The subfrontal approach to the anterior skull base

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The subfrontal approach represents a versatile technique allowing for broad exposure of the base of the anterior cranial fossa with minimal functional and aesthetic sequelae. A number of surgical manouvers will optimize the outcomes. These will be reviewed in detail in the article.
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Historical considerations

The skull base represents an area of variable overlap between the fields of Neurosurgery and Otolaryngology–Head and Neck Surgery. Involvement of various complementary specialties, including Interventional Radiology, Oncology, Radiation Oncology, and Facial Plastic Surgery, is of paramount importance in certain cases.

Early surgery of the skull base was centered on the pituitary gland. In 1893, Caton and Paul reported operating on a patient with acromegaly.[1] Extending these basic tenets, the anterior transfrontal approach was described by Killiani experimentally and by Frazier clinically.[2,3]

It was, however, the foresight and surgical expertise of Ketcham and his cosurgeons that opened the door to modern skull base surgery for malignant tumors of the cranial base, a heretofore poorly accepted concept.[4] This brave pioneering group reported complication rates approaching 80% coupled with long-term survival of approximately 60% in this otherwise incurable series of patients.[5]

Tessier made tremendous technical advances in pediatric craniomaxillofacial reconstructive surgery, improving surgeon comfort with removal and replacement of multiple areas of the facial skeleton after dutiful and diligent osteotomies.[6] Raveh popularized the subcranial approach based on the frontal bandeaux of Tessier.[7] The subcranial approach has much utility in accessing the midline and paramedian skull base, allowing excellent visualization and control of the cavernous sinus, optic nerves, and internal carotid arteries.

Anatomy of the anterior skull base and related structures

The base of the anterior cranial fossa is deeper medially than it is laterally and is formed by the orbital process of the frontal bone, ethmoid bone, and body and lesser wing of the sphenoid bone. Lying anterior to the crista galli is the foramen cecum, which is filled with a small extension of dura that needs to be elevated carefully during flap dissection to prevent tears. It is minimally vascular except in children where it may contain bridging veins coursing between the superior sagittal sinus and the nose. The superior sagittal sinus may be safely ligated anterior to the coronal suture. As it passes toward the foramen cecum, it becomes more attenuated and easier to ligate. On either side of the crista galli is the cribriform plate, through which run the olfactory nerves and small dural extensions sheathing branches of the anterior and posterior ethmoid arteries. The planum sphenoidale lies posterior to the cribriform plate.

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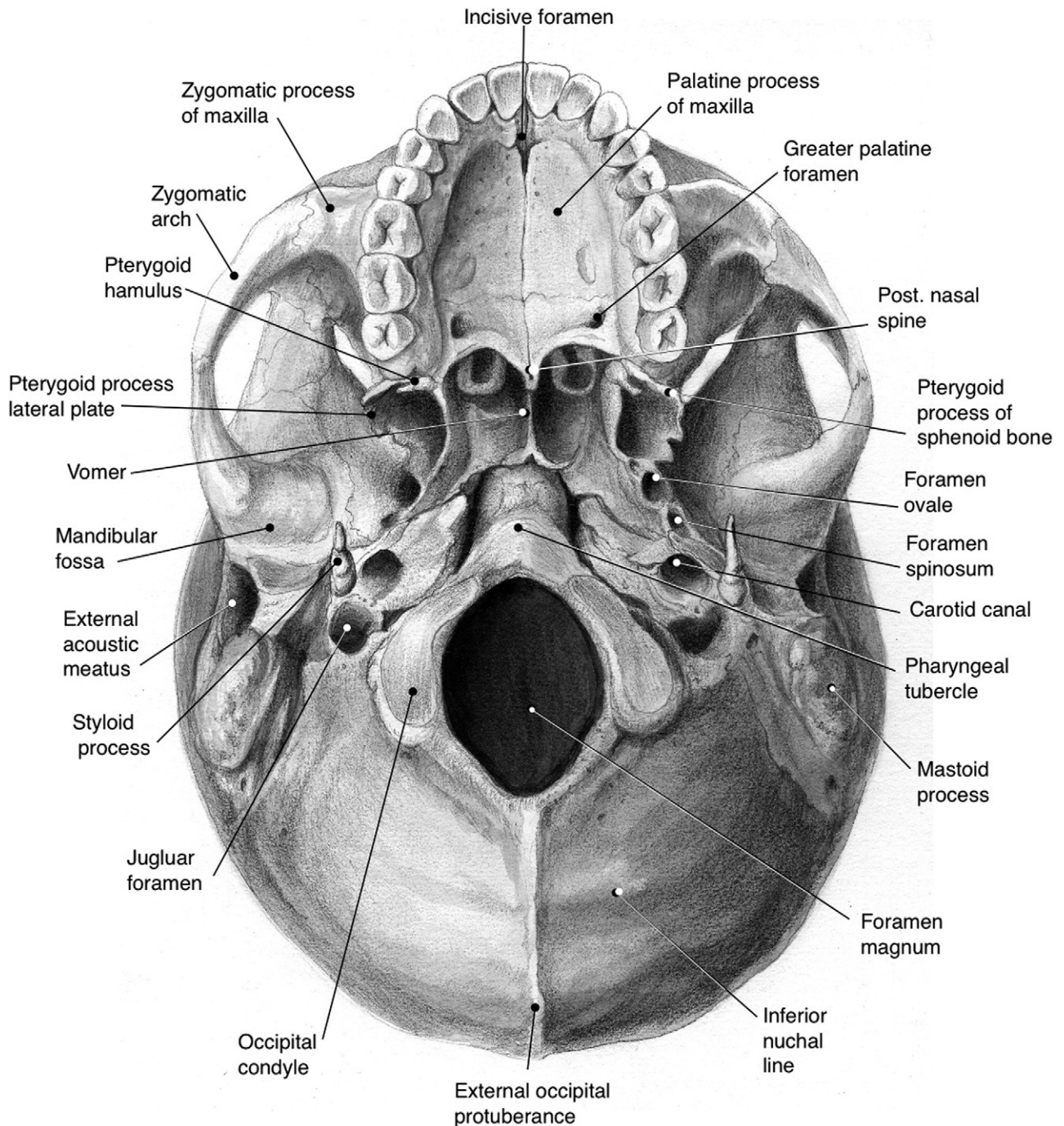E-mail address: yducic@sbcglobal.net.

Figure 1   Transcervical view of skull base anatomy.

The orbital portion of the frontal lobe of the brain has a predictable olfactory sulcus through which runs the olfactory tract. The medial part of this portion of the frontal lobe is supplied by the medial frontobasal branch of the anterior cerebral artery and the artery of Heubner, whereas the lateral aspect of the frontal lobe is nourished by the lateral frontobasal artery arising from the middle cerebral artery. The most medial part of the frontal lobe, so-called gyrus rectus, is a relatively silent area of the brain that can be removed during anterior craniofacial resections with little known neurologic sequelae if this is necessary.

