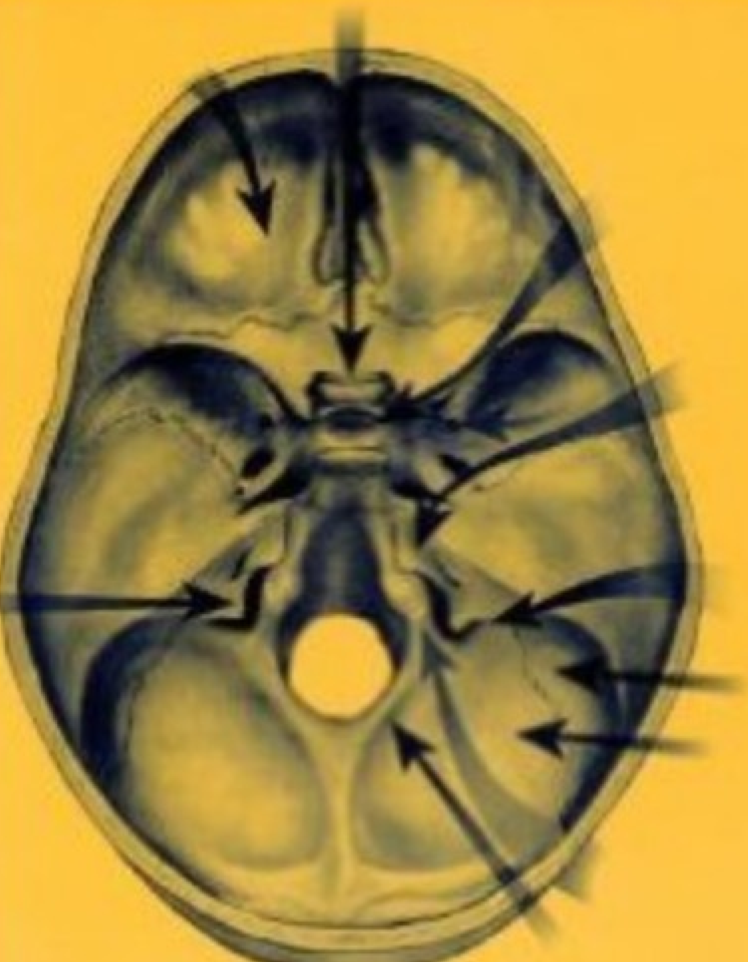
An Atlas of SKULL BASE SURGERY



Edited by D. M. Long MD, PhD, J. K. Niparko MD, B. W. O'Malley, Jr MD and S. J. Zinreich MD

With contributions by M. J. Holliday MD, L. R. Lustig MD, D. E. Mattox MD and M. Ng MD

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Donlin M.Long, MD, PhD

John K.Niparko, MD

Bert W.O'Malley, Jr, MD

S.James Zinreich, MD

The Johns Hopkins University, Baltimore, Maryland

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Contents

Editors and contributing authors

Editors

Donlin M.Long, MD, PhD
Professor and former Chairman
Department of Neurological Surgery
Johns Hopkins University
Baltimore, Maryland

John K.Niparko, MD
George T.Nager Professor and Director
Division of Otology & Neurotology
Department of Otolaryngology, Head & Neck Surgery
The Johns Hopkins University
Baltimore, Maryland

Bert W.O'Malley, Jr, MD
Professor and Chairman
Department of Otolaryngology, Head & Neck Surgery
University of Maryland
Baltimore, Maryland

S.James Zinreich, MD
Professor
Department of Radiology
The Johns Hopkins University
Baltimore, Maryland

Contributors

Michael J.Holliday, MD
Associate Professor
Department of Otolaryngology, Head & Neck Surgery
The Johns Hopkins University
Baltimore, Maryland

Daniel J.Lee, MD
Clinical Instructor
Department of Otolaryngology, Head & Neck Surgery
The Johns Hopkins University
Baltimore, Maryland

Lawrence R.Lustig, MD
Associate Professor
Department of Otolaryngology, Head & Neck Surgery
The Johns Hopkins University
Baltimore, Maryland

Douglas E.Mattox, MD
Professor and Chairman

Department of Otolaryngology, Head & Neck Surgery
Emory University
Atlanta, Georgia

Matthew Ng, MD
Clinical Instructor
Department of Otolaryngology Head & Neck Surgery
The Johns Hopkins University
Baltimore, Maryland

Illustrations

Donna Cavi

Sarah L.Williamson

Digital imaging

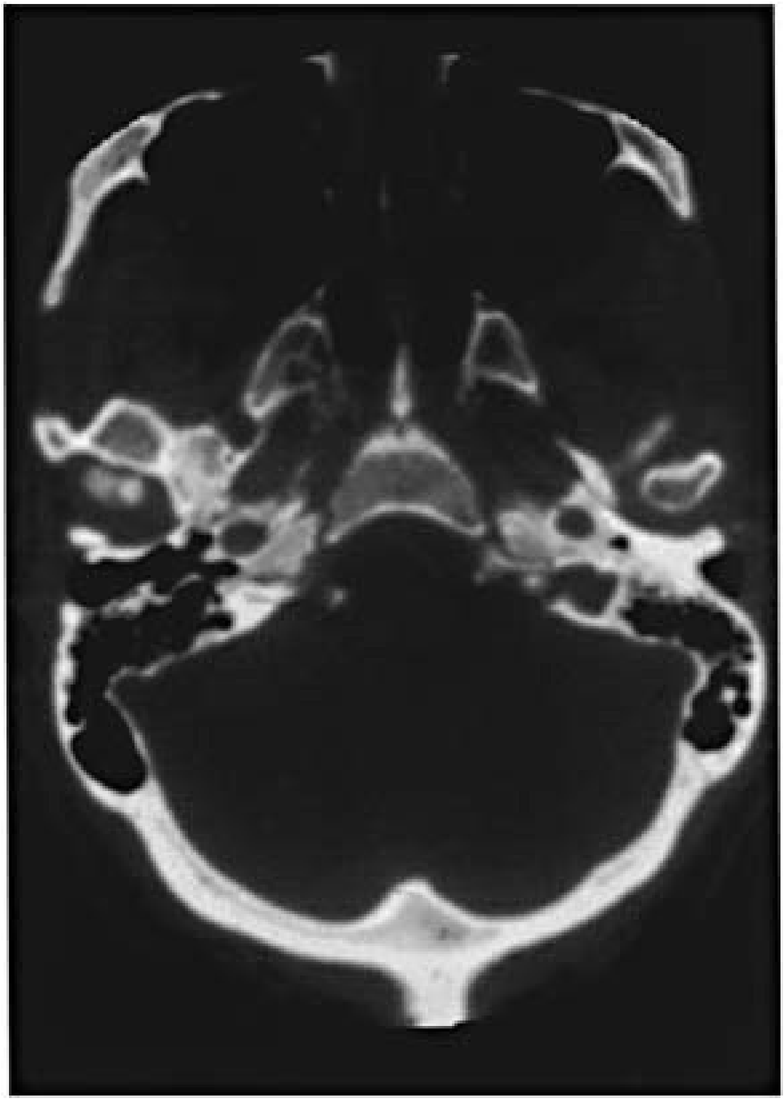
Robert F.Morreale

Foreword

This surgical atlas reflects our experiences in treating diseases within the base of the skull. All contributors have been members of the Johns Hopkins Center for Skull Base and the surgical techniques described herein reflect their training and experience. There are similarities and variations to every surgical approach. No technique, in and of its own, should be considered an ‘only’ approach. Each surgical approach must be individualized and tailored according to clinical presentation, pathology, and a patient’s informed wishes.

The skull base approaches that we describe in this atlas have worked well over time for our patients. The purpose of a good atlas is to direct the reader on how to reach a particular anatomic target efficiently and with safety. We have attempted to achieve this goal in the same spirit, recognizing the challenges presented by one of the most anatomically complex areas.

Each chapter has been arranged in a format that aims to help the reader to evaluate and plan the management of a patient with a skull base lesion in which the clinical presentation or cell type mandates an operative procedure. Illustrations have been adopted from actual surgeries to help to review the main steps, and computer-generated images have been derived from three-dimensional skull reconstructions to help conceptualize the anatomy and surgical trajectory.



Skull base surgery is a continually evolving field. As our understanding of the pathologies and natural histories of lesions that affect this area becomes clear with time, we will be better able to effectively treat patients who face monumental challenges to their quality of life. We persevere and strive to provide the best care for these patients, using the tools and training of dedicated mentors. Colleagues who have contributed to this text have served in that role for me. True to the team concept, their collective wisdom is immense.

