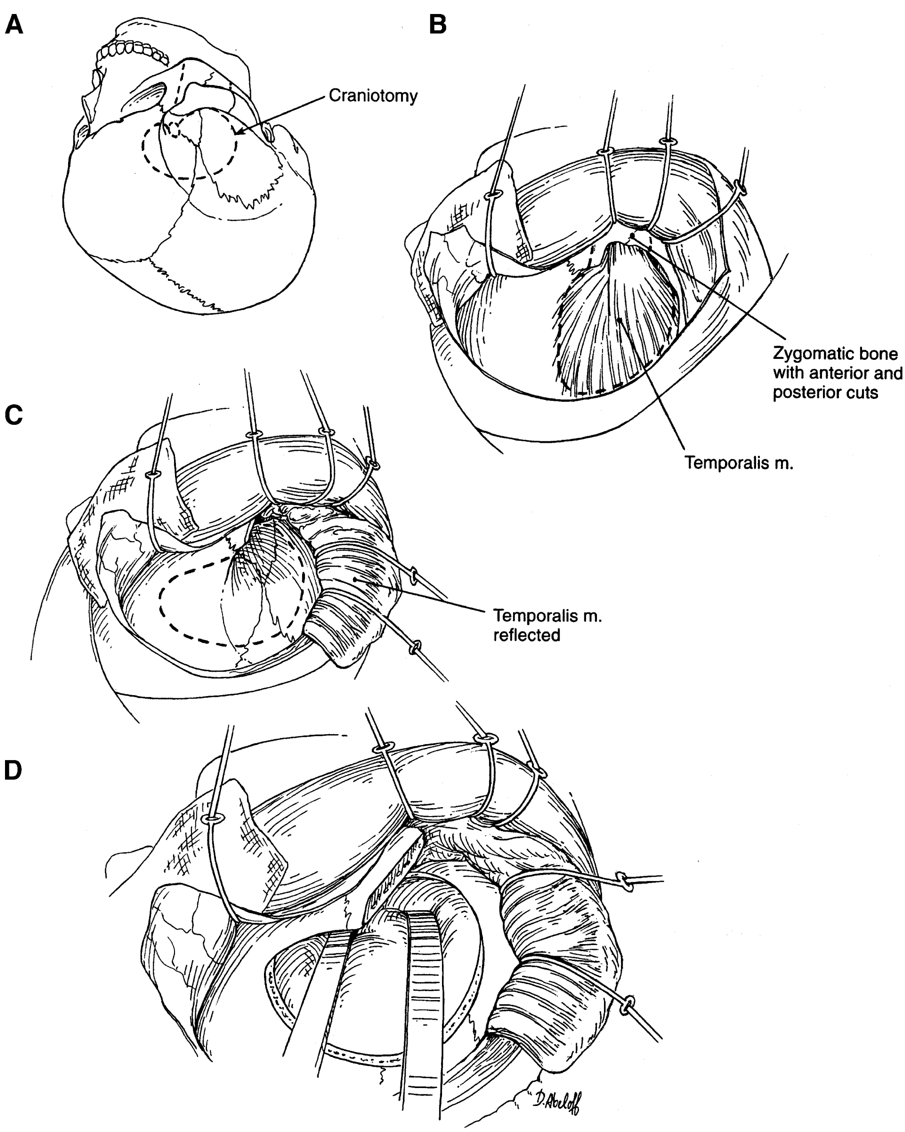


Fig. 1. (A) Craniotomy and zygomatic osteotomies are outlined for the transzygomatic technique. (B) The scalp is elevated utilizing an interfascial technique to expose the zygoma and lateral orbital rim. (C) The temporalis muscle is reflected inferiorly and posteriorly after zygoma removal. (D) After craniotomy, the sphenoid ridge is flattened with the high-speed drill.

flap, any bone overhanging the middle or anterior fossa floor is removed with rongeurs.

Orbitozygomatic craniotomy. Positioning of the head is identical to that done for the pterional or transzygomatic approach. The scalp incision may be a modified bicoronal or large frontotemporal incision that crosses the midline. This is necessary to provide adequate scalp elevation to expose the orbital rim. The scalp is elevated using the interfascial method, splitting the temporal fat pad to protect the frontalis branches of the facial nerve. The exposed pericranium medial to the superior temporal line is incised and elevated to preserve a frontally based vascularized pericranial flap. The periosteum of the lateral orbital rim and zygomatic arch is incised and elevated. This is done in such a way so as to leave a cuff of tissue for later reapproximation. The periosteum is reflected over the zygoma bone anteriorly and inferiorly until the zygomaticofacial foramen is exposed.

In preparation for the osteotomies, the periorbital fascia is elevated from the superior and lateral orbital walls to a depth of approximately 10 to 15 mm. The supraorbital nerve is carefully removed from its notch in the superior orbital rim and is reflected with the periorbita. In some cases, an osteotome or oscillating saw is used to incise a wedge of bone that incorporates the supraorbital foramen and its contents. The wedge of bone containing the nerve and its vascular bundle is reflected with the periorbita. The temporalis muscle and fascia must also be elevated from the greater wing of the sphenoid bone and the temporal squama. The muscle is reflected inferiorly and posteriorly.

A burr hole is placed over the pterion such that it straddles the sphenoid ridge. Using the high-speed drill, a groove is drilled from the burr hole toward the temporal base. The craniotome is then used to complete the frontotemporal osteotomy. The frontal extension of the flap is taken to the medial side of the supraorbital notch. The zygoma root is incised at its base in a plane parallel with the temporal squama. On the inferior surface of the arch, the masseter muscle attachment must be sharply removed. Next, the zygoma is incised in an oblique plane from the lateral orbital rim toward its infratemporal margin. This cut is made superior to the zygomaticofacial foramen. The intraorbital osteotomy is then made using either an oscillating saw or a curved osteotome. Completion of the osteotomies results in the creation of the one-piece orbitozygomatic bone flap (Fig. 2). The temporalis muscle can now be retracted posteriorly and inferiorly.