The thickness of the dura will vary across different areas of the skull base, ranging from relatively thick beneath the planum sphenoidale to quite thin in the region of the olfactory fossa. This is important when both elevating the dura in these regions as well as when one is repairing tears and dural resections in these regions.

Within the orbit are the superior and inferior orbital fissures that become routes of spread for anterior skull base tumors and infections. The superior orbital fissure connects the middle cranial fossa with the orbit and contains (from superior to inferior): the lacrimal nerve, frontal nerve, trochlear nerve, superior ophthalmic vein, nasociliary nerve, in-
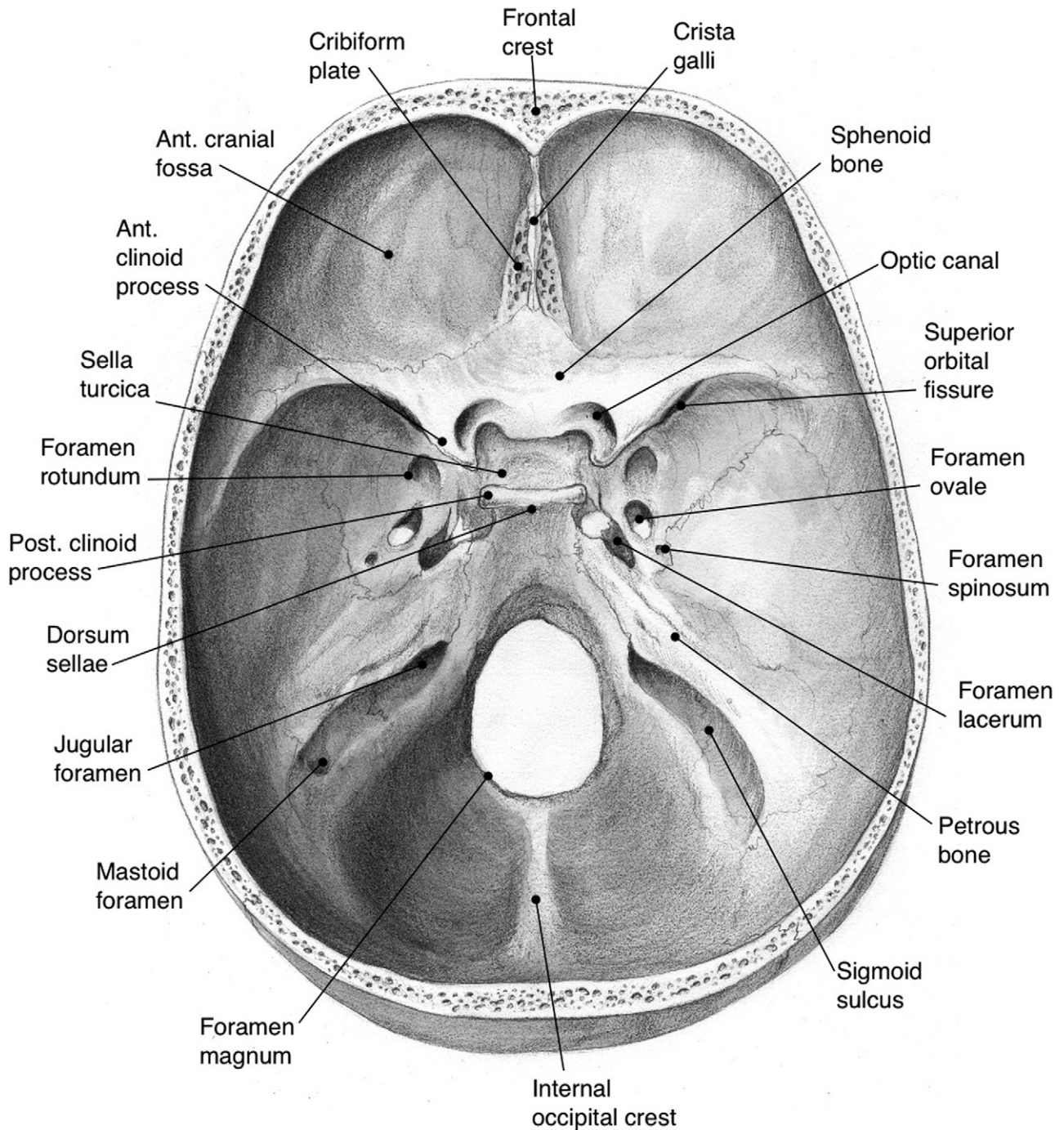
Figure 2   Transcranial view of skull base anatomy.

ferior ophthalmic vein, and abducens nerve. The medial part of this fissure is wide, narrowing as it extends superolaterally. The foramen rotundum, situated below the inferior and medial superior orbital fissure, transmits the second division of the trigeminal nerve. The foramen ovale transmits the third division of the trigeminal nerve as well as meningeal branches from the mandibular nerve and middle meningeal artery. The foramen ovale also contains a clinically relevant venous plexus connecting the pterygoid venous plexus to the cavernous sinus. The foramen spinosum is posterior and lateral to the foramen ovale. Within it runs the middle meningeal artery. In approximately 2% of patients, this canal will be duplicated or absent.[8] In the case of absence,