John K.Niparko, MD

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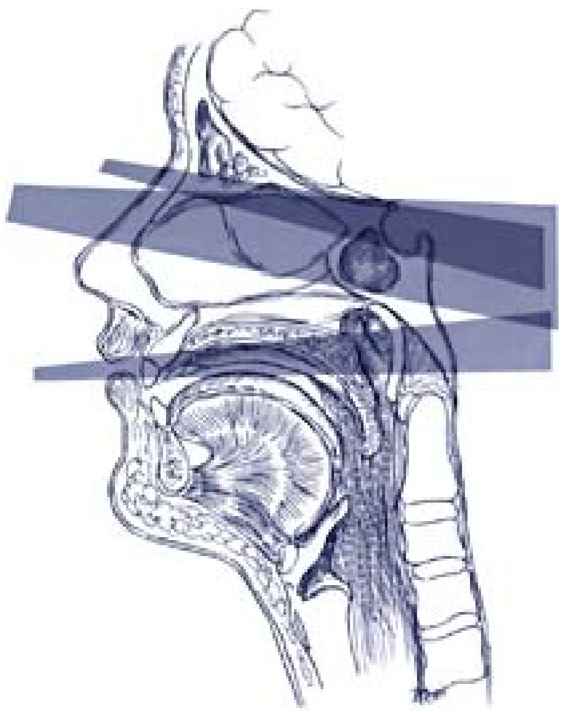
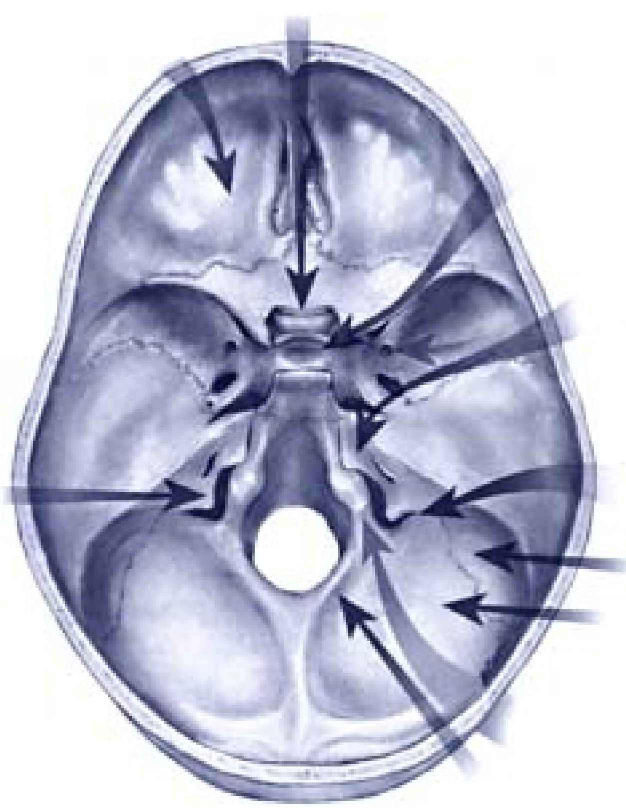
1
Surgery at the base of the brain

Donlin M.Long





The treatment of skull base tumors is a recent development in as much as the related surgical techniques have been described within the last century, and the radiation techniques within the past 20 years. In the early 1900s, surgeons worked alone, and the concept of a skull base ‘team’ did not yet exist. Working at the Johns Hopkins Hospital, Harvey Cushing is widely recognized as the first to introduce the concept of a team approach to operative management of tumors of the nervous system. In the first decade of the last century, he emphasized the need to consider simultaneously the multiple systems and diverse therapies to achieve the best results1.

The Johns Hopkins Center for Skull Base Surgery was founded in 1976. The conceptual father was George T. Nager, MD, world-renowned authority on pathology of the temporal bone, then Chairman of Otolaryngology at the Johns Hopkins Hospital. With Dr Nager’s urging, it became evident that the greatest advances in this complex surgical area could be made by organizing the overlapping specialties to take advantage of their diverse and unique skills. At the inception, the disciplines of Neurosurgery and Otology combined efforts. Neuro-ophthalmology followed and joined the team effort. Significant contributions and benefits from both diagnostic and interventional neuroradiology, dedicated neuroanesthesia, and a neurological intensive care team were readily recognized and incorporated into this ‘team’. The welcomed addition of radiation oncology provided yet further management options of adjunctive and primary-radiation delivered via stereotactic techniques.

This group of specialists has been organized in what we have termed, since 1980, the ‘center of expertise’ concept. In such an organization, the center focuses around highly specialized, well-defined categories of disease. The center provides for all the patients’ needs for the most comprehensive care for their particular disease. The goal of the center is to provide whatever treatment is best for the individual. This means that every standard therapy should be available. The center provides the options of the optimal operative approach, non-operative therapies, including all forms of radiotherapy and chemotherapy protocols, and access to investigational therapies if needed. Advanced intensive care and rehabilitative services, essential components for such comprehensive care, are also made readily available.

The ‘center of expertise’ concept goes well beyond simple provision of surgical care. It starts with thorough preoperative evaluation of patients and continues through the operative, perioperative, and postoperative periods. The latter addresses the patients’ needs for restoration of form and maximum function. The team needs to be able to identify and manage complications of any type whenever they occur. Moreover, when located within an academic institution, the center must play an educational role and provide a research base to answer important questions.

Surgeons have operated on the base of the brain for decades to reach the pituitary gland, the circle of Willis, and the cerebellopontine angle. Neurosurgeons, otolaryngologists and ophthalmologists possess a variety of surgical approaches which attack these same areas from extracranial sites. Interestingly, the most common of these approaches, the transnasal operation for pituitary tumors, was the first skull base operation described prophetically by a neurosurgeon and an otolaryngologist independently It is at the junction of these standard operations from the respective fields that both intracranial and extracranial exposures are required and constitute the concept of ‘skull base surgery’. The first lecture originating from our new center in 1976 was entitled ‘Extracranial approaches to intracranial tumors’. The concept was initially met with great skepticism, but now it is apparent that many pathologies which are not treatable by conventional intracranial or extracranial operations alone can be successfully approached by combinations of both.

For practical purposes, the skull base can be defined as an oval construct which surrounds the exit foramina of the cranial nerves and incorporates the foramen magnum. Many different tumors can be found in. this region and their anatomical relationships are extremely complex. Procedures can be grouped according to the region of access along the skull base and the trajectory of approach (Figure 1). One group of operations is designed to reach the anterior cranial fossa and mid-line structures, such as the pituitary gland and clivus, by traversing across the face, nasal cavity oral cavity and paranasal sinuses (anterior and mid-line approaches). A second category of operations is designed to cross the anterior or middle cranial fossae from the sides to the region of the cavernous sinus, sella and parasellar areas, cavernous and petrous carotid artery, trigeminal nerve, optic canal, and superior orbital fissure (anterolateral approach). A third