Extradural bone dissection. Extradural bone removal at the cranial base is then performed to maximize exposure while minimizing retraction of the brain. Frontal and temporal dura is elevated away from the sphenoid ridge, and the ridge is drilled flat with a high-speed drill. In most cases, it is necessary to uncover the optic canal and to remove the anterior clinoid process. Using diamond burrs and magnification with the microscope, the optic canal is skeletonized while constantly applying cool irrigation fluid. The anterior clinoid process is also removed, exposing the subclinoidal segment of the carotid artery. It is necessary to remove bone over the superior orbital fissure to expose periorbita. In cases with wide parasellar extension, it may be necessary to unroof the foramen rotundum and foramen ovale for adequate exposure and access to the cavernous sinus. Tumors with extension to the sphenoid sinus may be accessed via this approach by opening the planum sphenoidale from above [18].

Combined intra- and extradural dissection. After bone removal, attention is directed to the interface between the periorbita at the superior orbital fissure and the temporal dura. At this interface, a cleavage plane is present. While placing gentle and continuous posterior retraction on the temporal dura, this plane is developed sharply with a number 15 scalpel blade or sharp dissector. The dura propria is gradually separated from the connective tissue sheath that forms the outer cavernous membrane. Separation of the dura propria continues over the trigeminal complex and the posteromedial cavernous sinus (Fig. 3).

The dura is next opened at the junction between the frontal and temporal dura over the proximal Sylvian fissure. The incision is continued through the lateral portion of the optic nerve sheath. A second limb is cut in the medial direction over the tuberculum sellae (see Fig. 2C) The fibrous dural ring surrounding the carotid artery as it pierces the dura is then incised, continuing to the anterior petroclinoidal ligament. The dural leaves forming the anterior petroclinoidal ligament are split, and their reflection is incised. This incision is taken laterally and posteriorly along the anterior petroclinoidal ligament (see Fig. 3). This technique allows for mobilization of the carotid artery in either the medial or lateral direction to open the dissection routes to the suprasellar region more widely. The dural fold overhanging the oculomotor trigone is then (Fig. 4) opened sharply, and this incision meets that made in the anterior petroclinoidal ligament above. A suture is used to retract this dural flap laterally. The medial triangle of the cavernous sinus, that located medial to the oculomotor nerve and lateral to the sella, is then entered. Dissection may continue lateral to open the outer cavernous membrane between the third, fourth, and fifth cranial nerves (the superior and lateral cavernous triangles).

Tumor removal proceeds according to established microsurgical techniques. Removal of large benign tumors that invade the cavernous sinus, such as pituitary adenomas, is generally not particularly bloody, because the tumor compresses and displaces the cavernous venous plexus. The optimal technique is to debulk the tumor internally, working in corridors between the cranial nerves in the lateral wall of the cavernous sinus, and then to remove the tumor capsule as much as possible (Fig. 5). Resection of suprasellar tumor extensions is performed with strict attention to maintaining arachnoid planes so as to protect the surrounding neurovascular structures. In particular, the anterior cerebral arteries and their perforating branches, the pituitary stalk, and the hypothalamus are critical surrounding structures that are protected. At the conclusion of tumor removal, the dura is closed in a watertight fashion using fascial and muscle grafts as needed. Fibrin glue is also helpful to augment closure. In selected cases, lumbar drainage of cerebrospinal fluid (CSF)