the middle meningeal artery arises from the opthalmic artery instead. The optic canal transmits the optic nerve and the ophthalmic artery. In 1% of patients, the ophthalmic artery runs in a separate canal that is always inferior to the optic nerve.[9] The optic canal forms an indention within the lateral wall of the sphenoid in up to 80% of patients and is encompassed completely within the posterior ethmoid air cells in up to 13% of patients.[8] Within the medial orbital wall are the foramina for the anterior and posterior ethmoidal arteries, lying on average 24 and 12 mm posterior to the anterior lacrimal crest along the frontoethmoid suture line. The optic foramen lies, on average 6 mm posterior to the posterior ethmoidal artery.[10]
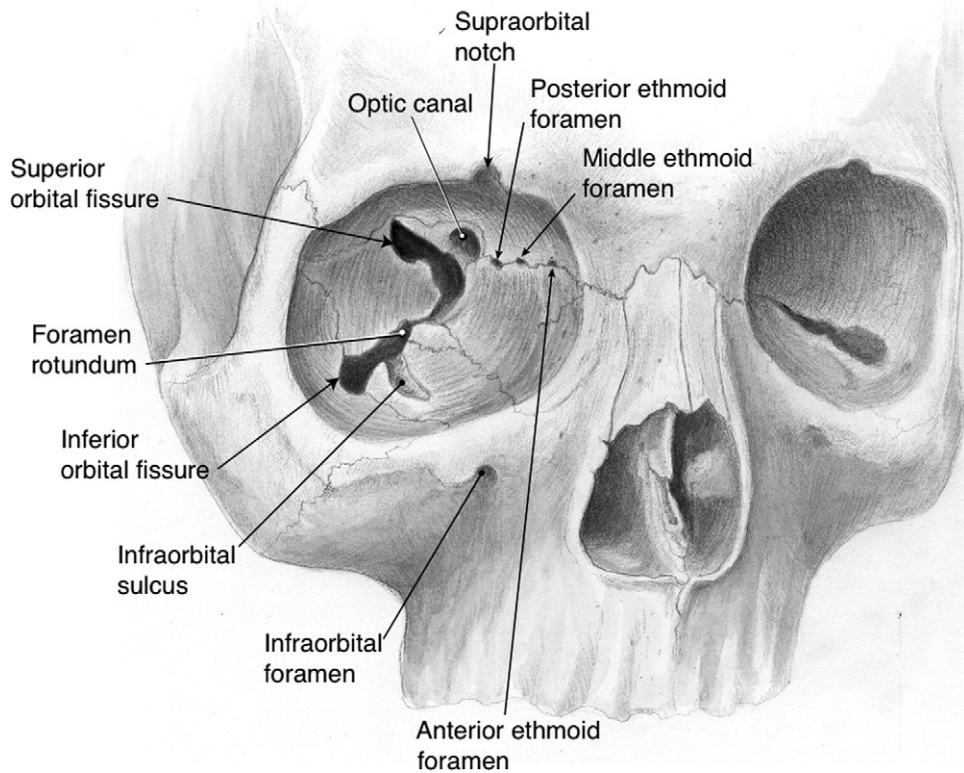
Figure 3   Osseous anatomy of the orbit.

The intratemporal portion of the internal carotid artery has a vertical and a horizontal component. The vertical segment begins at the carotid canal and is anchored by a firm fibrous ring that is difficult to mobilize. After this vertical 5-mm length course, it turns anteromedially into the horizontal portion where it lies medial to the Eustachian tube and inferior to the cochlea. Then it enters its petrous bone course before going into the cavernous sinus portion. Within the cavernous sinus, the two internal carotid arteries are separated by 4-18 mm. This needs to be kept in mind when mobilizing the carotid from tumors encasing the cavernous sinus. Generally, the classic "S" shape of the carotid artery within the sinus arises from the right angle bend it
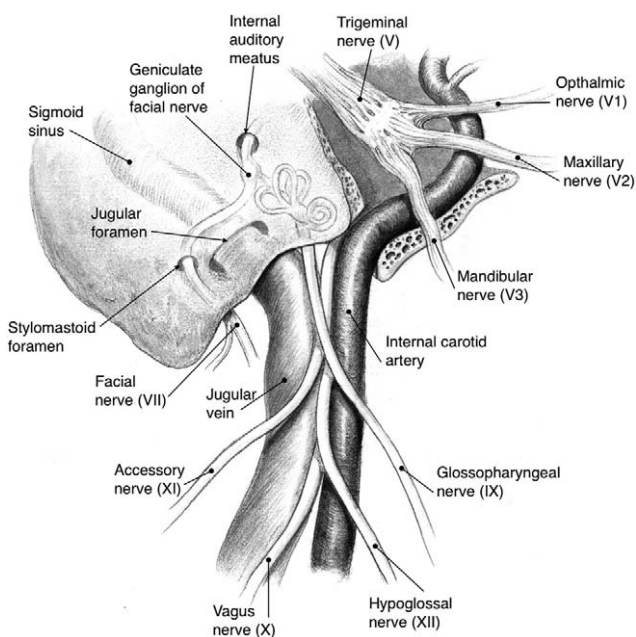

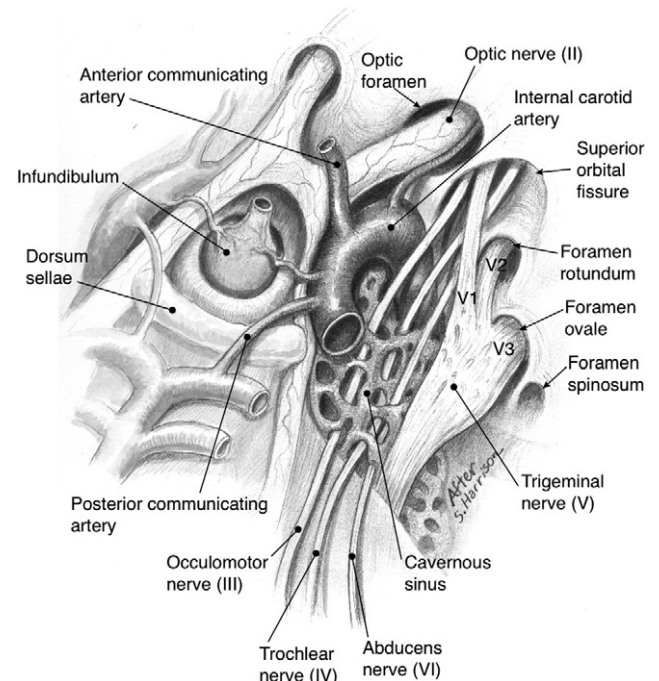**Figure 4**   Anatomy of the carotid artery at the skull base below the level of the cavernous sinus.

Figure 5   Anatomy of the carotid artery as it traverses the cavernous sinus.
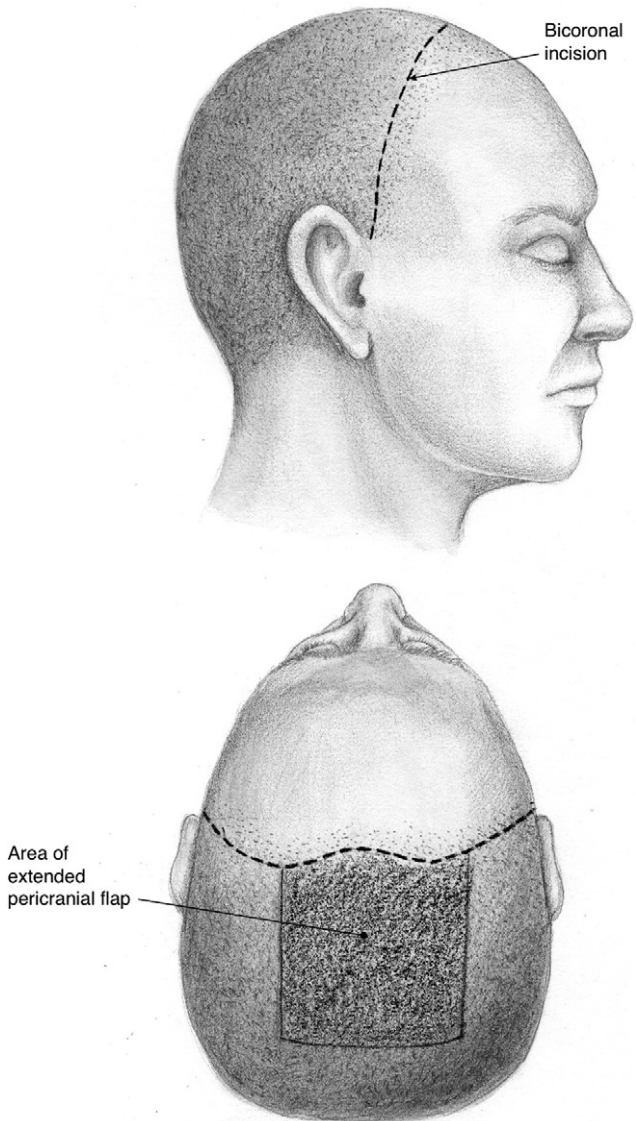
Figure 6   Proposed incision for standard bicoronal flap demonstrating area of extended pericranial flap elevation.