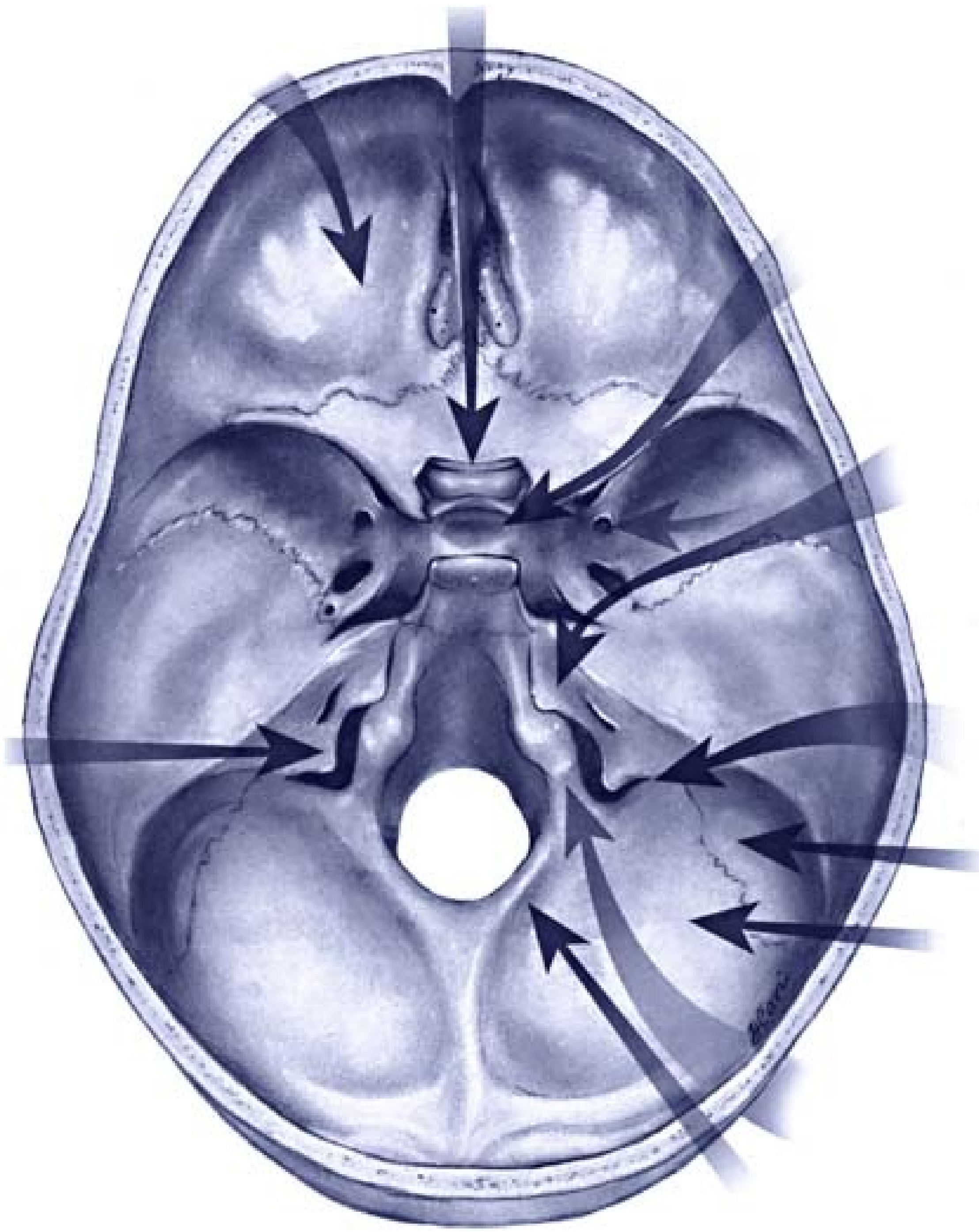


Figure 1

Schematic diagram of the approaches to the skull base based on the direction of surgical entry and access to the skull base: anterior and mid-line approaches, anterolateral approach, lateral approach, and posterolateral approach. The surgical construct of the skull base can be characterized as an oval that surrounds the exit foramina of the cranial nerves and incorporates the foramen magnum category takes the surgeon from a lateral direction to deep within the extracranial and intracranial recesses of the infratemporal fossa, cerebellopontine angle; and posterior cranial fossa. The jugular foramen and foramen magnum and the neurovascular structures, contained within and adjacent, are additional areas which are accessed using these approaches.

Because the brain is limited in its mobility and compressibility, skull base approaches are designed to minimize brain retraction and potential brain injury. The best approach is obviously the simplest and most direct which will allow the surgeon to accomplish the goal of complete resection successfully. The need for facility with multiple approaches is essential to the treatment of skull base tumors (Figure 2). For example, in making the choice of the appropriate bony incisions, it is our belief that the more straightforward the exposure, the less time is spent on this portion of the procedure for access. There is less chance of a postoperative deformity or dysfunction and less risk to vital neurovascular structures traversing the skull base. More circuitous and complex routes present unnecessary risk and danger.

The decision about how radical an approach to use for tumor removal is one that must be individualized. In a field as new as skull base surgery, natural histories are often not known and the long-term outcome for much of the surgery has yet to be established. With some tumors such as carcinoma or chordoma, the outlook is so dismal that the risks of the most radical approaches are well justified. With other tumors, such as those involving the pituitary gland, radical surgery is justified because associated risk is low and the results of surgery quite predictable. Surgery for cranial nerve schwannoma is almost equally successful, again with very low risk.

Some controversies call for an examination of patient outcomes. One major debate concerns meningioma. Contemporary techniques have reduced mortality to a very low level unless major arteries are involved in the tumor. However, current thinking does allow for consistent preservation or restoration of cranial nerve function. Most patients with skull base meningiomas present with cranial nerve deficits. Most retain them, and a significant number have new deficits after surgery. While all agree that the goal of surgery should be cure, there is still a major question about the price to be paid for cure.

There are still many unanswered questions. When should the carotid artery be sacrificed or repaired? What cranial nerve deficits are acceptable? What are the consequences of residual tumor? What is the role of radiation therapy focused or unfocused? These questions are actually more difficult than the technical issues. The problem is that the natural histories of many of the tumor types that involve the skull base are not well known. What about the patient with a small basal meningioma and a trivial cranial nerve deficit? Should surgery, which produces a greater deficit, be attempted, and if so, when?

At present, we have only expert opinion to guide us. Because of the nature of many of the skull base tumors, it will take years of careful evaluation to achieve adequate answers. For example, with skull base meningiomas, there is virtually no value to reports with less than 5 years of follow-up. Ten years of follow-up are better and it appears that we will not truly know outcomes of therapy with rigorous follow-ups of less than 20 years. It is incumbent upon all involved in this new field to evaluate all their patients, those operated upon and those not, and to scrupulously report their status without regard for current opinion.

Surgery at the skull base requires skills that are not commonly acquired in any of the individual specialties alone. Understanding of the detailed anatomy of the visual system, extraocular muscles, bony orbit, and orbital contents is important. The paranasal sinuses, oral cavity, sphenoid bone, pterygopalatine area, and temporal bone must all be understood in three dimensions. The circle of Willis, relationships of the base of the brain to the base of the skull, and intracranial nerve anatomy have to be equally well mastered. The skull base surgeon needs to know how to expose the brain and how to use refined drilling techniques to facilitate delicate skull base resections around cranial nerves and important blood vessels. The operating microscope and microneurosurgical instruments must be used effectively The surgical techniques for intraorbital surgery, intracranial surgery, head and neck surgery, and neurootology are all different, but the complete skull base surgeon must borrow the best techniques from each field and practice them in a complementary fashion.

The most straightforward way to provide patients with the advantages of this set of disparate skills is to assemble a team of specialists. Individual surgeons certainly can learn all

