OPEN ACCESS ATLAS OF OTOLARYNGOLOGY, HEAD & NECK OPERATIVE SURGERY

ANTERIOR SKULL BASE RESECTION: EXTERNAL APPROACHES

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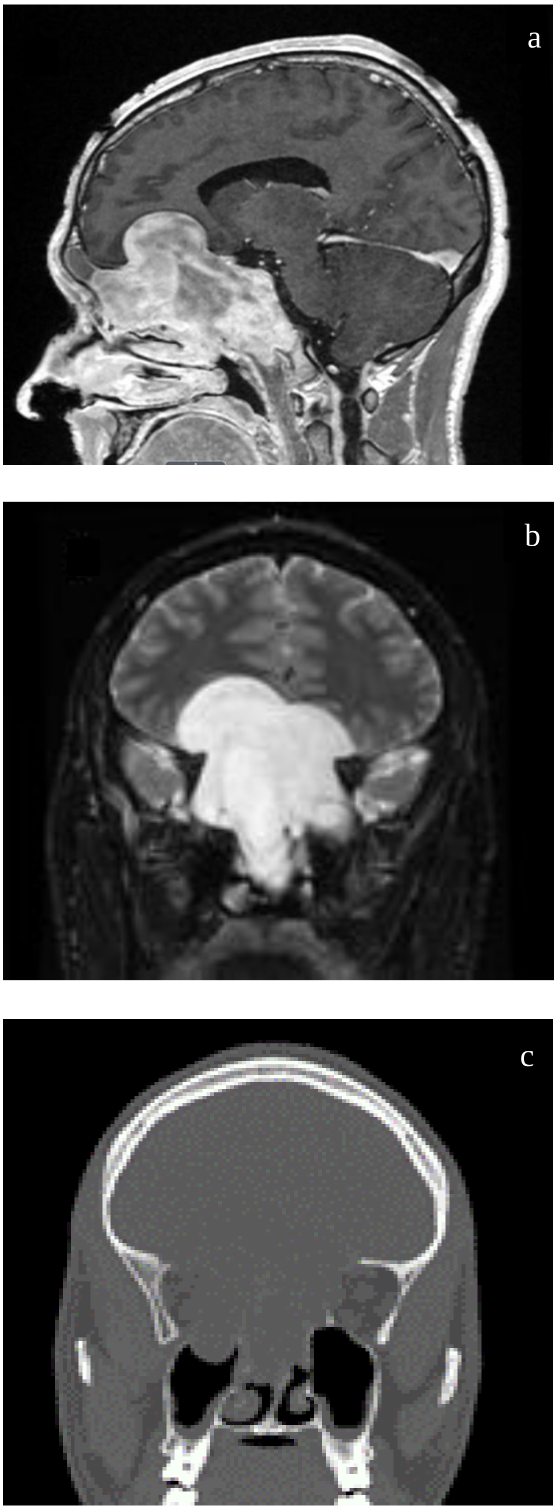
The sinonasal cavity and anterior cranial fossa can be involved by a wide variety of diverse, rare neoplasms. Surgical extirpation of these lesions is often the mainstay of multimodal treatment for both benign and malignant diseases. However, these tumours pose a variety of challenges for surgical management, including complex anatomic considerations *(Figures 1a-c)*.



Figures 1a-c: Preoperative images of a large heterogeneously enhancing chondrosarcoma occupying the entire skull base with significant intracranial extension

Relevant Anatomy

Also refer to Chapter on FESS for surgical anatomy

Nasal Cavities and Sinuses

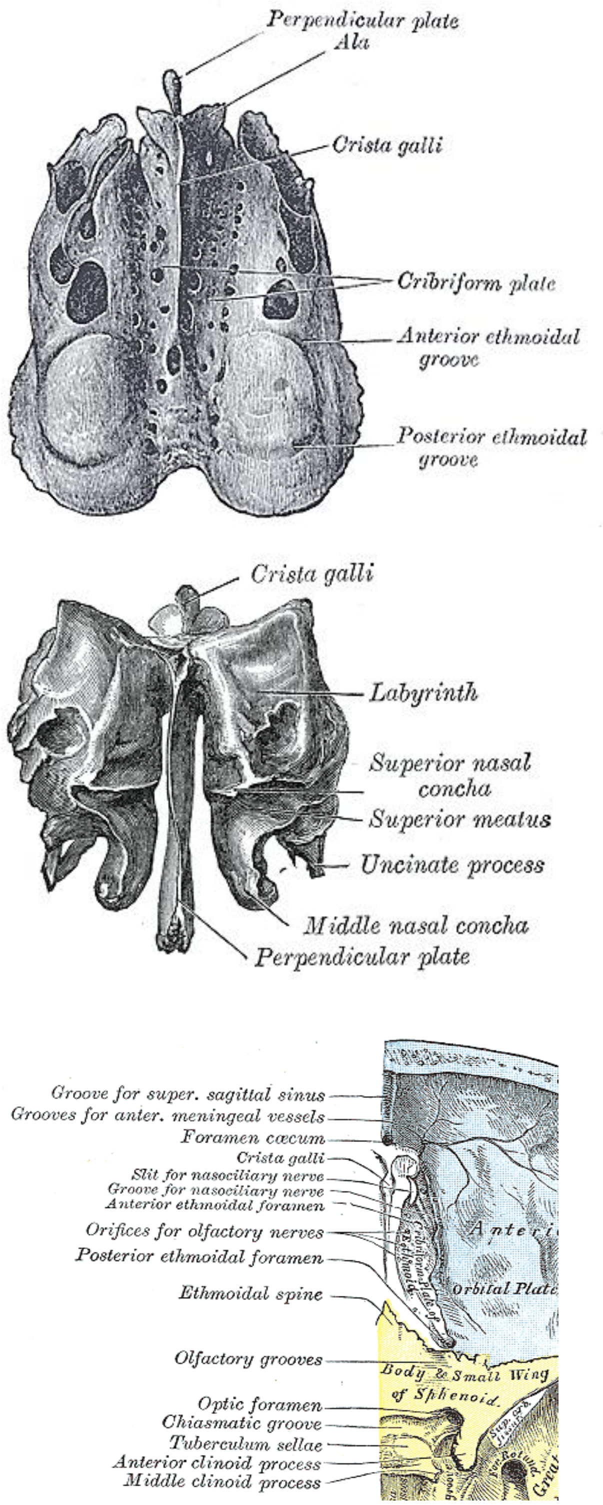
The nasal cavity can be imagined as a quadrangular corridor that is narrower at the top and divided into right and left compartments by a midline septum. It communicates with the exterior through anterior openings, the nares (nostrils). Posteriorly, it opens into the nasopharynx through the posterior choanae. Its external shape reflects its skeletal support, which is composed of the paired nasal bones and the upper and lower lateral nasal cartilages as they surround the pyriform aperture. The walls of each nasal fossa include the nasal septum medially, the horizontal portion of the maxillary bone and palatine bone inferiorly, and the inferior turbinates and ethmoid bones laterally.