takes in most patients at the posterior clinoid process after ascending vertically at the sinus entrance. In some patients, it will follow an almost straight course.[11] This can often be visualized on preoperative angiogram and may be important during dissection.

Preoperative considerations

The major advantages of the subcranial approach include broad exposure to the anterior cranial base with minimal brain retraction. There are no visible scars excepting poorly healed bicoronal incisions. The major disadvantage is the inevitable loss of olfaction that occurs. In small, laterally situated lesions, it may be possible to spare one of the olfactory nerves. This is not commonly seen. Midline and paramedian anterior skull base lesions may be treated with this approach. Surgically relevant exposure of the sinuses, orbit, clivus, sella, and base of anterior cranial fossa, both

intracranial and extracranial, is facilitated with this technique.

The surgeon needs to decide whether an intradural, extradural, or a combined approach is required. Such a decision should be based on histology. Any dural resection or incision in the subfrontal region should be augmented in addition to simple suture repair due to the combination of thin dura in this region as well as the fact it represents a dependent portion for potential cerebrospinal fluid leaks.

The surgeon always needs to be aware of the relative relationships of the internal carotid artery. If there is concern regarding the need for dissection or sacrifice of the carotid artery, one should consider preoperative magnetic resonance angiography or formal angiogram. At a vascular level, cerebrovascular accident may result from thromboembolism or from a reduction of cerebral blood flow below a critical level. The former is the more common route of stroke, which may manifest in a delayed fashion. When there is temporary occlusion of the carotid artery, collateral supply from the ophthalmic artery, circle of Willis, basilar artery, contralateral internal carotid artery, or branches from the external carotid artery may supply adequate blood flow to the brain for varying periods. Approximately 20% of patients have an inadequate collateral system. Artificially inducing hypertension of approximately 40 mm Hg above baseline mean blood pressure may improve the collateral circulation for a period. Barbiturate-induced anesthesia and hypothermia will serve to reduce metabolic demands intraoperatively. The ability to dissect the carotid artery away from encasing tumors depends on the presence of an adequate subadventitial plane, which is generally well defined within the neck and the petrous portion and virtually absent
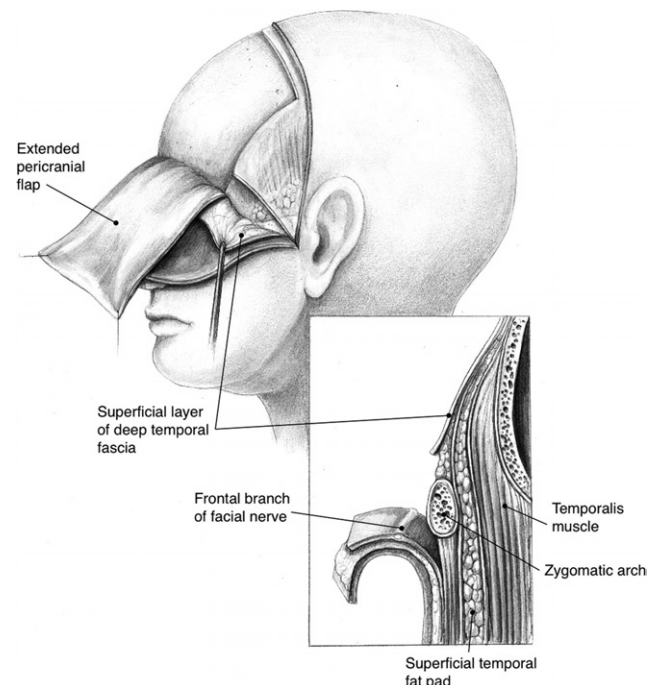

Figure 7   Extended pericranial flap has been raised, and temporal portion of the dissection has been performed to preserve the frontal branch of cranial nerve seven.
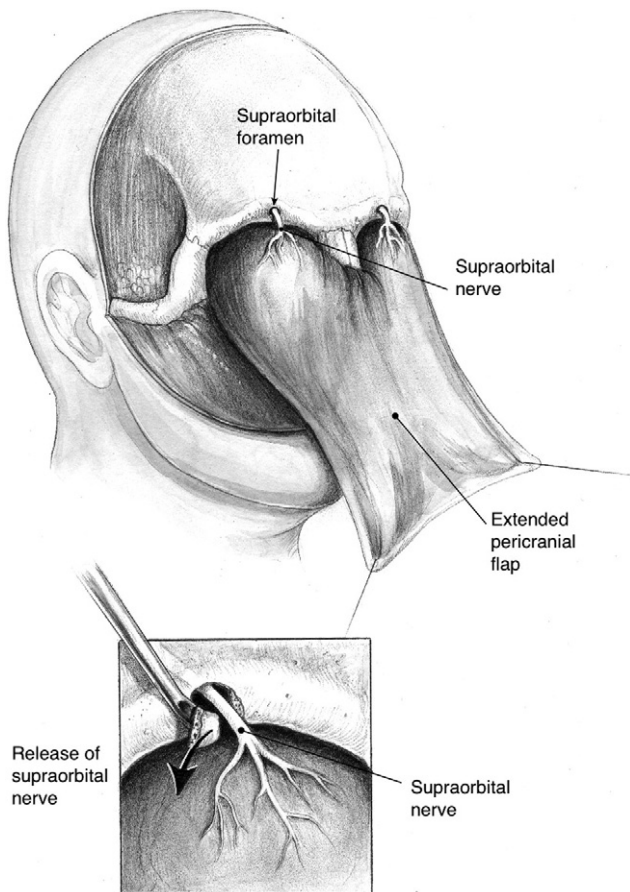
Figure 8 Supraorbital nerve release is demonstrated to improve access to subfrontal region for osteotomy.