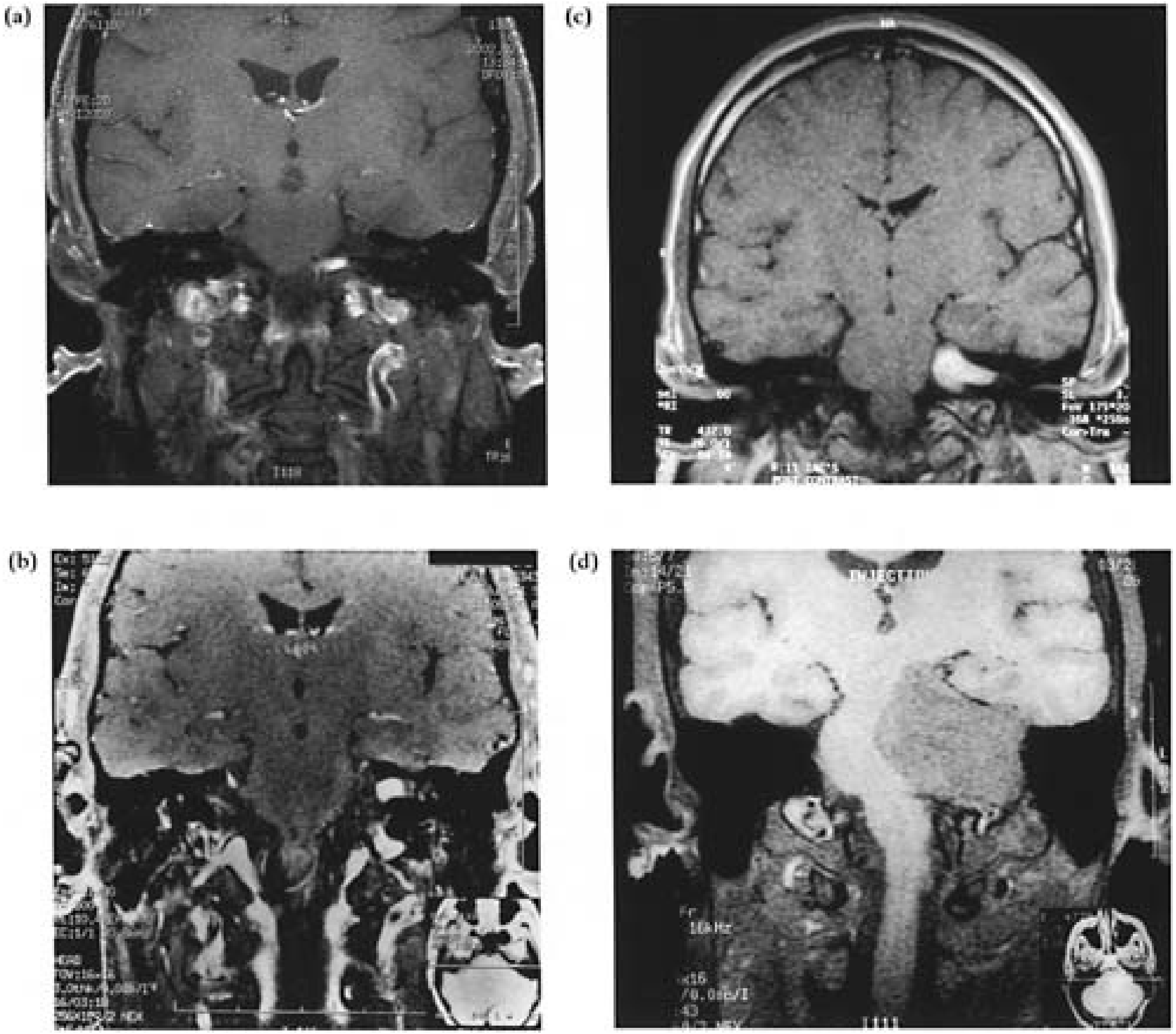


Figure 2

The optimal management and, if indicated, surgical approach to the excision of acoustic neuroma rely on combining information about patient symptoms, temporal bone anatomy, and tumor size. A range of tumor sizes is depicted, each presenting unique surgical challenges. Ironically, the severity of symptoms in this series of four cases was inversely related to tumor size. (a) Right intracanalicular acoustic neuroma in a patient with severe rotary vertigo; (b) left intracanalicular lesion in a patient with disequilibrium; (c) left-sided acoustic neuroma with cerebellopontine angle extension in a patient with hearing loss; (d) large left-sided acoustic neuroma with brain stem displacement in a patient with hearing loss these things, but these complex operations at the base of the brain should not be undertaken by any one individual until all of the knowledge is acquired and all of the skills are mastered.

The area of the base of the brain and the base of the skull is truly one of the last great surgical frontiers. The techniques currently available address the many tumors we encounter. However, we must refine these techniques and develop others. We hope that this surgical Atlas will be one of the steps which makes the founding motto of the Johns Hopkins Center for Skull Base Surgery a reality for all surgeons:

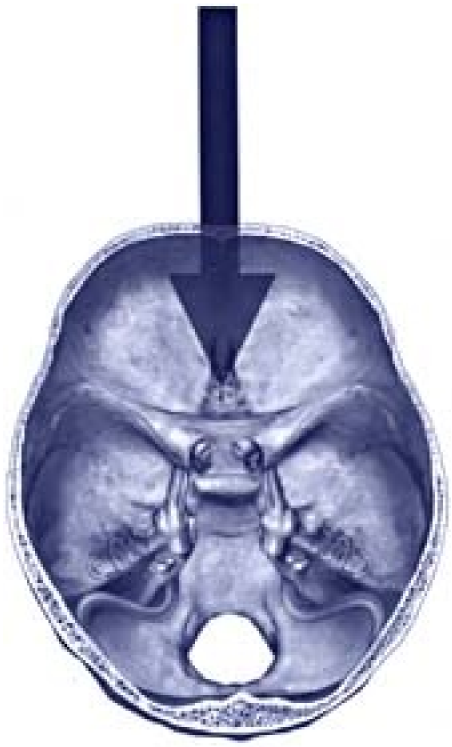
‘from terra incognita to angulus terrarum’

REFERENCE

1. Goodrich J. Amillennium review of skull base surgery. *Childs Nerv Syst* 2000; 16:669–85

2
Anterior craniofacial resection

Bert W.O'Malley, Jr



INDICATIONS

Anterior craniofacial resection is indicated for tumors and other lesions arising primarily from the ethmoid sinus, frontal sinus; or the region of the cribriform plate (Table 1). Tumors in these areas include meningioma; squamous cell carcinoma, adenocarcinoma, esthesioneuroblastoma, adenoid cystic carcinoma, sinonasal undifferentiated carcinoma, and melanoma. Vascular neoplasms and invasive fungal sinus disease are examples of lesions other than neoplasms that may require anterior craniofacial resection in the course of their treatment. For large tumors that invade the orbit, maxillary sinus, or the palate, an extended craniofacial resection is performed with orbital exenteration or partial palatectomy. The choice of reconstruction will also vary with both the site and size of tissue resection. Because the choice of approach, the extent of craniofacial resection, and the possible complications may vary significantly from benign or vascular lesions to malignant tumors, the pre-operative evaluation and planning period is a critical component in the overall surgical care of the patient.

PATIENT EVALUATION

Routine diagnostic imaging should include both computed tomography (CT) and magnetic resonance (MRI) imaging.

The CT scan provides details which assist the surgeon in determining the extent of bony landmark disruption (Figure 1) and provides a map of the important anatomical boundaries and skull base foramina which delineate the course of important neural and vascular structures encountered during the surgical procedure. The MRI scan provides greater soft tissue detail which is helpful in assessing the extent of neural, vascular, and brain invasion by these tumors (Figure 2). An MRI angiogram can also be obtained to further define the extent of tumor involvement with major vessels that course the paranasal sinuses and skull base. Extensive carotid artery involvement or proximity of invasive lesions to the carotid artery should be further evaluated with balloon occlusion tests or other select cerebral blood flow studies. These studies predict the need for vascular bypass in cases of planned carotid artery resection and provide insight into the risks associated with inadvertent carotid injury.

The MRI scan may also provide diagnostic information regarding tumor histology (Figure 3) and may help to differentiate between actual tumor and associated benign disease. With respect to lesions involving the paranasal sinuses, the comparison of T1-and T2-weighted images enables the differentiation of tumor versus sinus obstruction

Table 1 Regions accessible by anterior craniofacial resection

Frontal sinus

Maxillary sinus

Ethmoid sinus

Sphenoid sinus

Cribriform plate

Orbit

Nasopharynx

Planum sphenoidale

Figure 1

(a) Coronal CT scan demonstrating bony erosion of the left frontal process of the maxilla, lamina papyracea and the cribriform plate; (b) axial CT scan showing tumor invasion through the anterior wall of the right maxilla with posterior extension to the pterygoids, infratemporal fossa, and bony skull base

with mucus or mucopurulent secretion entrapment (Figure 4). The importance of pre-operative imaging cannot be overemphasized. Radiographic evaluations impact patient selection, designations of resectability, and choice of surgical approach and reconstruction, and help to predict the chance and extent of risks and complications.

ANATOMICAL CONSIDERATIONS

Specific anatomical boundaries exist for anterior craniofacial resection that designate both general limits of surgical resection and sites of critical vascular and neural structures. The frontal sinus is the anterior boundary, and tumors which

(a)

(b)

Figure 2

(a) Sagittal MRI scan with contrast showing tumor invasion through the anterior skull base into the frontal lobes of the brain; (b) axial MRI scan showing tumor invasion into the orbit and abutting the optic nerve

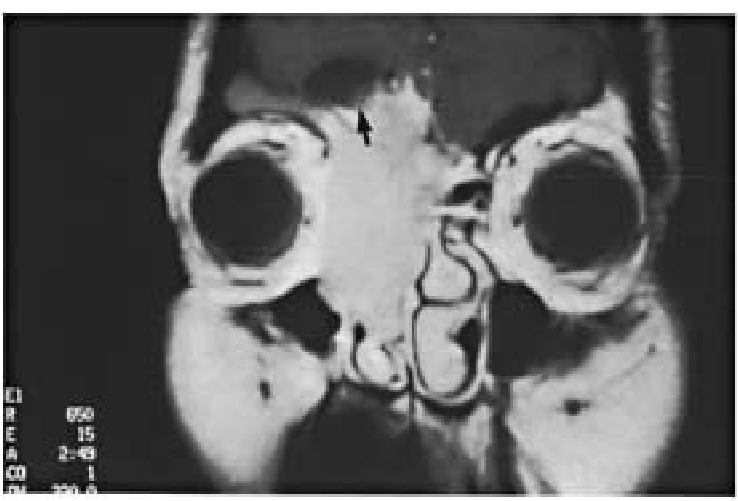


Figure 3

Coronal MRI scan demonstrating a cyst (arrow) at the right superior extent of the tumor which is invading the frontal lobes. The presence of this cyst is considered diagnostic for esthesioneuroblastoma