Superiorly, the nasal fossae are confined by the cribriform plate and the rostrum of the sphenoid sinus as it slants posteroinferiorly toward the nasopharynx. The inferior turbinate is an independent bone, whereas the middle and superior turbinates are part of the ethmoid bone.

The ethmoid air-cell labyrinth consists of 3-18 cells per side that are connected in the midline by the cribriform plate *(Figure 2)*. Each side is divided into an anterior and posterior group of cells based on the attachment of the middle turbinate to the lateral nasal wall *i.e.* basal lamella. An Onodi cell represents a posterior ethmoid cell which is located superior or lateral to the sphenoid sinus and can occasionally contain the optic nerve or portions of the carotid artery. It may be bigger than the sphenoid sinus.

The roof of the ethmoid labyrinth comprises a portion of the anterior skull base. Laterally, the ethmoid air cells are bound by the orbit (lamina papyracea), and along the roof of the ethmoid sinuses, the anterior and posterior ethmoid arteries can be found exiting the orbit and traversing the skull base toward the vertical lamella of the cribriform plate.

The frontal sinuses are paired cavities within the diploic frontal bone with frond-like pneumatisation and asymmetric shapes and sizes. The posterior wall is shared with the anterior cranial fossa. Their floors correspond to the roofs of the orbits and anterior ethmoid cells. The maxillary antrum is the largest of the paranasal sinuses and is situated lateral to the nasal cavity and inferior to the orbit. Its floor, which is formed by the alveolar process of the maxilla, lies 1-1.5 cm inferior to the nasal floor. The posterior and posterolateral walls of the maxillary sinus are contiguous with the pterygopalatine and infratemporal fossae, respectively. The medial wall of the antrum corresponds to the lateral wall of the nasal cavity and contains the drainage ostium. The sphenoid sinus lies in the center of the skull and is situated posterior to the nasal cavity cephalad to the nasopharynx. Its anterior wall bulges into the nasal cavity and contains the drainage ostium, which may be found at the sphenoethmoidal recess above and posterior to the middle turbinate.



Figures 2a-c: Bony anatomy of anterior skull base

There is a wide variety in the degree of pneumatisation of the sphenoid sinuses between patients and even from one side to the other. Superiorly, the planum sphenoidale constitutes the posterior portion of the anterior skull base. The sella typically sits within the superior sphenoid sinus.

Orbits

The orbit shares three of its walls with the paranasal sinuses. Its medial wall corresponds to the lateral wall of the ethmoid sinus. It bears, from anterior to posterior, the nasolacrimal sac lying on the lacrimal bone (lacrimal fossa), the anterior and posterior ethmoidal arteries, the trochlea, and the optic nerve with its foramen at the apex of the orbital cavity. Its inferior wall corresponds to the roof of the maxillary sinus. The orbital cavity contains the infraorbital fissure and infraorbital neurovascular bundle. The infraorbital fissure is continuous with the pterygomaxillary fissure. The superior wall is contiguous with the ethmoid or frontal sinuses and with the anterior cranial fossa. As previously stated, the superior orbital fissure serves as a passage for CN V1, III, IV, and VI and represents a potential pathway to the middle cranial fossa. The lateral wall is contiguous with the temporal fossa anteriorly to laterally.

Anterior Cranial Fossa *(Figure 2)*

The floor of the anterior cranial fossa comprises the frontal, ethmoid, and sphenoid bones. Laterally, the floor of the anterior cranial cavity corresponds to the roof of the orbits, while, centrally, it corresponds to the vault of the nasal cavity and the roof of the ethmoid sinuses. At the central anterior skull base, the most prominent structure is the cribriform plate, which contains multiple foramina, through which the olfactory filaments pass into the nasal cavity. Branches of the anterior ethmoid artery penetrate the vertical wall of the cribriform plate, the weakest point of the anterior skull base. Anterior to the cribriform, a bony prominence known as the *crista galli* is seen. The planum sphenoidale denotes the area posterior to the cribriform plate, and its posterior aspect marks the posterior boundary of the anterior cranial fossa.

Preoperative Workup

Workup of patients with any new sinonasal or anterior skull base mass should include a detailed examination, including cranial nerve examination, and nasal endoscopic evaluation. Biopsy of the mass should be performed either in the clinic (if bleeding risk appears low and patient is amenable) or in the operating room. Definitive surgical plans should not be executed without final (permanent) pathologic diagnosis whenever possible.

The extent of disease and hence the required extent of the resection is established endoscopically and by imaging. Cross-sectional imaging is imperative to ascertain the extent of the disease, potential cranial nerve and internal carotid artery involvement, and resectability and potential for cure. Typically, a CT scan is best to evaluate the bony anatomy (bony destruction or remodeling, intracranial extension) and is usually paired with MRI (with and without contrast) to evaluate the soft tissue extent of disease, including orbital, dural, vascular, brain or cranial nerve invasion *(Figure 1)*. A proper staging workup for metastatic disease (PET scan, or CT of neck and chest or ultrasound neck and chest x-ray) is critical in treatment planning. In the case of parameningeal sarcomas, MRI of the spine is indicated to ascertain the presence of "drop metastases".