in the intracavernous portion. Thus, tumors can be dissected only with great difficulty from the carotid within the cavernous sinus, often leaving it prone to both aneurysm and thromboembolic formation. The supraclinoid carotid artery lies within the subarachnoid space and thus there is a delicate arachnoid dissection plane present around the carotid artery in nonirradiated nonoperated patients. T2-weighted MRI scan is particularly useful at evaluating vascular encasement. If occlusion is suspected, consideration of balloon occlusion should be given. This is a somewhat controversial study as there is a definite, albeit small, false-negative rate, which obviously may result in significant morbidity. Coupling the balloon occlusion study with a SPECT (single photon emission computed tomography) scan or a xenon blood flow examination in addition to neurologic examination is considered the gold standard. If significant carotid artery dissection is anticipated, one should consider saphenous vein or radial artery interposition grafting. During the vascular occlusion required for completion of the anastomosis, the patient should be administered 2000 U of heparin, blood pressure elevated by 20% to 25%, and intravenous steroids administered. Subcutaneous heparin is administered early postoperatively and low-dose aspirin long-term. Despite meticulous microvascular technique, a stroke rate of approximately 9% to 13% is to be expected.[12]

Generally, I prefer to use MRI and CT in combination for evaluation of most skull base lesions. They provide complementary information that is useful clinically. Computer navigation may be useful for teaching but has little utility, in experienced hands, in facilitating tumor removal from the skull base. This modality does not replace thorough knowledge of skull base anatomy.

Patients need to be prepared for possible neurologic sequelae postoperatively. Alterations in speech, swallowing, appearance, loss or change of vision, and stroke are major potential neurologic outcomes that go hand-in-hand with skull base procedures. The patient should accept these potential risks.

Technique

After induction of anesthesia, the head is generally shaved or a 1-cm strip along the proposed incision line is shaved (Figures 1-17). One percent lidocaine with 1/100,000 epinephrine solution is infiltrated along the incision line and intranasally. Supraorbital and sphenopalatine blocks are also performed. Intranasal 4% cocaine nasal packing is applied to complete the mucosal decongestion. The incision should be undulating for camouflage but also needs to be placed anterior to the vertex for exposure. Placing this incision too far posteriorly will limit the access and should be avoided. The incision will often continue into the preauricular region as this will allow exposure to the superior half of the maxilla during flap elevation, which is required for plate fixation. Patient is placed in pin fixation only if navigation is being used.
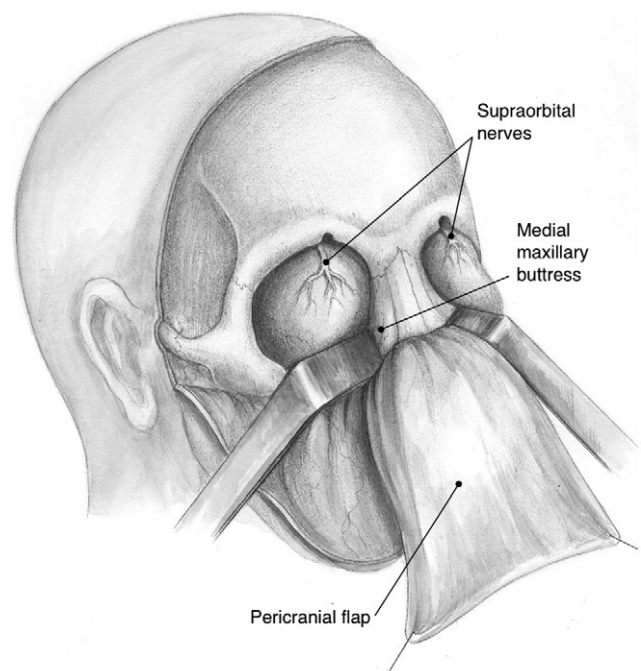

Figure 9 Bicoronal flap has been fully mobilized allowing good access. Trochlea has been detached and does not need to be reattached.
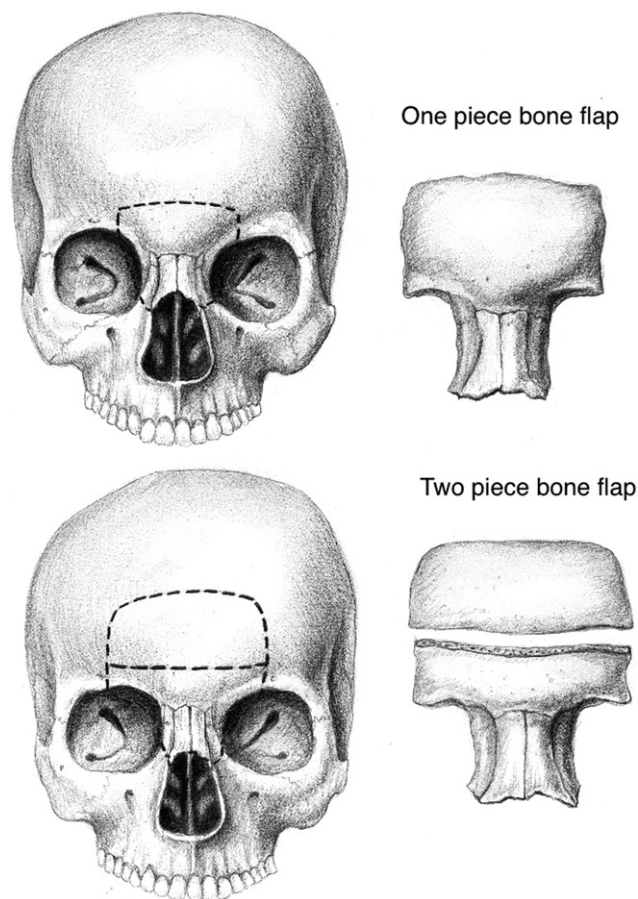
Figure 10 Osteotomy may be performed as a single piece or two pieces, according to surgeon preference.

The incision is then made down to, but not through, the pericranium. Dissection in a suprapericranial plane is carried out posteriorly to the occiput. This allows the creation of an extended pericranial flap, essentially doubling the length available for reconstruction of the skull base.[13] This flap is then incised at the occiput transversely and vertically along a line approximating the medial aspect of the temporal fossa. The flap is then dissected from the underlying calvarium to the supraorbital rims. Laterally, it is elevated off the deep temporal fascia to the level of the superior temporal fat pad, at which point the superficial layer of the deep temporal fascia is incised. Dissection deep to this layer is carried to the zygomatic arch to preserve the frontal branch of the facial nerve integrity. If there is a supraorbital foramen, a small 2- to 3-mm osteotome is used to convert it into a notch by removing the thinnest portion of the bone facing the orbit. This allows the supraorbital nerve to be mobilized out of the frontal bone and into the soft tissue orbital contents. The trochlea is then sharply detached. It is not necessary to reattach this structure at surgery completion. The medial canthal ligaments are detached. The lacrimal sac is elevated off the lacrimal crest and its junction to the nasolacrimal duct sharply transected. The dissection then continues along the inferomedial maxilla to the infraorbital nerves bilaterally. At this point, there should be excellent access to the superior half of the maxillofacial skeleton.