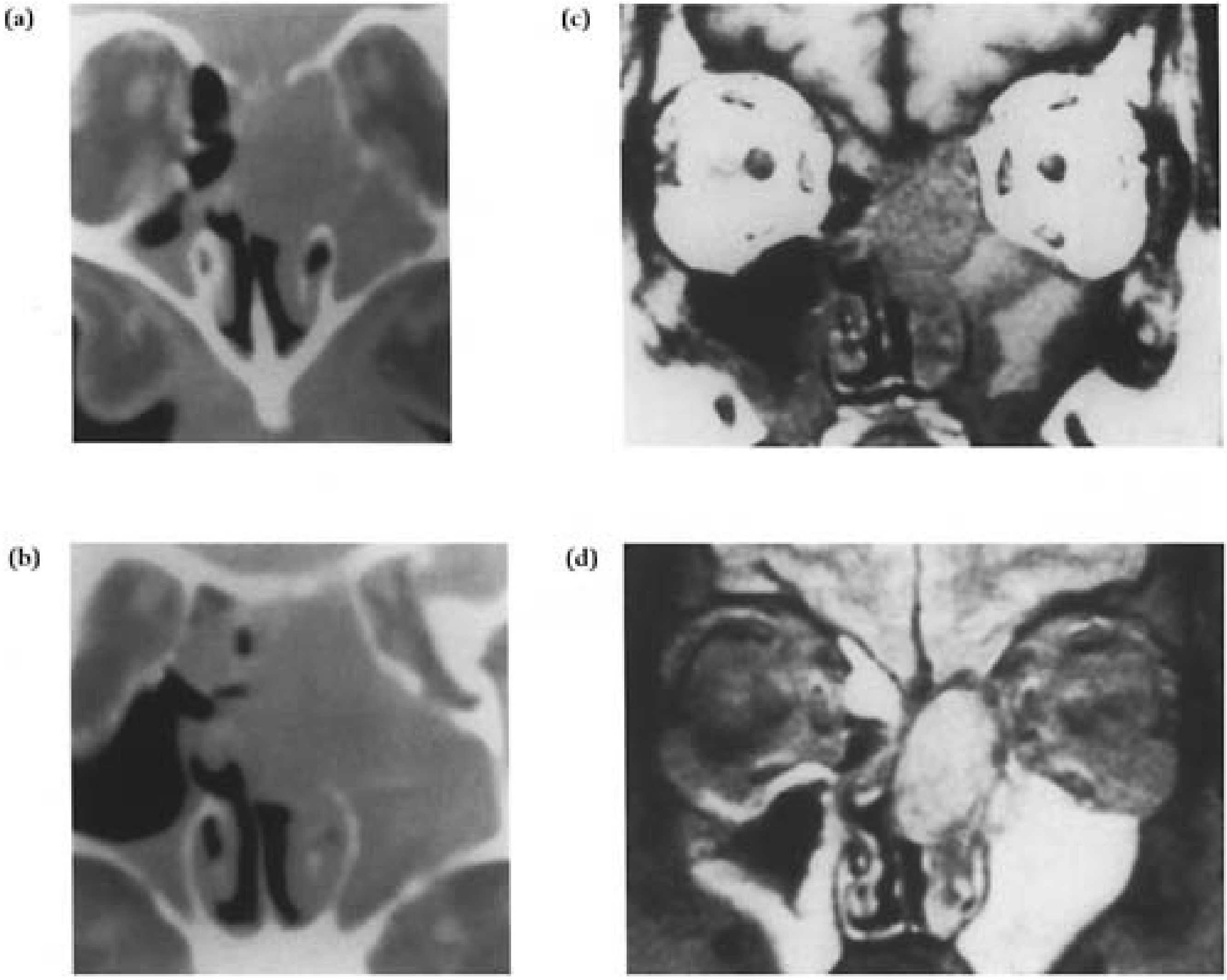


Figure 4

(a) and (b) Anterior and posterior coronal CT scans of squamous cell carcinoma of the ethmoid sinus and cribriform region; (c) T1-weighted MRI scan demonstrating the tumor; (d) T2-weighted MRI scan with fat suppression that differentiates tumor in the ethmoid sinus from inflammatory changes and mucus in the maxillary antrum extend beyond its anterior wall may require extensive skin resection and complex reconstructive procedures. The planum sphenoidale and sphenoid sinus are the posterosuperior boundary. Surgical resection posterior to the planum sphenoidale places the optic nerves and optic chiasm, as well as the pituitary stalk, at risk for injury.

Surgical dissection posterior and lateral in the sphenoid sinus risks injury to the carotid artery and cavernous sinus. The remaining boundaries are comprised of the nasopharynx posteroinferiorly, the medial wall of the orbits superolaterally, the medial wall of the maxillary sinus inferolaterally, and the floor of the nose inferiorly (Figure 5).

(a)