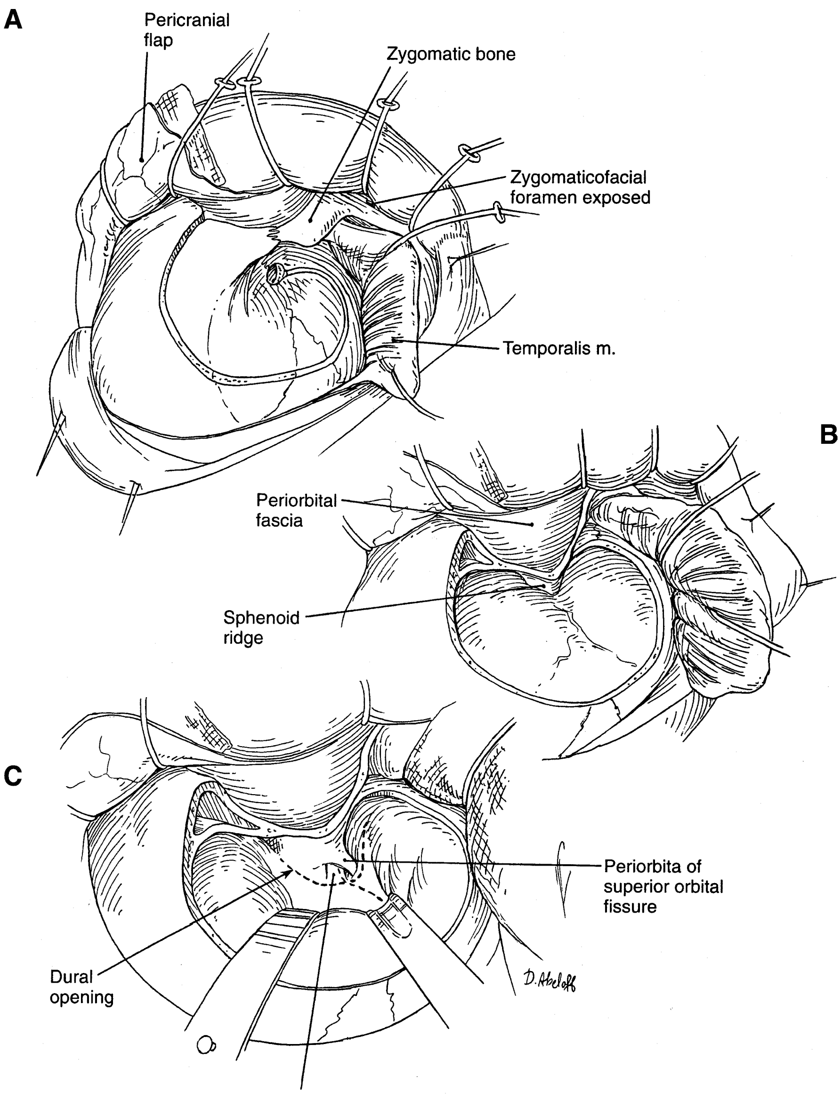


Fig. 2. (A) The soft tissues have been reflected for the orbitozygomatic approach, and the initial craniotomy cuts have been made for one-piece flap removal. (B) With the flap removed, the remainder of the sphenoid ridge is reduced with the drill in preparation for the extradural bone removal at the cranial base. (C) Extradural bone removal results in exposure of the optic sheath, subclinoidal segment of the carotid artery, and periorbita at the superior orbital fissure. The dural incision outlined results in preservation of temporal bridging veins.

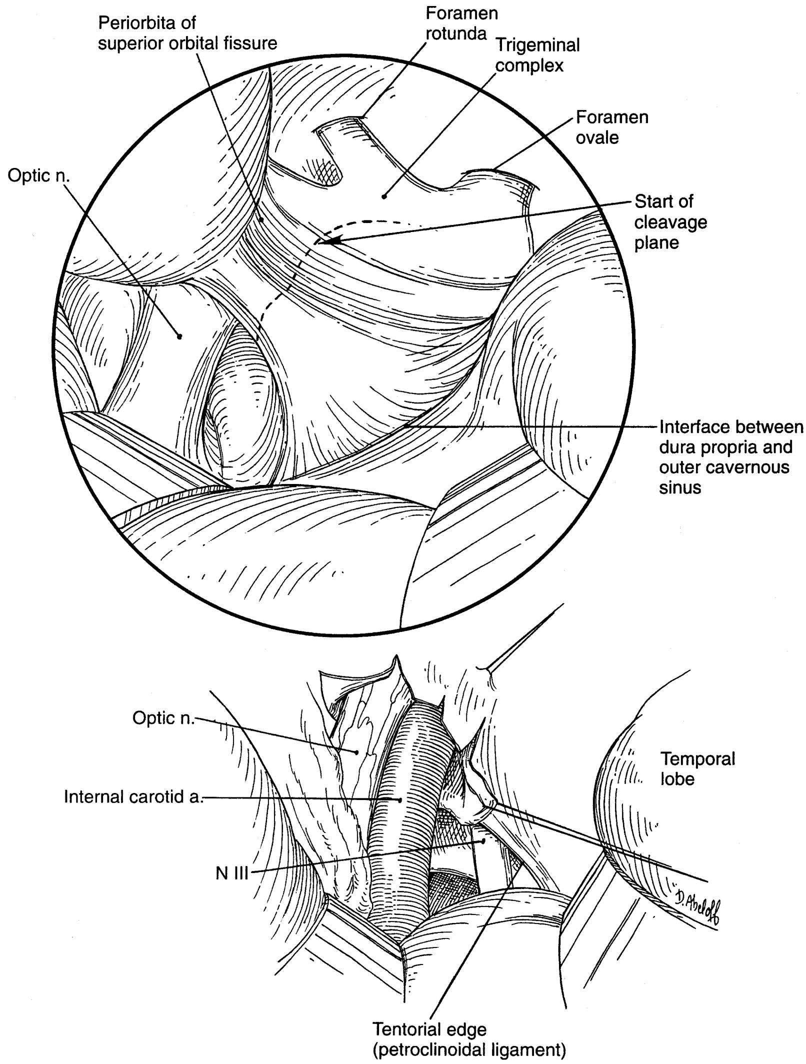


Fig. 3. The extradural cavernous dissection is begun by separating the temporal dura propria from the outer cavernous membrane. After separation of the dura propria and opening the dura, the fibrous dural ring around the carotid artery is incised to mobilize the vessel.

for approximately 72 hours is advisable to help prevent postoperative CSF leakage.

Bifrontal transbasal approach

Development and indications

The transbasal approach was first developed in 1960 by Tessier to correct craniofacial abnormalities. It was subsequently applied to neurosurgical cases by Derome [19] for the resection of tumors at the frontal cranial base. The approach provides a wide exposure of the frontal and central cranial base via a bifrontal craniotomy. It is well suited for pathologic findings that affect the clivus, upper air sinuses, medial orbits, suprasellar region, and third ventricle via the lamina terminalis. The classic approach as described by Derome [19] has been expanded by several groups in an attempt to increase exposure and decrease the degree of necessary frontal lobe retraction. Removal of the central segment of the supraorbital bar, termed the *extended* transbasal approach, has been advocated