Next, the surgeon decides if he/she is going to perform a one- or two-piece subcranial approach. In a single piece, the frontal bone osteotomy is extended along the supraorbital rims to the orbital roof, along the medial orbit, and superior aspect of the medial maxillary buttress. In a two-piece approach, a small frontal craniotomy is performed, dura elevated from the floor of the anterior cranial fossa, then the inferior segment incorporating supraorbital rims, medial orbit, roof of orbit, and medial buttress is removed as a second piece. More dural tears are noted in the one-piece technique particularly in the transorbital osteotomy; however, by removing the segments in two pieces, even with preplating, slight alterations in the relationships between the two segments as well as palpable and occasionally visible supraorbital osteotomies may affect esthetic outcomes. In a single-piece subcranial approach, the pericranial flap is brought in from a lateral direction, whereas it is generally brought in between the frontal and the subfrontal segments in a two-piece subcranial approach.[14] As much of the delicate orbital roof bone should be preserved as possible, incorporating it into the bone flap. Prior to performing the osteotomies, miniplates are applied across the proposed frontal segment, at least one plate per line of osteotomy, across the supraorbital rims and along the medial maxillary buttress. Plates are then removed and osteotomy completed with a straight cutting burr of small dimension to limit amount of bone loss across the osteotomy itself. The upper lateral cartilages are detached from the undersurface of the nasal bones. The removed subcranial segment(s) is(are) kept in saline until the completion of the procedure.
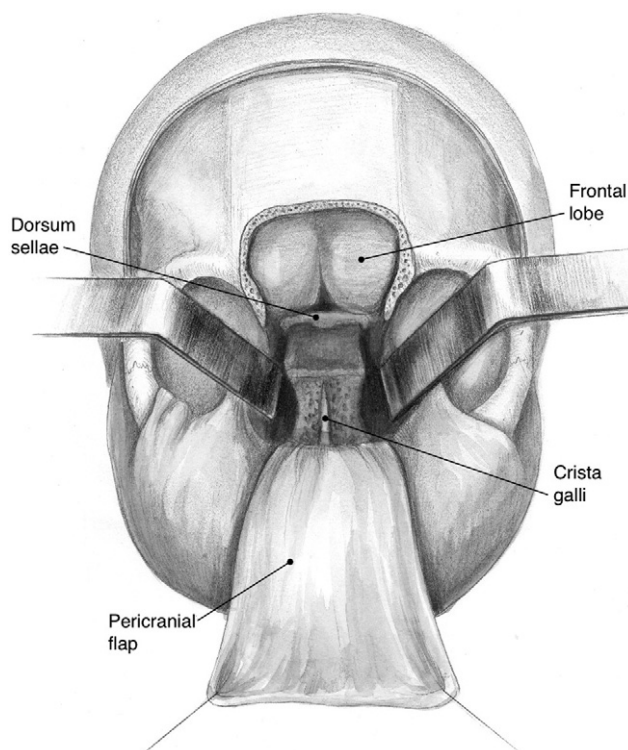

Figure 11 Transcranial view once bone segment has been removed.

The frontal sinus is cranialized completely, removing any remnants from the bone flap and the patient. The pericranial flap is not elevated from the bicoronal flap (except the extended portion) until it is needed for reconstruction to prevent tears or desiccation. It should be covered with a moistened gauze during the procedure.

Now, the surgeon should have broad access to the frontal and subfrontal region of the skull base. The tumor is resected and any dural tears repaired and augmented with tensor fascia lata, homograft dura, or xenograft. Tissue glue is applied to augment the dural reconstruction. The pericranial flap is then elevated from the bicoronal skin flap and laid into the defect as a accordion. It is sutured to the dura anterolaterally. Posteriorly, a few tacking transosseous sutures may be possible, but watertight closure is not able to be done due to lack of material for adequate suture placement. The bone flap is then returned and preadapted miniplates and screws reapplied. The nasofrontal ducts are obliterated with temporalis muscle free grafts. At this point,
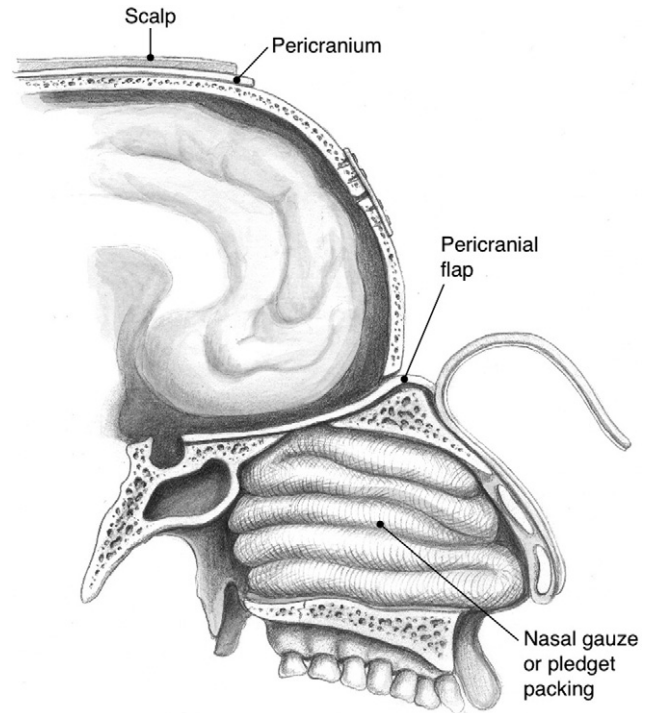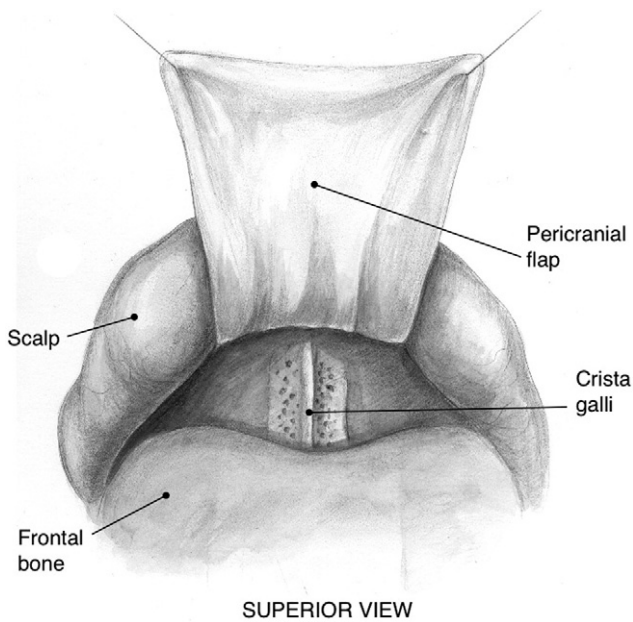