Surgical Planning

Surgical planning must consider two key components:

- The surgical approach must facilitate a complete, oncologic resection of the tumour, preserving normal tissue and protecting neurovascular structures
- The operative plan must include a robust reconstructive algorithm to restore the separation of the cranial cavity and upper aerodigestive tract with adequate cosmetic and functional outcomes

Two distinct surgical techniques should be considered when planning surgery

- ***Traditional open approaches*** involve a transcranial subfrontal approach (most frequently via coronal incisions) combined with a transfacial approach (lateral rhinotomy, midface degloving, Weber-Ferguson incisions) to facilitate *en bloc* resection of the median anterior cranial base (cribriform plate, roof of ethmoids), superior nasal septum, ethmoid sinuses and lateral wall(s) of the nasal cavity (medial maxilla and lamina papyracea). When needed, it may be combined with orbital exenteration or a subtemporal approach to access the lateral skull base, orbit and infratemporal fossa

- ***Endonasal endoscopic approaches*** have evolved over the last 30 years and permit comprehensive sinonasal resection and anterior skull base extirpation *in lieu* of a traditional transfacial approach. The endoscopic approach is equivalent, both oncologically and functionally to a traditional craniofacial resection. Furthermore, the endoscopic approach may be combined with a subfrontal approach to avoid facial incisions. Each of these approaches is detailed below.

Open Craniofacial Approach: Surgical Technique

The open craniofacial approach is described in the following steps:

- Access to the mid- and upper face and cranium
- Sinonasal approaches
    a. Lateral rhinotomy
    b. Midfacial degloving
    c. Expanded endonasal
- Reconstruction
- Closure

Access to mid- and upper face and cranium

- ***Intraoperative navigation***, though generally not critical, can be registered to the preoperative imaging to assist with intraoperative confirmation of surgical landmarks
- Make a straight ***scalp incision*** in a coronal plane of the skull from one preauricular crease to the contralateral preauricular crease
- Carry the incision down to the calvarium from temporal line to temporal line
- At the temporal line, the dissection plane is transitioned to just above the deep layer of the temporalis fascia
- Elevate the scalp in a subpericranial plane, transecting the attachments of the pericranium at its junction with the deep temporal fascia, around the superior border of the temporalis muscle
- ***It is imperative to preserve the pericranium, as this is typically utilised as the reconstructive layer that will separate the intracranial space from the sinonasal cavity*** *(Figure 3)*
- As the scalp is elevated anteriorly, the orbital rims and glabella are exposed

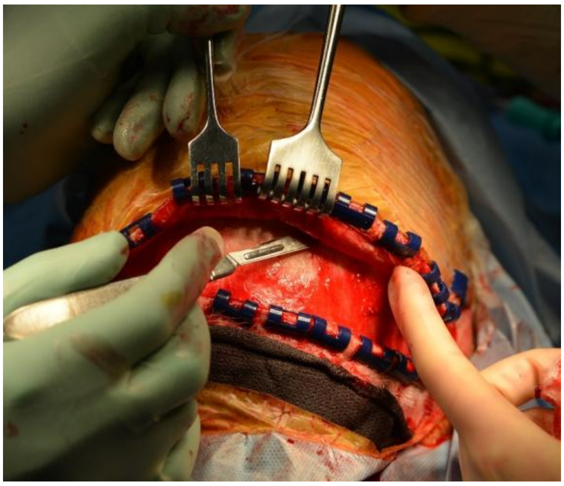


Figure 3: Elevating the scalp flap in a subgaleal plane. The rake is used to lift the scalp while the loose areolar tissues and pericranium are sharply dissected off the galea. Alternatively, the scalp and pericranium can be elevated as one flap initially, and the pericranium back-elevated off the scalp later in the dissection if needed

- A 1cm incision over the periosteum of the zygomaticofrontal area serves as an internal relaxing incision, allowing mobilisation of the scalp flap with minimal retraction
- ***Alternatively, the scalp flap and the pericranium can be elevated separately***. To perform this manoeuvre, the standard coronal incision is performed but the scalp flap is elevated in a subgaleal plane, leaving the loose areolar tissue and pericranium attached to the skull *(Figure 4)*. Laterally the deep temporalis fascia is left intact as the scalp is mobilised like the conventional flap elevation noted above. The dissection continues until a point 2cm above the supraorbital rims. At this point, the pericranium is mobilised separately off the skull by incising along the temporal lines and across the coronal line posteriorly *(Figure 5)*.

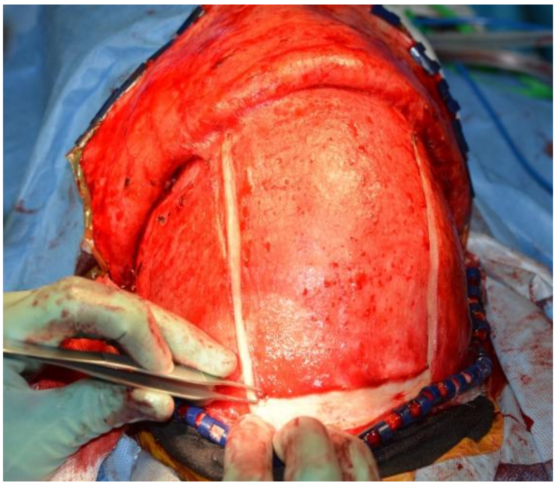


Figure 4: Pericranium is then incised and mobilized off the skull, following the temporal lines laterally and the coronal incision for the posterior cut. If needed, the posterior cut can be extended several centimeters further posteriorly, if additional length will be required for the reconstruction