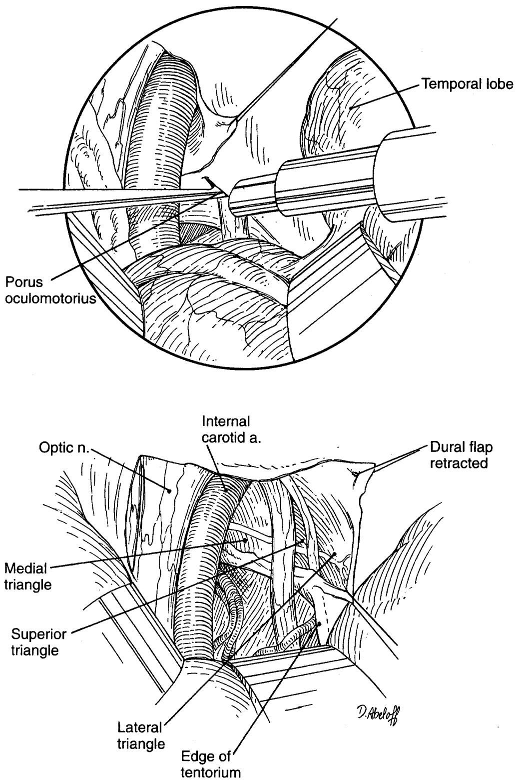


Fig. 4. The anterior petroclinoidal ligament is split, and the incision is connected to that made at the oculomotor trigone to open the medial triangle of the cavernous sinus. The entry corridors between the third, fourth, and fifth cranial nerves may now be utilized for tumor removal in the cavernous sinus.

for lesions with both far superior and far inferior extensions. Removal of the extra bone at the frontal base decreases the degree of brain retraction for a given amount of exposure in either direction. A more inferior-to-superior viewing trajectory is the result, with a minimum of frontal lobe retraction. This concept has also been applied to what is termed the *extensive* transbasal approach. This technique incorporates total removal of the supraorbital bar, with the idea of providing a wide basal approach with minimized brain retraction. Removal of the supraorbital rims yields exposure benefits particularly in visualizing the area inferior to the contralateral orbit and the contralateral clivus. It is also beneficial if complete orbital skeletonization is employed as a means of mobilizing the orbital contents laterally so as to widen the exposure to the central base. Such an extensive approach would only be rarely necessary, as in the case of large extensive pituitary tumors.

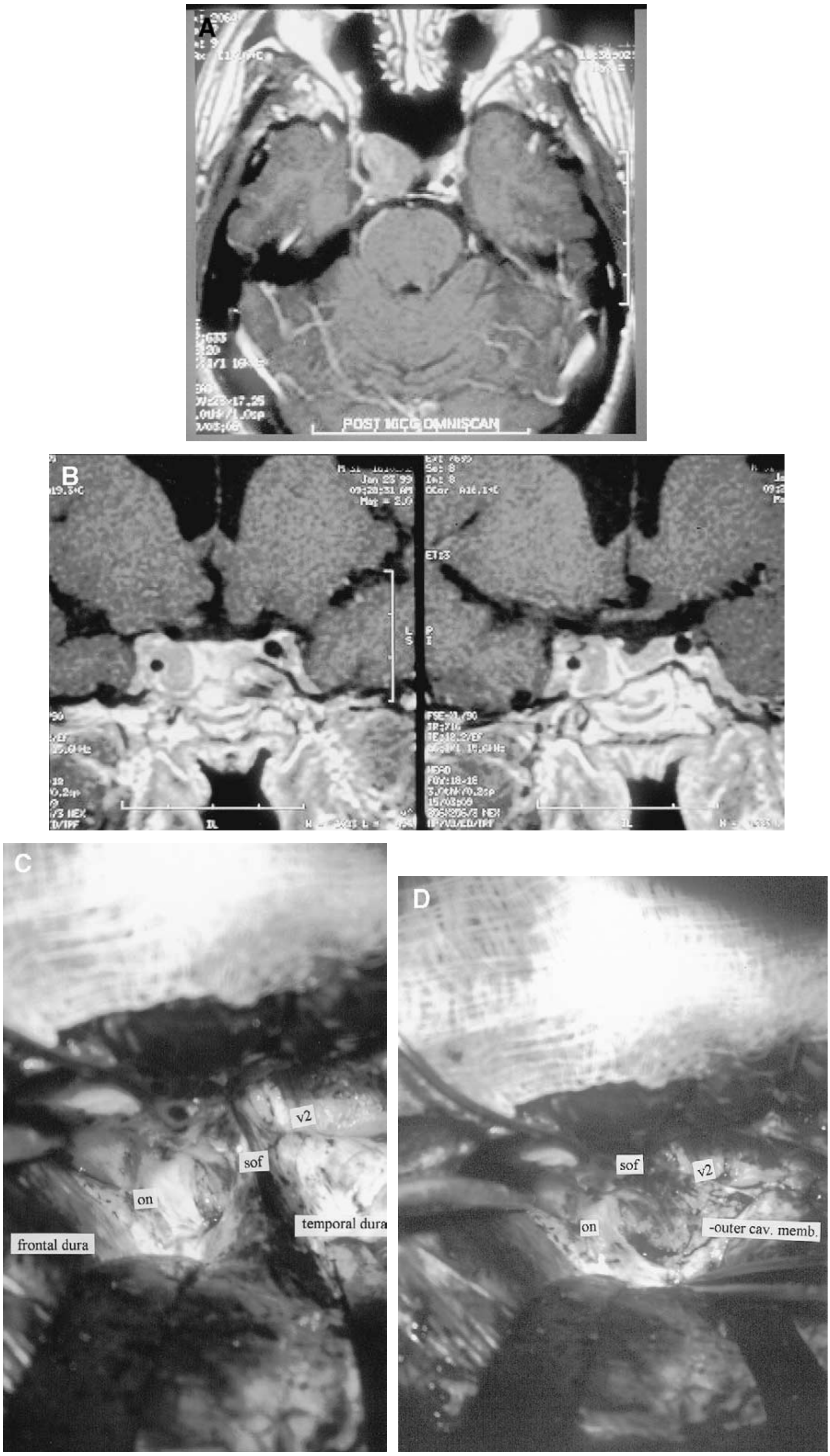
Technique

After the induction of general endotracheal anesthesia, the head is placed in rigid three-pin fixation with the nose straight up. The vertex is oriented 15° to 20° toward the floor. A bicoronal scalp incision is made, and the scalp is elevated in the subgaleal plane, leaving pericranium adherent to the skull. A long and wide vascularized pericranial flap is then elevated, based anteriorly on the supraorbital rim. The temporalis fascia and muscle are incised to create an opening for burr hole placement over the pterion on each side.