Figure 13 Lateral view of pericranial flap sealing skull base following tumor extirpation with skull base defect.

soft tissue resuspension of the face is accomplished. First, the superior and inferior canaliculi are intubated with silastic stents, which are left in position until they fall out on their own or for at least 6 months. The medial canthal ligaments are reattached into their native position with Mitek (DePuy Mitek, Raynham, MD) anchors.[15] The anchors are driven into the area of the lacrimal crest and the ligament attached in three dimensions to allow for precise replication of its native presurgical position. Transnasal wiring is not as precise and is more time-consuming and
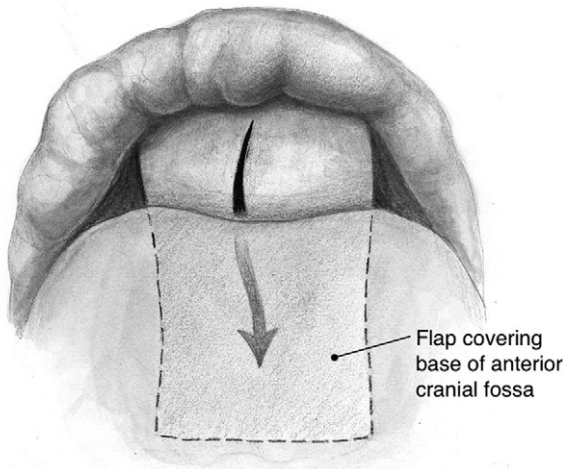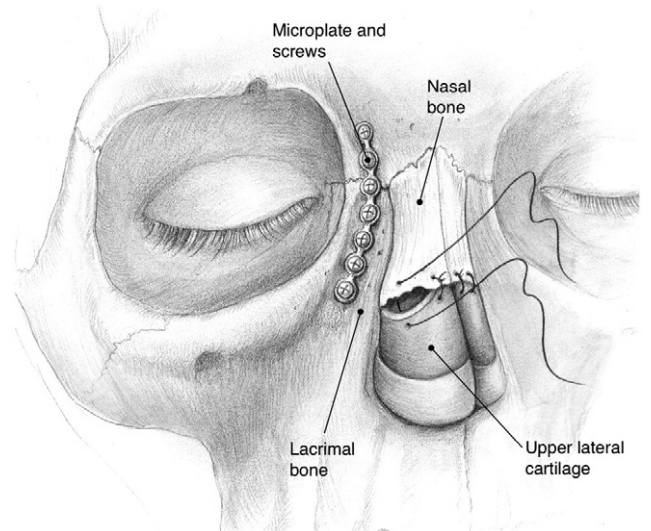

Figure 12 Pericranial flap inset to cover base of anterior cranial fossa with an intact skull base as one would see in posttraumatic CSF leaks of the skull base.

Figure 14 Microplates or miniplates may be used to secure the nasofrontal segment. Upper lateral cartilages are resuspended to undersurface of the nasal bones.
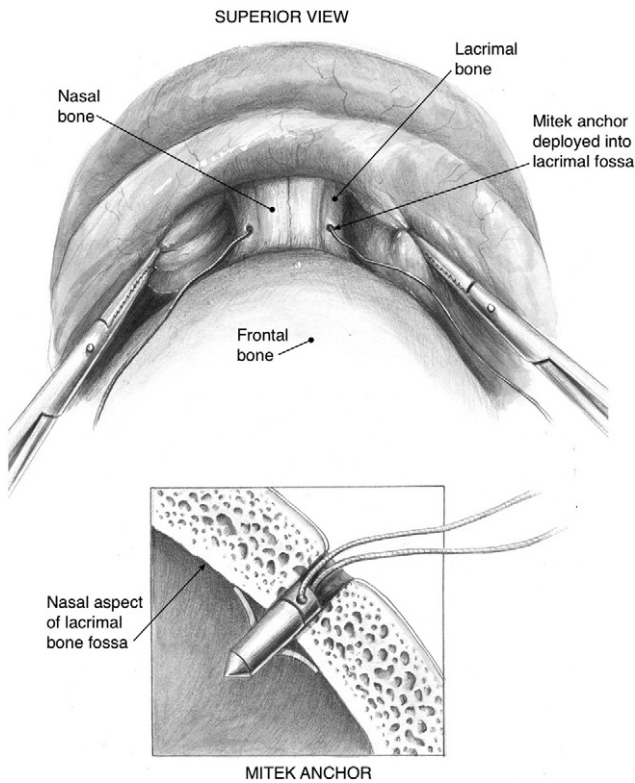
Figure 15   Mitek anchor medial canthal reattachment.

Figure 17   Miniplates maintaining osteotomized segment in position. Temporalis fascia resuspended at completion of procedure to maintain temporal contour.