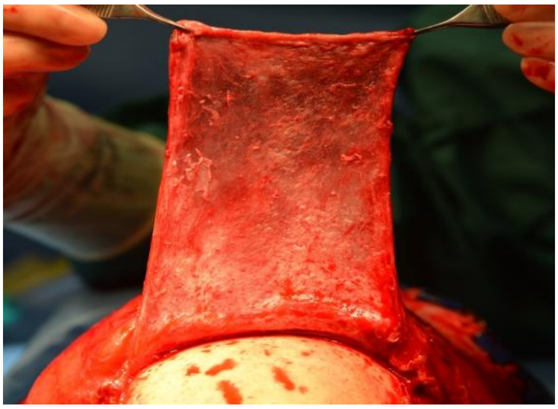


Figure 5: The pericranium is fully mobilised for the reconstruction, either by back-elevating off the scalp flap or elevating separately

- The ***frontal branch of the facial nerve*** lies just deep to the superficial temporalis fascia (temporoparietal fascia) inferior to an imaginary line extending from the root of the zygoma to the superior orbital rim. It only comes into play if the resection needs to be extended laterally to expose the middle cranial or infratemporal fossa. In such cases the frontal branch needs to be preserved either by identifying and dissecting the nerve or dissecting in a plane that does not place the branch at risk. The deep temporalis fascia divides into a superficial and deep layer, containing between them a temporal fat pad. The superficial layer is incised superior to that imaginary line extending from the root of the zygoma to the superior orbital rim *i.e.* prior to encountering the frontal branch, and the scalp flap is elevated in an interfascial plane between the superficial and deep layers of the deep temporalis fasciae. This plane can be followed to the orbital rim and down to the zygoma, depending on the extent of exposure needed at the nasion, and will protect the frontal branch

- As the scalp flap is turned anteriorly and inferiorly, the supraorbital rims are exposed, and the ***supraorbital neurovascular bundles*** are dissected from the supraorbital notches, as depicted in *Figure 6*. When a true supraorbital foramen is present, it may be opened inferiorly using a 3 - 6mm osteotome and mallet. This manoeuvre allows inferior mobilisation of the supraorbital neurovascular bundle and dissection of the periorbita from the superior and medial orbital walls. Notably, as the periorbita are dissected from the orbital rim, the orbital roof takes a superior trajectory around the orbital rim with an acute angle that must be anticipated or the periorbita will be violated. Although not critical, maintaining the integrity of the periorbita lessens trauma to the orbits and limits fat herniation into the surgical field. Any remaining periosteum is elevated to expose the nasal root and nasal bones *(Figure 7)*.

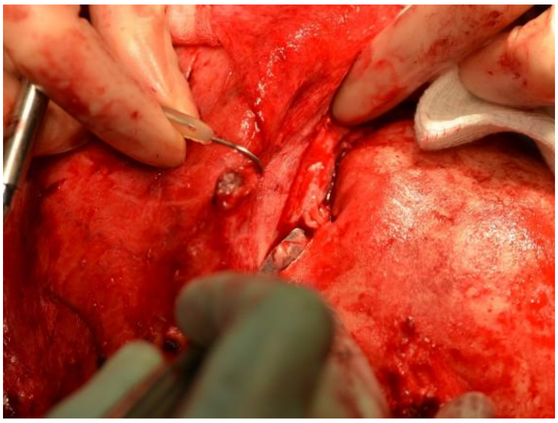


Figure 6: The left supraorbital neurovascular bundle supplies sensation to the left frontal region and serves as one of the key vascular pedicles to the pericranial flap. Here the bundle is mobilised from the supraorbital notch (or foramen as needed) to maintain its integrity as it exits the periorbita and enters the pericranium and scalp. This allows bony osteotomies to be made without compromising the pericranium or sensation in the frontal region

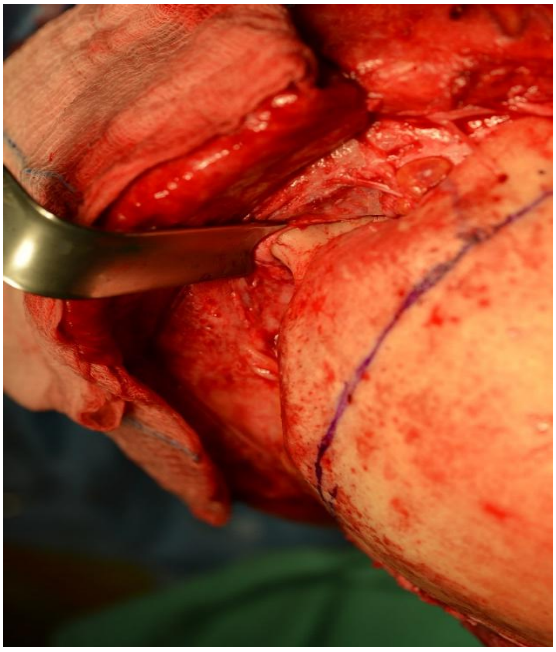


Figure 7: Fully mobilising the superior periorbita allows the scalp flap to be further retracted as the entire nasal root and superior nasal bones are exposed. The purple line highlights the planned division between the frontal craniotomy and the orbital bar

- ***This coronal approach exposes the superior cranium, frontal area, glabella, nasal bones, temporalis muscles and temporal fossae, and the superior two thirds of the orbits***
- ***A bifrontal craniotomy is next performed to expose the frontal lobes.*** It is typically performed in conjunction with the neurosurgical team *(Figure 8)*. The craniotomy typically encompasses the frontal bone bilaterally from the keyhole pterional burr holes and down to approximately 2cm from the orbital rims *(Figure 8)*. Typically, small burr holes are placed on each side of the sagittal sinus; thus, facilitating its dissection and avoiding laceration. The frontal sinus is often transgressed with these cuts, and the posterior table is usually removed from the frontal bone graft, with the remainder of the sinus completely stripped of mucosa to cranialise the sinus. These craniotomy cuts also can be extended laterally for tumours that extend into the orbit or infratemporal fossa.