A bifrontal bone flap is then cut with the craniotome, being careful to avoid injury to the superior sagittal sinus. The inferior margin of the craniotomy is made following the contour of the supraorbital ridge and glabella (Fig. 6). This results in maximization of the exposure along the frontal floor, lessening retraction of the frontal lobes. Alternatively, when far superior access is necessary, an extended transbasal approach may be used. This is done simply by adding the removal of the mesial supraorbital bar to the approach. Osteotomies are made at the nasofrontal suture and just medial to the supraorbital notches on each side. This central block of bone is removed to allow more radical inferior angulation of the microscope with diminished retraction of the frontal lobes. After craniotomy, the frontal sinus is exenterated of mucosa and the posterior wall is removed with the high-speed drill.

At this juncture, either a primarily extradural or intradural approach is applied. The decision rests on the exposure needs to treat the individual tumor. Tumors that have limited intrasellar and parasellar involvement with large suprasellar extension may be treated by an intradural method alone. If a large parasellar and/or intrasellar component exists, however, extradural bone removal at the cranial base is necessary for adequate exposure.

The purely intradural approach is performed by opening the dura in a linear incision at the frontal poles. This allows the frontal lobes to be retracted, mostly with dura overlying them, protecting the venous structures at the midline. The superior sagittal sinus is ligated and divided near the crista galli. The olfactory tracts are then dissected from their pia-arachnoid attachments and left in place in the olfactory grooves so as to preserve olfaction. The tumor is removed, and the dura is repaired using fascial grafts as necessary.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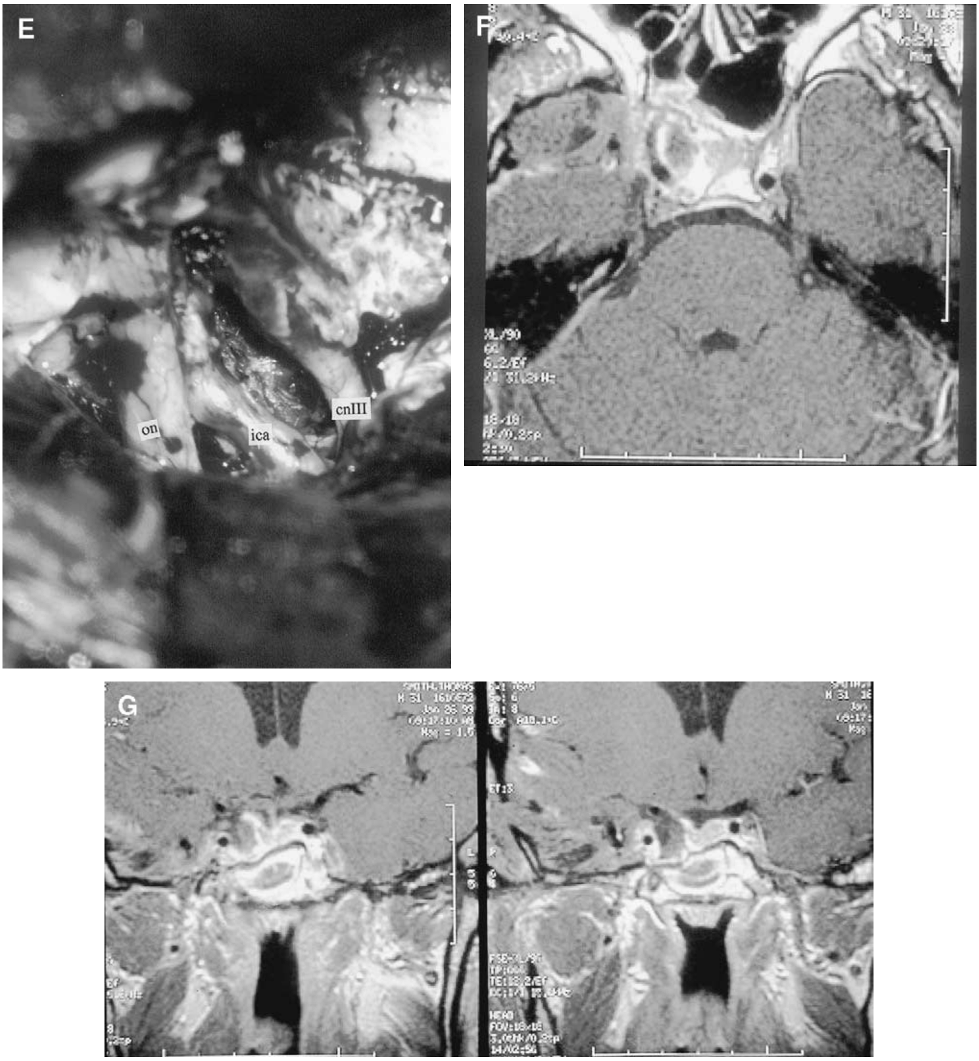