more difficult to achieve even an adequate result. Next, transosseous tunnels are drilled into the distal aspect of the nasal bones. Long-acting or nonresorbable sutures are then used to suspend the upper lateral cartilages. They should be placed a few millimeters superior to the caudal edge of the nasal bones to better approximate their normal anatomic position, rather than attaching them to the distal edge.[16] The
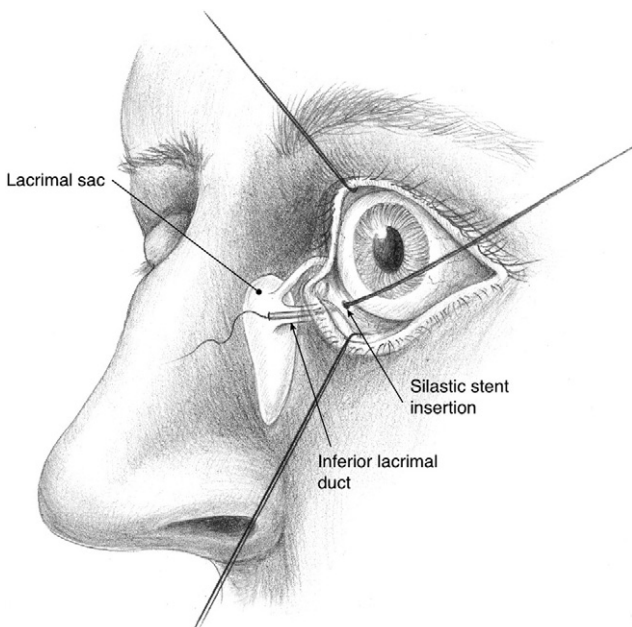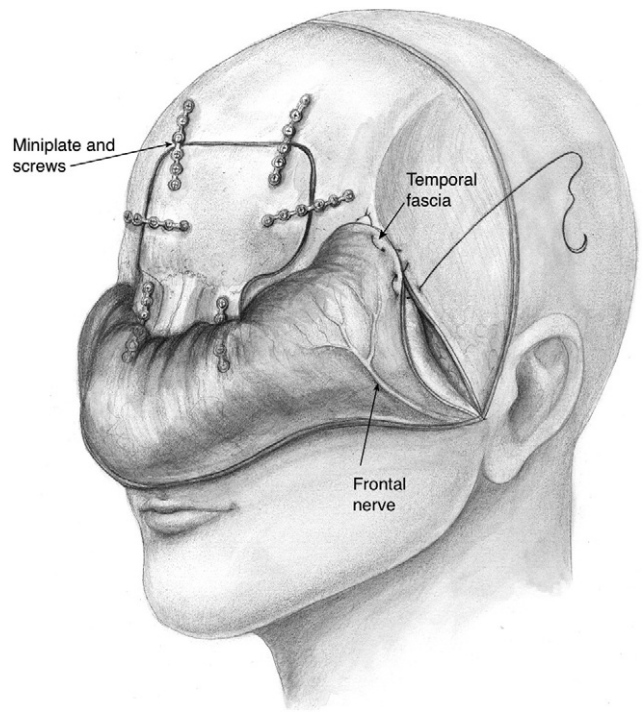

Figure 16   Silastic stent insertion into the superior and inferior lacrimal canaliculi to decrease postoperative epiphora.

cut edges of the superficial temporal fascia are closed to prevent irregularities postoperatively that may be visible. The bicoronal flap is then closed in two layers over suction drains placed posterior to the frontal osteotomy areas. Intranasal packs are placed for early postoperative support of the skull base pericranial flap reconstruction.

Next, one determines whether a tracheotomy is required.[17] If there is a defect in the skull base of at least 4 cm^2, then a prophylactic tracheotomy is generally performed. The tracheotomy avoids prolonged postoperative intubation and allows for serial neurological examinations in an awake patient. It completely diverts the airway, preventing the patient from building upper airway pressure from coughing, sneezing, or valsalva. A tracheotomy tube with inflated cuff makes nose blowing impossible and does not rely on a sedated and possibly confused postoperative patient from blowing their nose. I believe that complete airway diversion may also assist in wound healing during the early postoperative period by diverting lower airway secretions from the wound and preventing shear and stress forces on the skull base reconstruction from positive pressure, allowing tension-free healing. The cuff is left inflated for 3-5 days, and then the patient is decannulated. There is no need for downsizing, capping trials, or change to a cuffless tracheotomy. The patient is admitted to an intensive care unit setting for observation. Postoperatively, the patient is advised not to blow their nose for 3 months and sneeze via an open mouth. Nasal saline spray, not irrigation, is instituted once nasal packs are removed to help control long-term nasal crusting. There is generally no need for debridement intranasally, except in patients with poor nasal hygiene.

Complications

Serious complications are rarely seen with this approach. Neurologic sequelae related to the tumor and its removal and/or cerebrovascular accident from decrease blood flow or thromboembolism are often unpredictable in occurrence and severity. Bone flap loss is rare. If it does occur, either titanium mesh cranioplasty or secondary osseous bone graft cranioplasty should be performed.[18] Long-term nasal crusting is to be expected following the removal of the posterior septum, which is often needed to facilitate exposure. Anosmia is likewise to be expected. Cerebrospinal fluid leaks are uncommonly seen in our practice. They are generally managed conservatively or endoscopically if they fail to resolve with bedrest and time. Pneumocephalus, meningitis, brain abscess, and death are all thankfully rarely seen but are possible with every skull base surgery.

References

1. Caton R, Paul FT: Notes of a case of acromegaly treated by operation. BMJ 2:1421, 1893
2. Killiani OT: Some remarks on tumors of the optic chiasm with a proposal how to reach the same by operation. Ann Surg 40:35, 1904
3. Frazier CH: An approach to the hypophysis through the anterior cranial fossa. Ann Surg 57:145, 1913
4. Ketcham AS, Wilkins RH, Van Buren JM, et al: A combined intracranial facial approach to the paranasal sinuses. Am J Surg 106:698-703, 1963
5. Ketcham AS, Hoyle RC, Van Buren JM, et al: Complications of intracranial facial resection for tumors of the paranasal sinuses. Am J Surg 112:591-595, 1966
6. Tessier P, Guiot G, Rougerie J: Osteotomies cranio-naso-orbito-faciales hypertelorisme. Ann Chir Plast 12:103-118, 1967
7. Raveh J: Das einzetge vorgeham bei der widerherstellungvon fronto-basal-mittelgesichtsfrakturen modifikatinen und behandlungsmodalitaten. Chirurgie 54:677-686, 1983
8. Van Alyea OE: In discussion of operation on the sphenoid. Trans Am Acad Ophthalmol Otolaryngol 53:542-543, 1949
9. Lang J: Structure and postnatal organization of heretofore uninvestigated and infrequent ossifications of the sella turcica region. Acta Anat 99:121-139, 1977
10. Neal GO: External ethmoidectomy. Otolaryngol Clin North Am 18:55-60, 1985
11. Lindblom K: A roentgenographic study of the vascular channels of the skull. Acta Radiol 30:146-152, 1936
12. Sekhar LN, Sen CN, Jho JD: Saphenous vein bypass graft of the cavernous internal carotid artery. J Neurosurg 72:35-41, 1990
13. Smith JE, Ducic Y: The versatile extended pericranial flap for closure of skull base defects. Otolaryngol Head Neck Surg 130:704-711, 2004
14. Ducic Y: Frontal sinus obliteration utilizing a laterally based pedicled pericranial flap. Laryngoscope 109:541-545, 1999
15. Ducic Y: Medial canthal ligament attachment in skull base surgery and trauma. Laryngoscope 111:734-738, 2001
16. Ducic Y, Pontius AT: Nasal reconstruction in surgery of the anterior skull base. Otolaryngol Head Neck Surg 130:176-186, 2004
17. Ducic Y, Zuzukin V: A rational approach to the use of tracheotomy in surgery of the anterior skull base. Laryngoscope 118:204-209, 2008
18. Ducic Y: Titanium mesh and hydroxyapatite cement cranioplasty. J Oral Maxillofac Surg 60:272-276, 2002