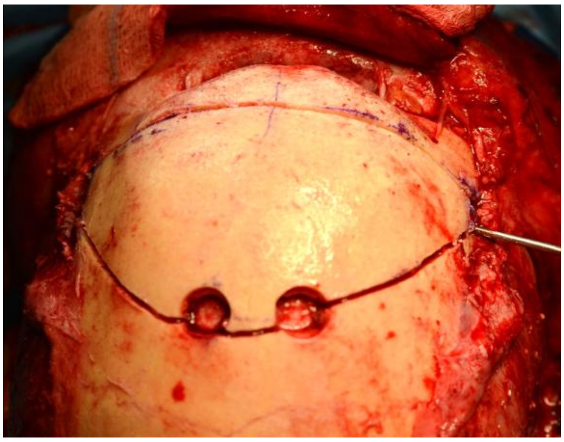


Figure 8: A bifrontal craniotomy, widely exposing the frontal lobes to limit brain retraction

- Following the craniotomy, the ***subfrontal approach is facilitated by removing the orbital bar*** *(Figure 9)*. The subfrontal approach maximises exposure of the anterior skull base while minimizing the retraction of the frontal lobes. It comprises removal of the bone forming the superior orbital rims bilaterally, glabella and nasion, down into the nasal bones *(Figures 9, 10)*. The lateral bone cuts are placed at the lateral orbital rims and a posterior cut joins these incisions by traversing the anterior orbital roofs (retracting the periorbita to protect the orbital contents) and across the frontoethmoidal junction just posterior to the frontal outflow tracts. A transverse incision across the nasion, or further inferiorly through the nasal bones, is then performed, often requiring a curved osteotome to free the anterior superior attachment of the nasal septum to the orbital bar to fully mobilise the graft
- Direct exposure of the anterior skull base has now been achieved
- ***The subfrontal exposure limits the need for frontal lobe retraction***
- The ***dura is elevated from the floor of the anterior skull base*** and is sharply divided from the crista galli, which is removed

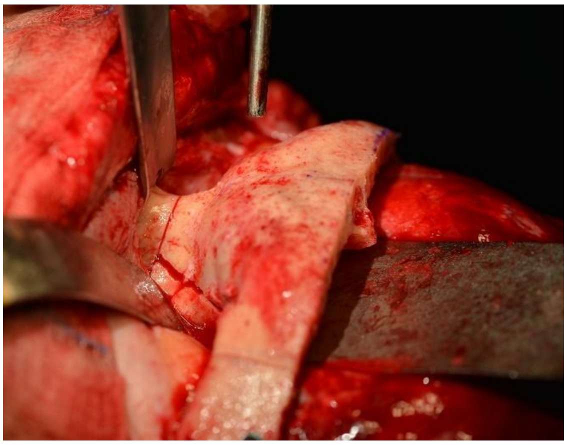


Figure 9: Removal of the orbital bar after the bifrontal craniotomy viewed from the patient's left. It demonstrates the osteotomies required to mobilise the orbital bar, including the lateral osteotomy through the orbital rim, which is then carried down along the roof of the orbit and into the root of the nasal bones

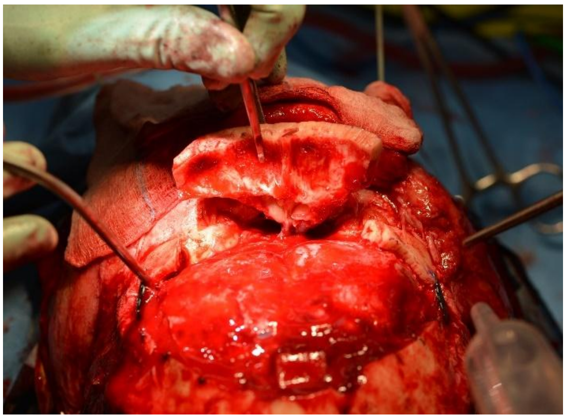


Figure 10: This demonstrates en bloc removal of the orbital bar, exposing the frontoethmoid region and superior orbits

- Careful elevation of the frontal lobe dura from the roof of the orbits and crista galli exposes the cribriform plate
- The dural sleeves along the ***olfactory nerves*** are individually divided and ligated; however, multiple lacerations of the dura often result around the perforations of the olfactory nerves through the cribriform plate
- ***Intracranial tumour extension*** with dural involvement requires one to leave a patch of involved dura attached to the specimen and even to resect a portion of one or both frontal lobes to secure adequate tumour margins
- Gently ***elevate the anterior fossa dura*** in a posterior direction to identify the planum sphenoidale, the anterior clinoid processes and optic canals *(Figure 2c)*
- Drilling with a high-speed drill through the ***planum sphenoidale*** exposes the sphenoid sinus allowing its inspection
- A high-speed drill or reciprocating saw is then used to ***cut around the cribriform*** plate and through the floor of the anterior cranial fossa
- The ***anterior skull base can be fully mobilised*** with a high-speed drill utilising this approach, from the frontal sinus to the planum *(Figure 11)*

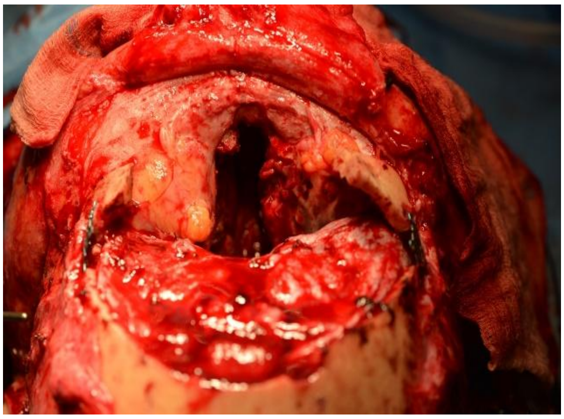


Figure 11: Final exposure of the anterior skull base after removal of the tumour demonstrates how the left orbit is fully skeletonised (note the orbital fat) and the entire nasal cavity has been removed. The frontal lobes have been decompressed after creating a CSF leak allowing wide exposure without significant brain retraction