Fig. 5 (*continued*)

The primarily extradural approach is a combined intra- and extradural strategy that affords extensive exposure of the central cranial base. The frontal dura is elevated from the floor, with the lateral margins of elevation being the sphenoid ridge on either side. The dura is tethered around the midline at the cribriform plate and crista galli. The olfactory nerves are cut, and the dura is mobilized from the cribriform plate and crista galli. The dura is then repaired with fine suture. Alternatively, osteotomies may be made around the circumference of the cribriform

Fig. 5. Case example. (A,B) Axial and coronal MRI with contrast views of residual tumor in the right cavernous sinus after an initial transsphenoidal approach. The patient suffered from painful ophthalmoplegia approximately 6 months after the initial surgery. (C) Frontotemporal craniotomy was followed by extradural bone removal to expose the optic sheath, superior orbital fissure, and subclinoidal carotid artery. (D) The dura propria is separated from the outer cavernous membrane. (E) The dura is opened, and the carotid ring is incised. The medial cavernous triangle is entered, and the tumor is resected. (F) Operative view of the medial cavernous triangle after tumor removal. (G) Postoperative axial and coronal contrast-enhanced MRI demonstrating gross total removal of tumor from the cavernous sinus.

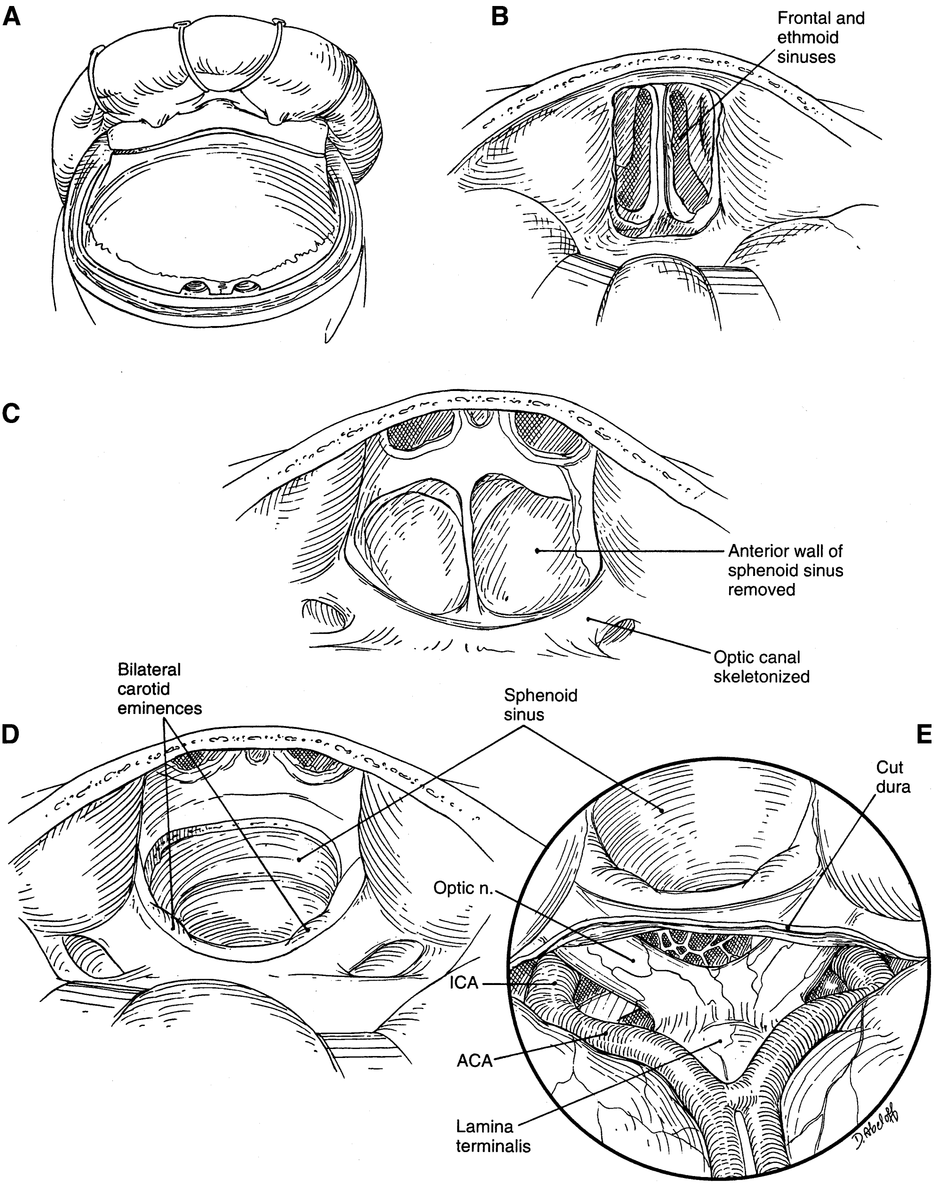

Fig. 6. (A) Bicoronal incision and scalp elevation followed by bifrontal craniotomy are the initial steps of the frontal transbasal approach. (B) Cranialization of the frontal sinus and removal of ethmoid bone opens the view of the sinuses. (C) Expansion of the opening to include the planum sphenoidale results in exposure of the sphenoid sinus. The optic canals are skeletonized. (D) Removal of clival bone may be of benefit in cases of tumor with clival invasion. (E) Opening the dura affords wide exposure of the suprasellar region and access to the lamina terminalis.

plate, and the olfactory mucosa is mobilized with the bone and dura. This technique offers a modest chance of preservation of olfaction. The posterior margin of dural elevation is the tuberculum sellae.