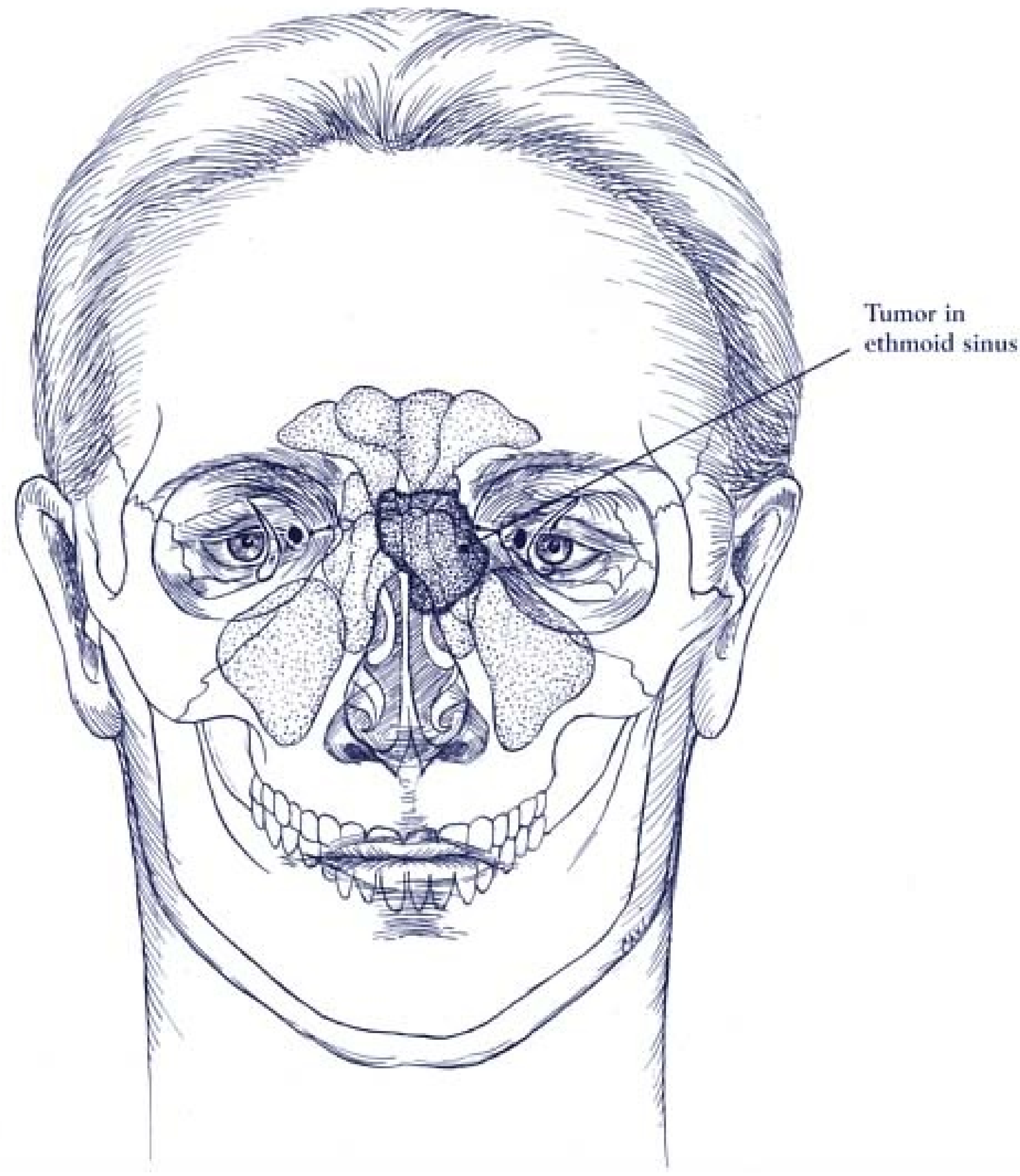
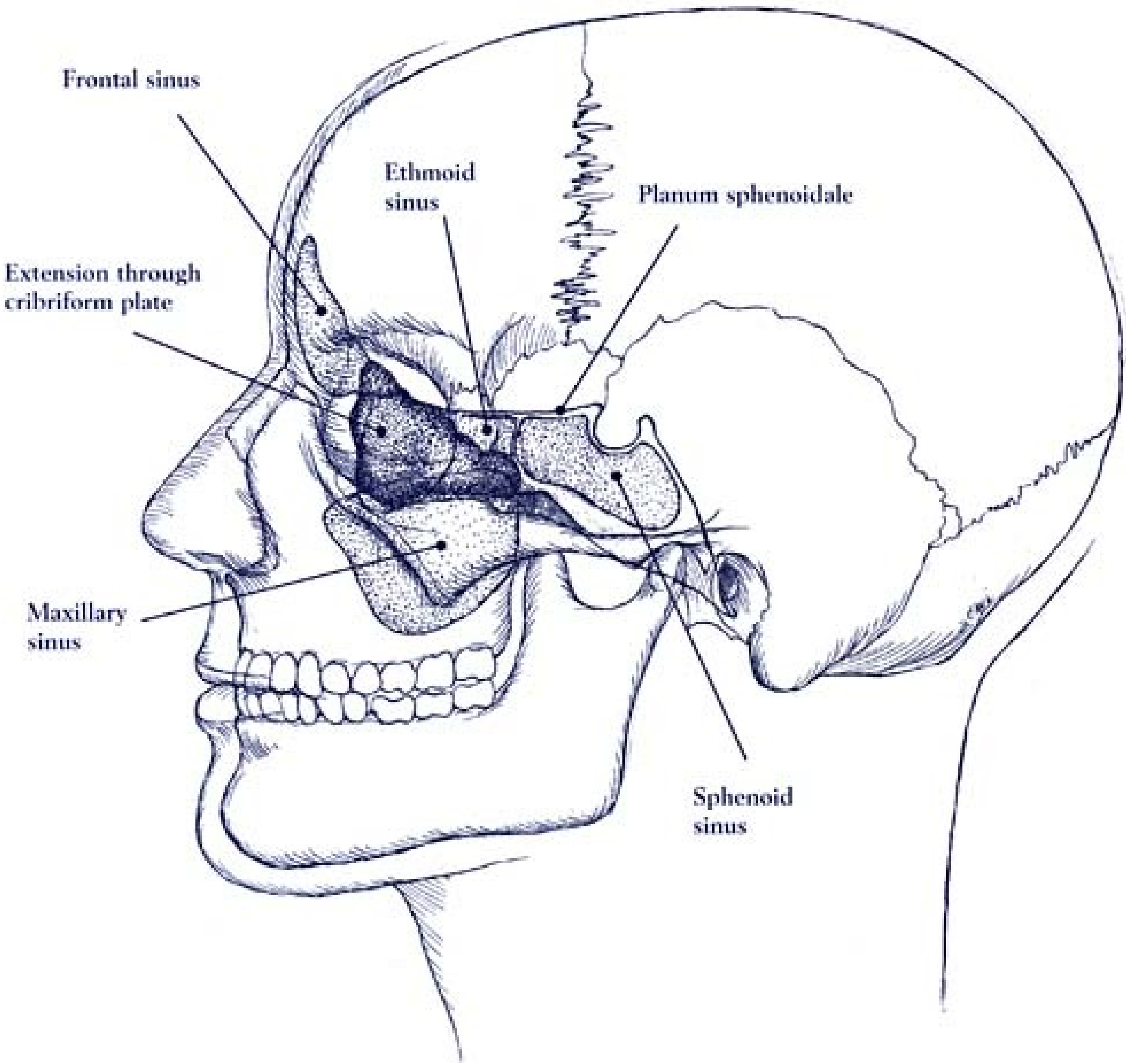


Figure 5

Anterior (a) and lateral (b) anatomical sketches depicting a primary ethmoid tumor with extension into the cribriform plate. Note the relationships between the important surgical boundaries *(see opposite page)*

(b)


Frontal sinus
Ethmoid sinus
Planum sphenoidale
Extension through cribriform plate
Maxillary sinus
Sphenoid sinus

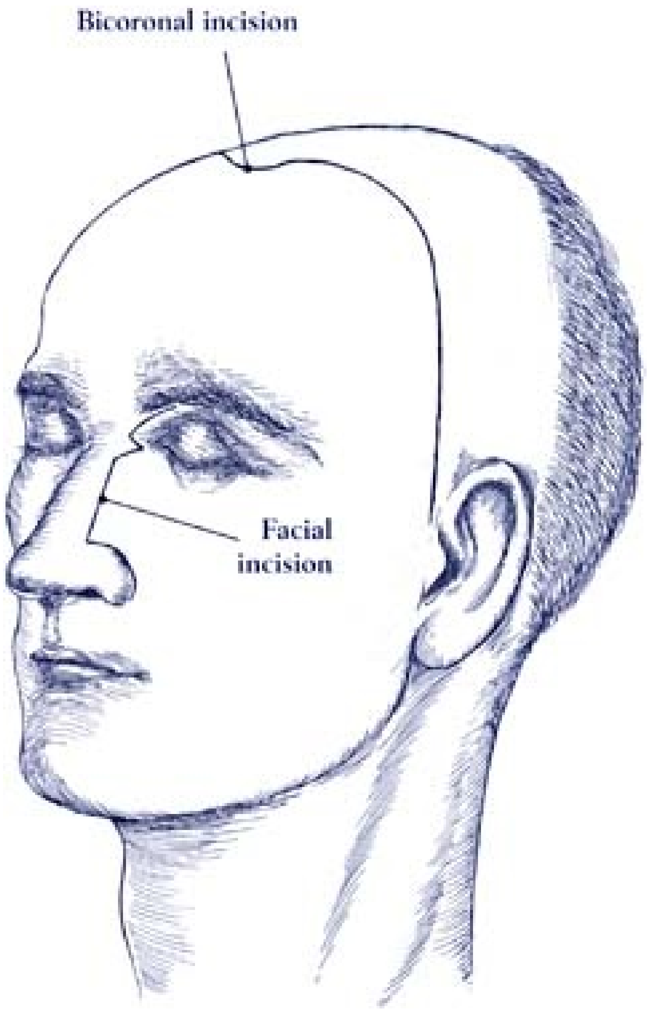


Figure 6

Standard facial and coronal incisions for, anterior craniofacial resection

PROCEDURE

Anesthesia and patient positioning

The patient is placed supine on the operating table, general endotracheal anesthesia is induced, and placement of urinary arterial and central venous catheters is performed as needed. The head is elevated by 10–15° to facilitate venous drainage and can either be fixed with Mayfield pins or supported by a horseshoe head rest. A lumbar catheter may be placed pre-operatively to provide drainage of cerebrospinal fluid and cerebral decompression for increased exposure of the anterior skull base with less need for frontal lobe retraction. Placement of a lumbar catheter is not mandatory, however, and may increase the risk of complications such as excessive cerebral decompression or pneumocephalus. With respect to pneumocephalus, spinal drainage may result in negative intracranial pressure that facilitates entry of air into the cranial cavity.