- In most instances the ***medial orbital walls*** are included in the resection to provide adequate margins and facilitate the control of the ethmoidal arteries
- The intracranial exposure allows the complete and often *en bloc* removal of the anterior cranial base with visualisation and protection of the optic nerves and the lateral walls of the sphenoid sinus including the internal carotid arteries
- ***At this point of the resection, the superior margins and exposure have been achieved, and the tumour has been safely separated and removed from the cranial contents***

Sinonasal Approaches

A separate inferior (sinonasal) exposure is often required to obtain adequate inferior and lateral margins, as the tumour typically limits visibility into the nasal cavity via a subfrontal approach. This can be performed through a variety of approaches, including ***lateral rhinotomy with medial maxillec-***

tomy, midface degloving, or endoscopic endonasal assistance.

a. *Lateral Rhinotomy Approach* *(See Medial maxillectomy chapter)*

- A vertical skin incision is made along the lateral nose, from the medial canthus to the nasal ala, then joining a curvilinear incision along the alar-facial groove on the tumour side *(Figure 12)*. The incision is carried through the muscular layer to the pyriform aperture. To prevent subsequent alar retraction the incision around the ala is carried vertically toward the maxilla and not under the ala; furthermore, the medial aspect of the nasal ala is not transected

Figure 12: Lateral rhinotomy incision

- The ***nasal mucosa*** is incised along the piriform aperture through the lateral nasal vestibule avoiding the tip of the inferior turbinate
- Detachment of the ***medial canthal ligament*** facilitates elevation of the periosteum of the medial wall of the orbit, keeping the orbital contents within its periosteal sac
- The ***nasolacrimal duct*** is transected at its junction with the nasolacrimal sac and the sac is divided and marsupialised
- The ***anterior and posterior ethmoid vessels*** are identified at the frontoethmoidal suture and controlled with bipolar electrocautery
- Lateral elevation of the cheek flap exposes the medial maxilla and infraorbital nerve, which is preserved
- The anterior wall of the maxillary antrum is opened
- Osteotomies are performed through the nasal process of the maxilla, through the lacrimal fossa and the anterior aspect of the lamina papyracea, connecting to the previous osteotomies
- The medial wall of the maxilla is cut with an osteotome or drill along the nasal floor
- The remaining posterior aspect of the lateral nasal wall is cut in a posterior and cephalad direction using curved Mayo scissors from the nasal floor to the sphenoid rostrum
- A septal incision is created along nasal floor and carried cephalad with curved Mayo scissors. A strut of nasal septum is preserved, if able, to support the external nasal framework
- Transection of the attachment of the nasal septum to the rostrum of the sphenoid sinus allows the mobilization of the specimen
- The defect is inspected, and additional bone or soft tissue margins are obtained under direct visualization. Exposure of the contralateral sinonasal cavity is somewhat limited with this approach

b. *Midface Degloving Approach*

To avoid facial incisions, the sinonasal tumour component may be resected and mobilised via a sublabial approach. It provides wide exposure to the midface, allowing for mobilisation of the periorbita, dividing the ascending process of the maxilla, septal incisions and medial maxillectomy incisions to obtain clear tumour margins

- Make a wide sublabial incision (1st molar to 1st molar) onto the bone of the maxilla
- Dissect in a subperiosteal plane along the anterior maxilla up to the orbital rim and infraorbital nerve
- Expose the nasal cavity by incising the mucoperiosteum around the piriform aperture and elevating the now mobile nose (lower lateral cartilage and nasal skin) and soft tissue envelope off the remaining nasal framework
- Incise the nasal mucosa along the floor of the pyriform aperture
- Gently elevate the medial crura of the lower lateral cartilages off the septum with a full transfixion incision and connected to an intercartilaginous incision along the pyriform aperture
- The soft tissue envelope is then elevated with the lip and lower lateral cartilages

c. Expanded Endonasal Approach

Endoscopic endonasal approaches (EEA), can be used to supplement traditional subfrontal approaches to avoid facial incisions (combined open-endoscopic resections) or as an oncologically equivalent approach for the resection of the anterior cranial base. EEA evolved following advances in rod-lens endoscopy, improved digital camera and video monitor definition, customisation of surgical instruments, and refinements in electrophysiological monitoring, jointly with image-guided surgery equipment.

- Examine the nasal cavities with a zero-degree rigid endoscope
- Depending on the bulk and origin of the tumour, dissection may commence either with tumour debulking or with traditional endoscopic sinus surgery
- Dissection of the paranasal sinuses follows a technique similar to that used for the treatment of inflammatory disease
- Whenever necessary, ***debulk the tumour*** to provide an adequate working space and visualisation, identifying and maintaining the origin of the tumour and assessing its boundaries. The extent of the tumour determines the need for unilateral versus bilateral exposure
- Following an ***uncinectomy***, create a wide ***medial maxillary antrostomy*** giving access to the posterior maxillary wall and providing orientation with respect to the medial and inferior orbital walls
- Complete ***anterior and posterior ethmoidectomies, middle turbinectomies, and exposure of the nasofrontal recess*** to define and expose the paramedian anterior skull base, including the roof of the ethmoid sinuses, the vertical and horizontal lamellae of the cribriform plate, and the anterior and posterior ethmoidal artery canals
- Wide bilateral exposure of the ***sphenoid sinuses*** with complete removal of the rostrum provides unencumbered access to the planum sphenoidale and defines the posterior tumour limit
- Similarly, a ***Draf III frontal sinusotomy*** (modified endoscopic Lothrop procedure) provides access to the cribriform plate and posterior table of the frontal sinus and defines the anterior limit
- ***At this point the reconstructive plan should be considered.*** If a ***nasoseptal flap*** is available (it is often not due to oncologic involvement), it should be harvested at this point. Using monopolar cautery, the superior incision is placed along the superior septum beginning at the sphenoid ostium, to be carried anterior and cephalad towards the olfactory groove. Anterior to the anterior head of the middle turbinate the incision is carried along the

superior-most septum to reach the mucocutaneous junction. The inferior incision is typically performed across the inferior choana and along the inferior margin of the septum, at the junction with the nasal floor, and carried anteriorly to meet the anterior incision. The flap is elevated in a submucoperichondrial plane, left pedicled to the posterior septal branch of the sphenopalatine artery. The flap is then tucked in the nasopharynx to complete the resection