Extradural bone removal begins at the frontal sinus ostea. With the high-speed drill, the ethmoid and sphenoid sinuses are unroofed. Bone removal is limited laterally by the orbits, which are skeletonized. The anterior wall of the sphenoid sinus is removed. This provides a view of the sphenoid sinus and upper nasopharynx, exposing the midline nasal septum and the superior turbinates. Posteriorly, the optic canals are both unroofed. The

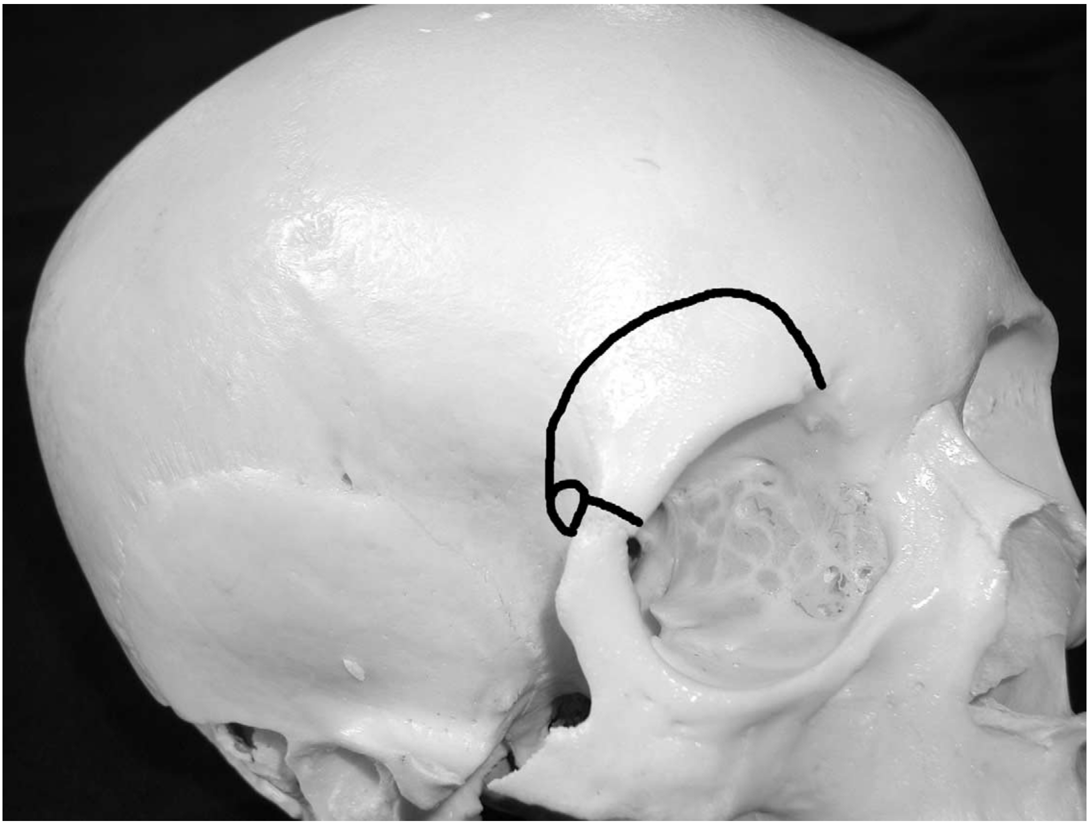

Fig. 7. The craniotomy utilized for the supraorbital approach is outlined. The entry hole is made just below the linea temporalis in the frontal bone.

anterior clinoid processes are removed if access to the cavernous sinus is required. A wide view of the sphenoid sinus is afforded at this point. The optic canals and the bilateral carotid eminences are visible. Any remaining bone over the pituitary fossa is removed. For lesions with inferior extensions, the clivus may be removed at this point with the drill.

The dura is opened along the frontal base, and the frontal lobes are retracted under protection of the overlying dura. This provides a luxurious exposure above the optic chiasm to the lamina terminalis. A prefixed chiasm limits access in the midline trajectory. A postfixed chiasm allows access to the lesion inferior to the optic apparatus on either side of the pituitary stalk.

Dural closure is performed in watertight fashion using patch grafts as necessary. The bony defect in the frontal floor must be reconstructed if it is greater than 3 to 4 cm in diameter. This rule prevents herniation of the frontal lobe and creation of an encephalocele. Titanium mesh works well to reconstruct the floor and is best covered over by the vascularized pericranial graft preserved initially. Nasopharyngeal mucosal reconstruction has not been found to be necessary. Patients may have some difficulty over the long term with significant crusting over the reconstruction site, however, and may require frequent use of saline sprays to reduce discomfort.

Supraorbital approach

Development and indications

The supraorbital approach for supra- and parasellar lesions derives from the subfrontal transsphenoidal approach [18] and the supraorbital craniotomy technique suggested by Delashaw et al [20] and Jane et al [21]. The approach combines the best aspects of both methods to minimize brain retraction while affording excellent exposure in a cosmetically satisfying minimalistic fashion. To summarize, the supraorbital rim is removed with