Cranial approach

Craniofacial resections are performed through coronal scalp and classic lateral rhinotomy and paranasal facial skin incisions (Figure 6). The bicoronal incision is placed posterior to the hairline to maintain cosmesis and to allow at least

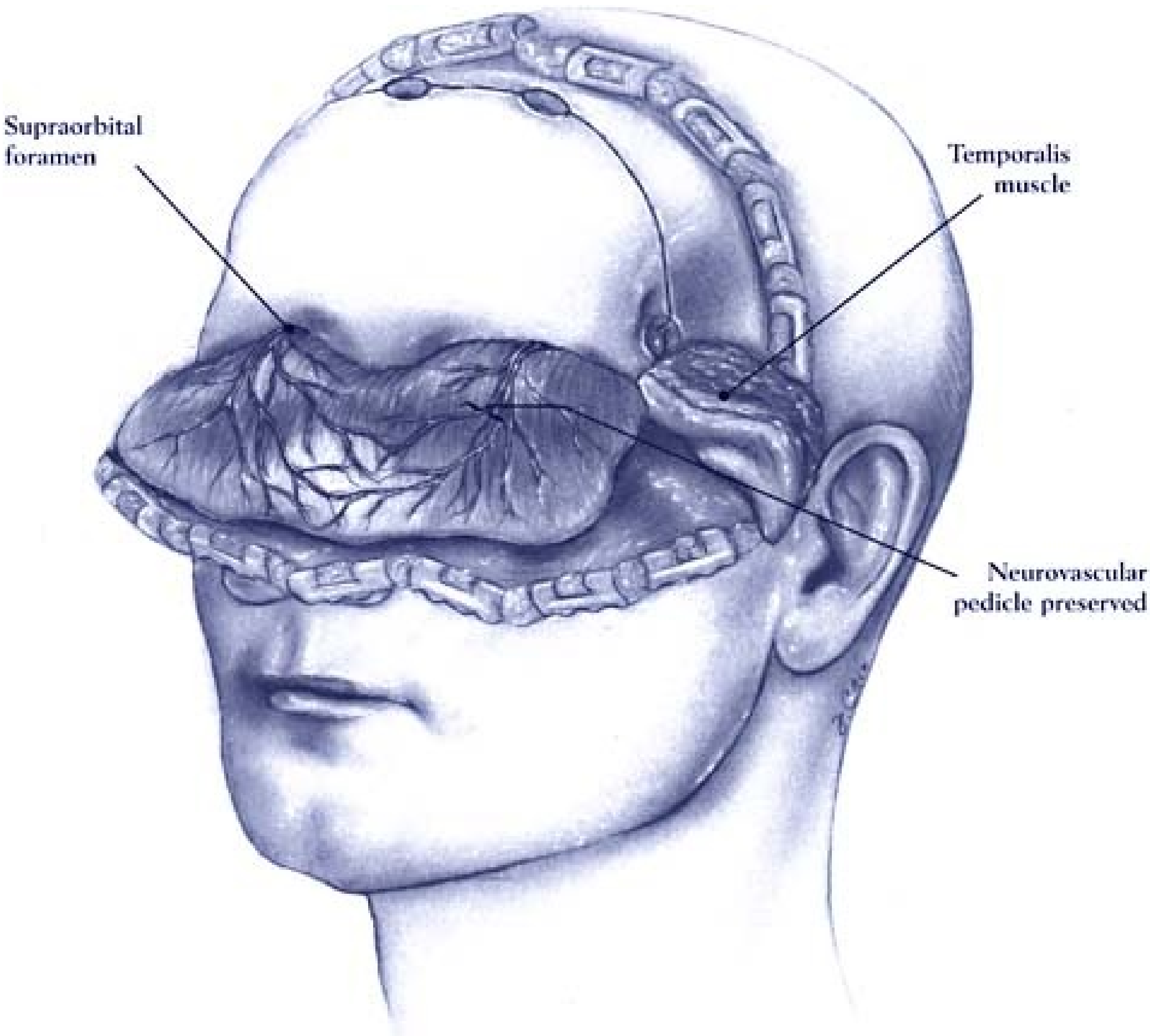


Figure 7

Drawing of a scalp flap with pericranium attached and vascular pedicle preserved 10 cm of length for a pericranial tissue flap, should it be needed. Extending the incision to the preauricular crease allows full rotation of the scalp flap inferiorly and provides increased exposure of the superior orbital rims and nasion region. The coronal scalp flap is raised at the level of the frontal bone and the pericranium and loose connective tissue remain attached until the time of reconstruction. Keeping the pericranium on the scalp flap serves two important functions. First, an attached pericranium is less likely to be damaged by retraction, folding, or surgical trauma. Second, the attached pericranium becomes edematous as the case proceeds, thus helping the surgeon to raise an intact, thick flap that includes the areolar tissue and its vascular network (Figure 7). In raising the scalp flap, dissection in the temporal fat pad decreases the risk of injury to the frontal branch of the facial nerve.

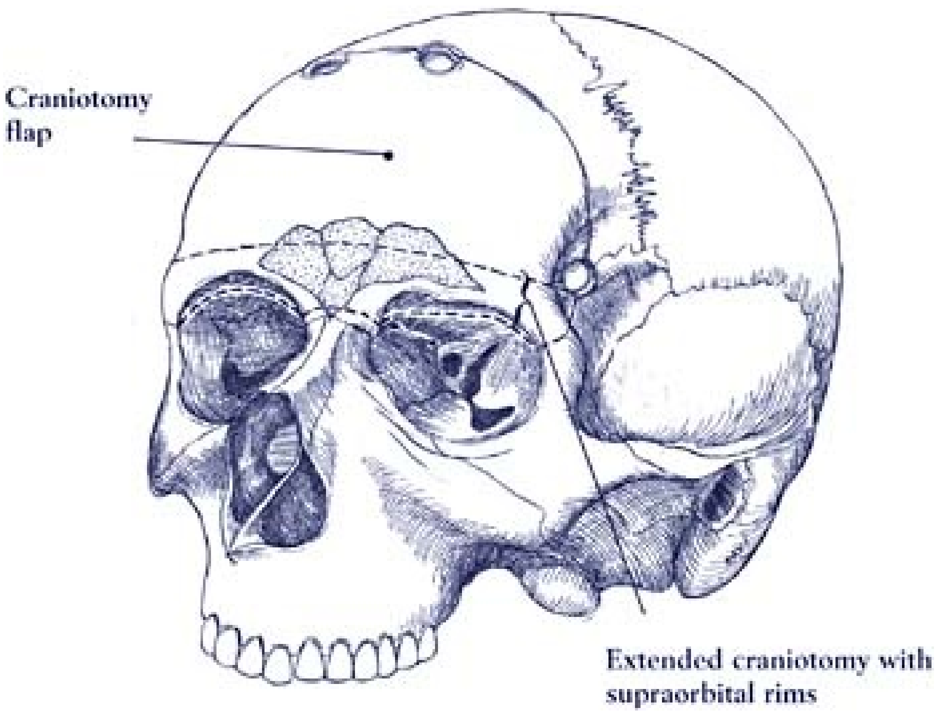


Figure 8

Standard and extended frontal craniotomy for direct access to the anterior skull base with

Frontal craniotomy is performed in the standard fashion. For craniofacial resections, an inferior frontal bone cut that enters the frontal sinus just above the supraorbital rim provides better direct exposure of the anterior skull base and allows for reduced frontal lobe retraction (Figure 8). In certain cases, such as tumors with extensive involvement of the anterior skull base, the supraorbital rims may be included in the frontal craniotomy bone flap as one complete piece (Figure 8). Incorporating the rims in the flap provides the most direct access to the skull base and obviates the need to make a second set of bone cuts to remove what has previously been described as a ‘supraorbital bar’. After performing the craniotomy, the posterior wall of the frontal sinus is removed with either a high-speed drill or rongeurs, and the dura is reflected along the cribriform plate to the mid-to posterior planum sphenoidale.

Facial approach

After providing exposure to the anterior cranial fossa, tumor involving the dura or frontal lobes is resected and frozen section margins are obtained as needed. At this point, attention is turned to the facial approach. For primarily unilateral tumors, a lateral rhinotomy incision on the side of the tumor may be all that is needed for adequate surgical exposure. For extensive tumors that involve both ethmoid sinuses, the entire cribriform plate, or both medial bony orbits, a similar or limited second incision in the medial canthal and lateral nasal region increases surgical exposure to the medial orbit. After exposing the nasal bones, medial orbit, and maxilla as needed, the anterior and posterior ethmoid vessels are identified and cauterized with bipolar cautery The lateral resection margins are now defined and osteotomies are performed with a reciprocating saw or osteotome along the floor of the orbit and vertically at the surgical limit defined by the posterior ethmoid foramen (Figure 9). A medial maxillectomy is performed if tumor extends inferiorly or involves the region of the maxillary ostium. Anterior osteotomies are made from the anterior crest of the lacrimal fossa to the nasion to define the anterior bony margins of tumor resection.