- A wide ***posterior septectomy*** is then performed, ensuring adequate preservation of the anterior septal strut to maintain nasal support. The contralateral septal mucosa can be utilised as a reverse septal flap provided that there is no tumour invasion
- The ***sphenoidotomies are connected and widened***
- This completes a wide exposure of the median anterior skull base, from orbit to orbit and from the sella turcica to the frontal sinus *(Figure 13)*
- The ***lamina papyracea*** may be eggshell fractured and carefully removed as a lateral margin, if necessary, or to better identify and control the ethmoidal arteries. The integrity of the underlying periorbita should be preserved unless tumour invasion mandates its removal
- Bone over the ***anterior and posterior ethmoidal canals*** may be removed by gentle curettage or drilling, exposing the ethmoidal arteries that then may be cauterised (bipolar electrocautery is strongly recommended)
- Using a high-speed drill with a 3 mm extended-tip coarse diamond or hybrid burr, a horizontal ***osteotomy*** is made through the planum sphenoidale several millimeters anterior to the optic canals
- Using the Draf III frontal sinusotomy, another horizontal osteotomy is made posterior to the frontal outflow to expose the crista galli
- These osteotomies are then connected bilaterally with osteotomies along the lateral aspect of the roof of the ethmoid sinuses (junction of the ethmoid sinus roof and orbital roof
- These rectangular osteotomies incurporate the cribriform plates, septum, and portions of the planum sphenoidale and roof of the ethmoid sinuses and surround the tumour
- Any remaining bone is thinned and elevated to expose the dura of the ventral skull base and the crista galli, which is resected
- ***Olfactory filaments*** are cauterised and the bone of the anterior skull base is resected
- ***Dura*** can be opened or resected along the with ***olfactory bulbs*** *(Figures 14,15)* as needed for tumour clearance
- ***Margins are sampled*** circumferentially to ensure an adequate oncologic resection

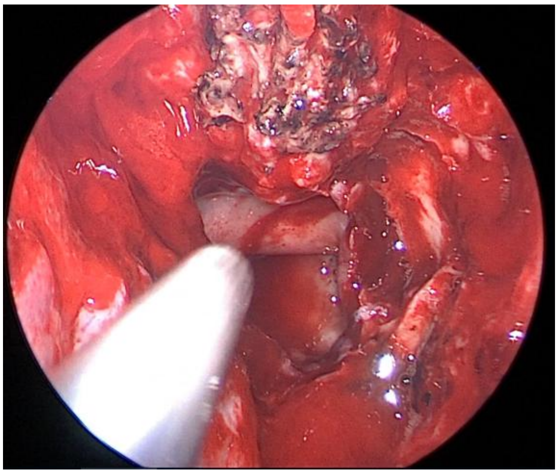


Figure 13: Expanded endonasal approach for exposure of the anterior skull base. After total extirpation of the sinuses, nasoseptal flap harvest (if indicated) and a posterior septectomy, the sphenoid ostia are enlarged into a common sphenoid cavity, widely exposing the skull base from orbit to orbit. A Draf III frontal sinusotomy is helpful in joining and defining the frontal exposure

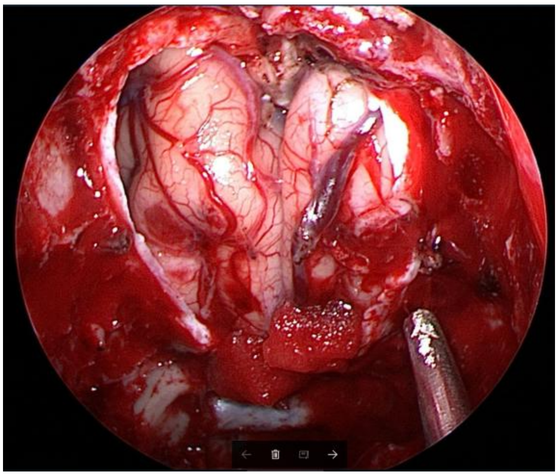


Figure 14: The cribriform plate is drilled and the anterior skull base can be resected to include the underlying dura

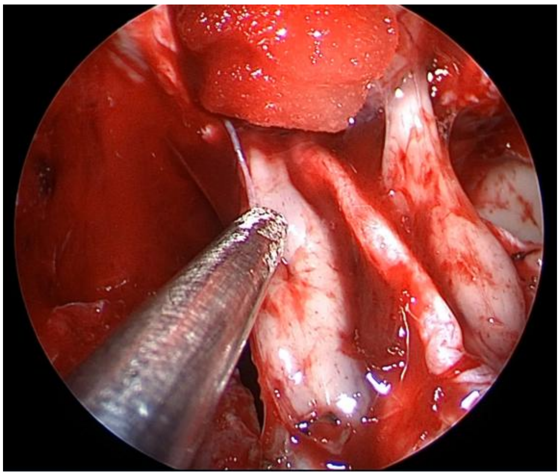


Figure 15: As the cribriform and olfactory bulbs are being gently mobilised from the skull base in an anterior to posterior direction, the olfactory nerves can be identified, transected and sampled for a margin as indicated

- ***Alternatively***, the endoscopic drill is used to connect the endoscopic resection to the previously performed osteotomies done via the subfrontal approach, when being used in combination with open approaches. This allows complete mobilisation and *en bloc* removal of the tumour

Reconstruction

The primary goal of reconstruction is to achieve a watertight dural closure to minimise the risk of a postoperative CSF leak and meningitis.