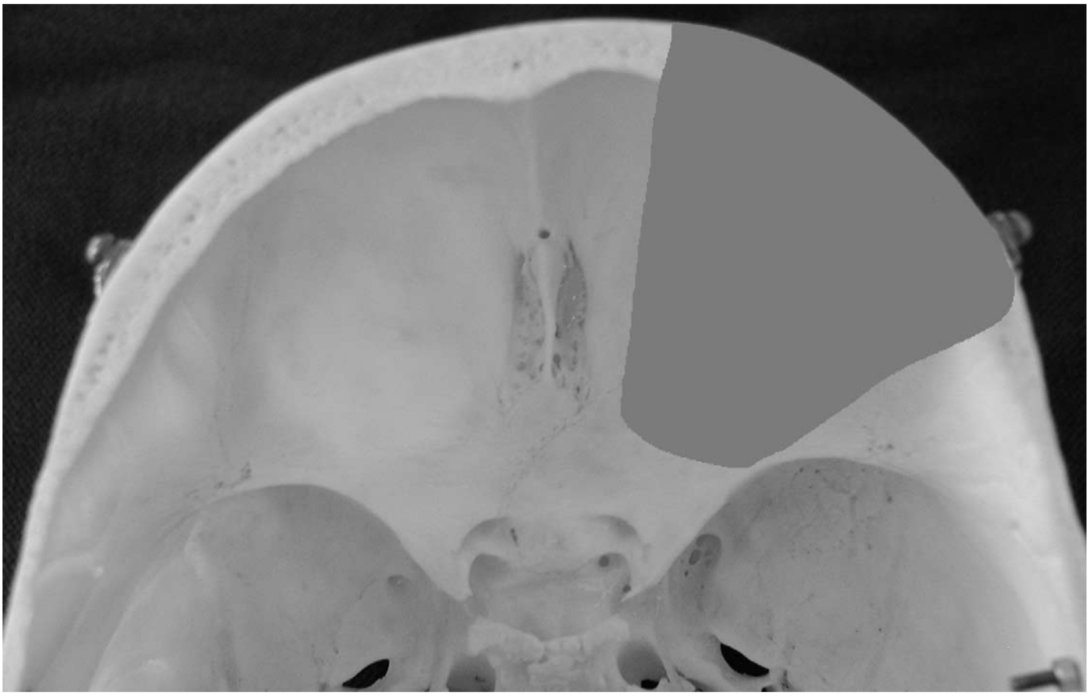

Fig. 8. Axial view of the bone removed at the orbital roof to afford exposure with a minimum of frontal lobe retraction.

a small frontal craniotomy. Combined with removal of the orbital roof, a low-approach trajectory to the supra- and parasellar region is afforded for resection of the tumor. This approach has also been reported recently for clip ligation of anterior communicating artery aneurysms and suprasellar neoplasms, with good results [22–27]. The approach is not well suited to those tumors with significant extension within the cavernous sinus, because exposure there is limited. The suprasellar compartment is well visualized, however. The sphenoid sinus may be accessed by opening the planum sphenoidale.

Technique

The patient is positioned supine with the head in three-pin fixation turned 30° to 45°, with the vertex slightly downward. Placement of a lumbar catheter before positioning for drainage of CSF is optional. Two scalp incisions may be employed. A large frontotemporal incision may be made in same fashion as that used in the orbitozygomatic approach. Alternatively, an incision within the eyebrow may be made, which provides superb cosmesis and is much less time-consuming. The eyebrow incision is made incising at an angle that approximates the angle of the hair follicles of the brow. A small lateral extension outside the brow may be necessary in some patients. The incision is carried through the galeal layer. The subgaleal plane is then undermined superiorly, and small scalp hooks are used to retract the wound edges superiorly and inferiorly. The periosteum is then incised in an arc-shaped incision, preserving a generous flap that is elevated and reflected inferiorly. The supraorbital nerve is preserved if possible. In cases where it traverses a foramen, the bone around the foramen is cut in wedge fashion and retracted anteriorly with the nerve intact. The periorbita is elevated from the orbital roof to a depth of approximately 1 cm. The temporalis fascia and muscle are elevated at their anterior superior attachment to expose frontal bone below the linea temporalis.

The high-speed drill is used to make an entry hole below the linea temporalis. A craniotome is next employed to cut the frontal bone in an arc ending at the supraorbital notch (Fig. 7). Osteotomies are made medially at the orbital rim and laterally near the frontozygomatic suture. An intraorbital osteotomy then completes the craniotomy. Alternatively, the orbital roof may be scored with an osteotome, and the roof is fractured to remove the cranial flap. The sphenoid ridge is then drilled in the lateral corner of the exposure to widen the opening. The periorbita and frontal dura are elevated from the remaining orbital roof, and it is removed with the drill or rongeurs (Fig. 8). Intradural removal of bone over the planum sphenoidale or optic canal with removal of the anterior clinoid process may be performed as deemed necessary. The tumor is then removed according to established microsurgical principles.

The dura is closed in watertight fashion using adipose and fascial grafts at the cranial base as necessary. Openings in the frontal sinus are covered by fascia. The bone flap is resecured using plates. Closure of the brow incision is with a fine absorbable subcuticular suture.

Summary

Uncommonly, pituitary tumors require a complex intracranial approach. In such instances of extensive para- and suprasellar involvement, an approach that incorporates basic techniques enhanced by developments in contemporary cranial base surgery is effective. Tumors with extensive invasion of the cavernous sinus unilaterally are generally best approached by a frontotemporal transcavernous strategy. Those with bilateral cavernous sinus involvement are better suited for a bifrontal transbasal type of approach. Suprasellar tumors are best exposed by a strategy that affords the surgeon an adequate inferior-to-superior viewing angle, which is generally accomplished by removal of all or part of the orbital rim. These approaches yield benefits in decreased frontal lobe retraction, which may be particularly important in cases requiring a bilateral approach. Finally, some tumors with more modest extensions outside the bounds of the sella are now treated with a more minimalistic type of approach via a small incision in the eyebrow. This marks a move toward a "minimally invasive" type of strategy. Sound judgment based on adequate experience with these approaches must be exercised to ensure appropriate application of this strategy.

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