- Small dural lacerations are closed primarily
- Large defects require the use of a free tissue graft. Cadaveric dura, pericarpdium, acellular dermis, and fascia lata can be used
- Reconstruction of the skull base infrastructure is ***best achieved with a vascularised flap*** to ensure a durable watertight seal. This is typically completed with a ***pericranial*** or ***galeo-pericranial*** flap (open approach) or ***nasoseptal*** flap (endoscopic approach) *(Figure 16)*

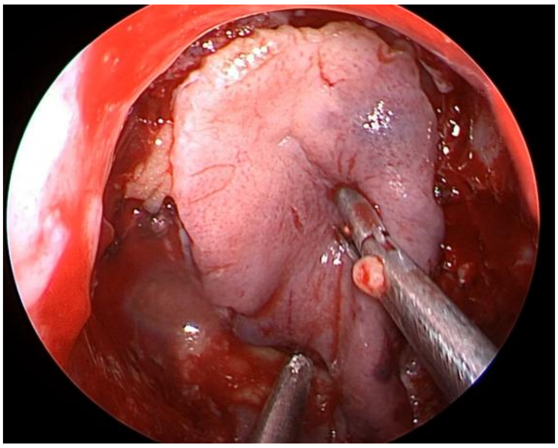


Figure 16: After the resection is complete, an inlay reconstruction is typically performed of the skull base (fat, fascia lata, or a collagen matrix). The nasoseptal flap is then rotated into place, widely covering the defect with bony contact 360 degrees around the skull base defect

Pericranial flap

The pericranial flap is pedicled on the supraorbital neurovascular bundles (and sometimes supratrochlear neurovascular bundles and anterior branches of the superficial temporal artery) *(Figures 4, 5,* *6)*. A unilateral blood supply is sufficient for the survival of the flap.

- The pericranium is elevated off the previously elevated scalp flap or is elevated independently if a subgaleal scalp flap is performed *(Figures 4, 5)*
- The flap is elevated in a subgaleal plane but remains attached to the scalp flap 1-2 cm above the orbital rims to prevent injury to the supraorbital pedicles
- The flap is then gently tucked in the epidural space and below the orbital bar and craniotomy bone grafts *(Figure 17)*

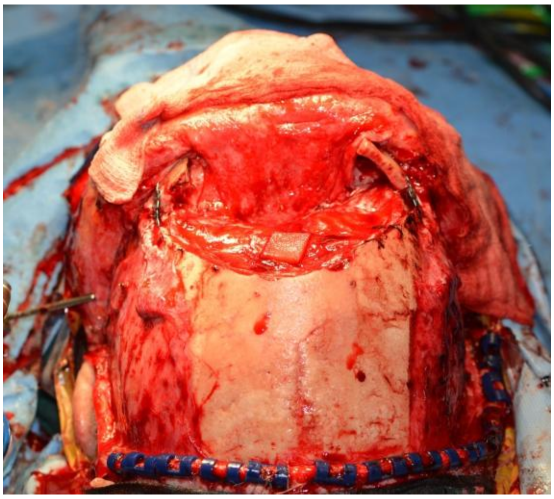


Figure 17: The pericranium is tucked into the epidural plane between the remnant cribriform/orbital roof and the dura. This is typically done prior to replacing the frontal bar or bifrontal bone flaps to create a watertight closure

Endoscopic reconstruction

- This is best completed with a ***naso-septal flap***, although ***lateral wall flaps*** are a viable alternative
- Having elevated the flap earlier with the endoscopic approach, the open skull base defect is cleared and exposed
- Fat, fascia lata, *Duragen* or other free grafts can be used as ***inlay grafts for a multilayered reconstruction***
- The ***nasoseptal flap*** is then rotated extracranially into position to cover the defect *(Figure 15)*. The flap should have adequate overlap circumferentially to the remaining bony surface
- The flap is generally bolstered with sponge-type packing to secure the graft tightly against the skull base

Closure

- The supraorbital and craniotomy bone grafts are replaced into their anatomic position with adaptation miniplates (wires or even sutures may yield an adequate result)
- The pericranial flap is typically placed between the supraorbital graft and the nasal bones
- The scalp is then rotated back into position and the facial and scalp incisions are closed in standard fashion

Postoperative Care, Identification and Management of Complications

- The patient is typically extubated immediately postoperatively
- It is imperative to communicate with the anaesthesia team, as with an open skull base defect, the patient *cannot* be supported with positive pressure mask ventilation, or significant pneumocephalus could result
- The patient is transferred to a monitored intensive care setting for close neurologic monitoring, and a postoperative CT scan is routinely performed to rule out intracranial haemorrhage, brain contusion or significant pneumocephalus
- A lumbar spinal drain is not routinely required but may be considered in patients with a tenuous reconstruction. Alternatively, acetazolamide may be administered to decrease the production of CSF, in turn decreasing the pressure

and diminishing the potential for a postoperative CSF leak

- The patient is checked daily for a CSF leak by sitting the patient upright and flexing the neck, monitoring for a steady drip of clear fluid from the nose ("tilt test")
- IV antibiotics are continued for 48 hours and advanced to oral antibiotics with the patient's diet. Antibiotics are continued until the nasal packing is removed, approximately 1 week post-operatively
- The patient usually remains in the hospital for 3-5 days
- The patient is typically seen in the clinic 1-2 weeks postoperatively. The nasal cavity is gently debrided and packing removed
- Saline irrigations are then initiated to hydrate the raw mucosal surfaces and gently hydrodebride residual packing and crusting
- Multiple postoperative debridement visits are typically required while the nose is healing
- The two most common major complications of anterior skull base resection are CSF leak and tension pneumocephalus. Others include brain contusion, oedema, stroke, meningitis, intracranial abscess, and osteomyelitis
- Following a viable reconstruction, a CSF leak may be managed conservatively with lumbar spinal drainage, but a low threshold for surgical re-exploration should be maintained
- Tension pneumocephalus is treated with percutaneous aspiration through a gap between the cranium and the craniotomy bone graft. Recurrent tension pneumocephalus may require diversion of the nasal airway including endotracheal intubation, a nasal airway (nasal trumpet), or a tracheotomy

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