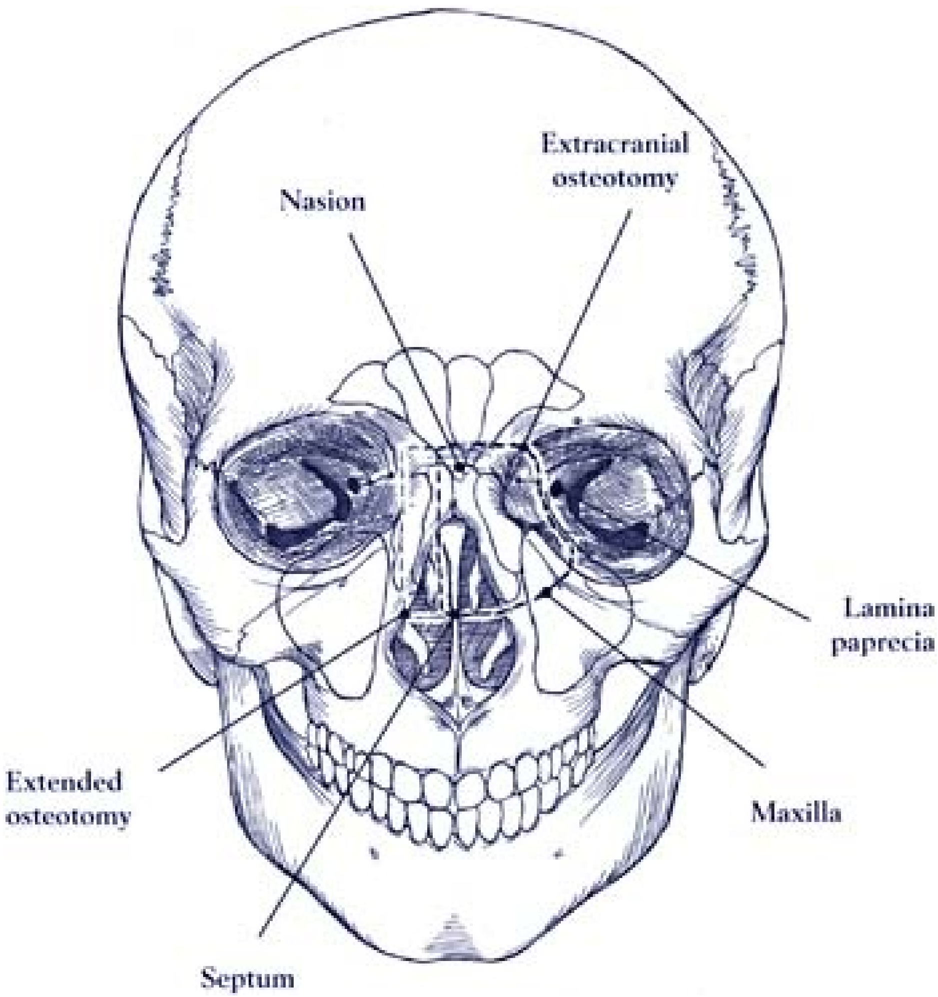


Figure 9

Facial osteotomies for extracranial tumor removal

Upon completion of the facial dissection and osteotomies, there is good exposure of the tumor specimen from both above and below the skull base. At this point, osteotomies are made in the fovea ethmoidalis bilaterally to define the superolateral resection margins (Figure 10). Anterior osteotomies are made in the frontal sinus ducts or just anterior to the ducts, as needed to define the anterosuperior margins of resection. The last intracranial osteotomy is made in the planum sphenoidale to define the posterosuperior skull base margin (Figure 10). Anterior and posterior cuts are made in the bony septum from the intracranial view with either an osteotome or heavy Mayo scissors. The horizontal inferior cut in the septum is then made with a scalpel using direct exposure through the lateral rhinotomy incision.

Reconstruction and postoperative care
After completing the tumor resection, frozen section margins can be obtained from the septal margins and any remaining mucosa of the ethmoid or maxillary sinuses. Upon confirmation of tumor-free margins, the reconstruction begins with a repair of any defects in the frontal dura. The dural repair may be performed with a free

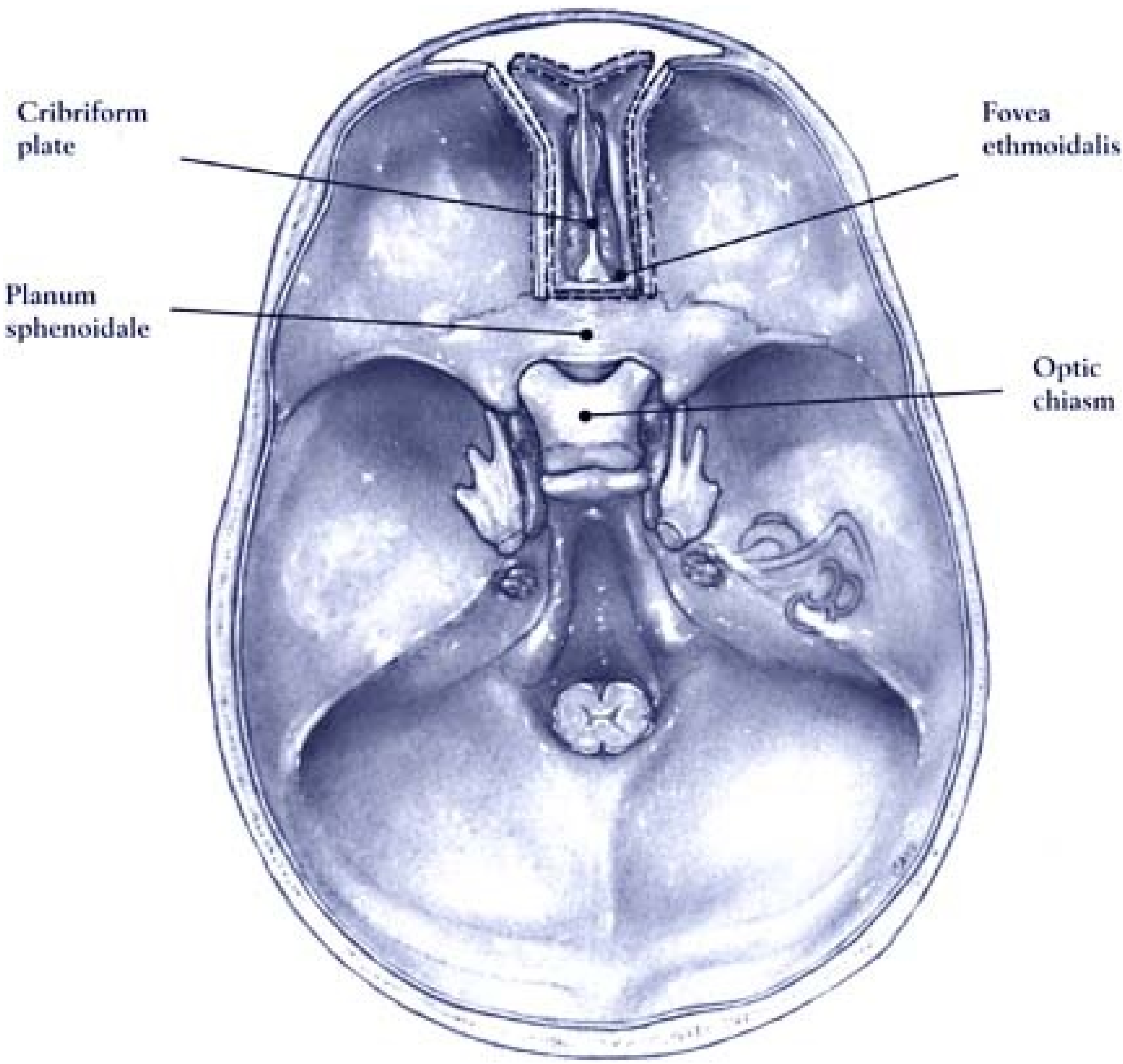


Figure 10

Intracranial view of the anterior skull base outlining the typical sites for the intracranial osteotomies

pericranial graft that is obtained from the skull posterior to the coronal scalp incision or using other free fascial grafts or dural substitutes. The size of the bone defect in the anterior skull base is then evaluated to determine whether rigid reconstruction is needed. Points to consider in this decision are whether the defect is large enough to allow brain herniation and whether the brain rests substantially on the periorbita and globe, resulting in transmitted pulsations to the orbit. Bony defect repair can be performed with either a split-thickness calvarial bone graft taken from the inner table of the frontal craniotomy bone flap or using rigid titanium mesh.

A vascularized pericranial flap is raised from the coronal scalp flap to be used to resurface the anterior cranial fossa, and provide a protective barrier between the contaminated nasal cavity and the sterile intracranial cavity. Dissection is performed at the level of the galea to create a rectangular pericranial flap that receives its blood supply from the supraorbital and supratrochlear vessels (Figure 7). If not resected with the specimen, the nasofrontal ducts may be obliterated with free temporalis muscle plugs. The pericranium is placed over the anterior skull base defect and is secured on the remaining planum sphenoidale by tucking it under the frontal lobes and dura or by directly securing it

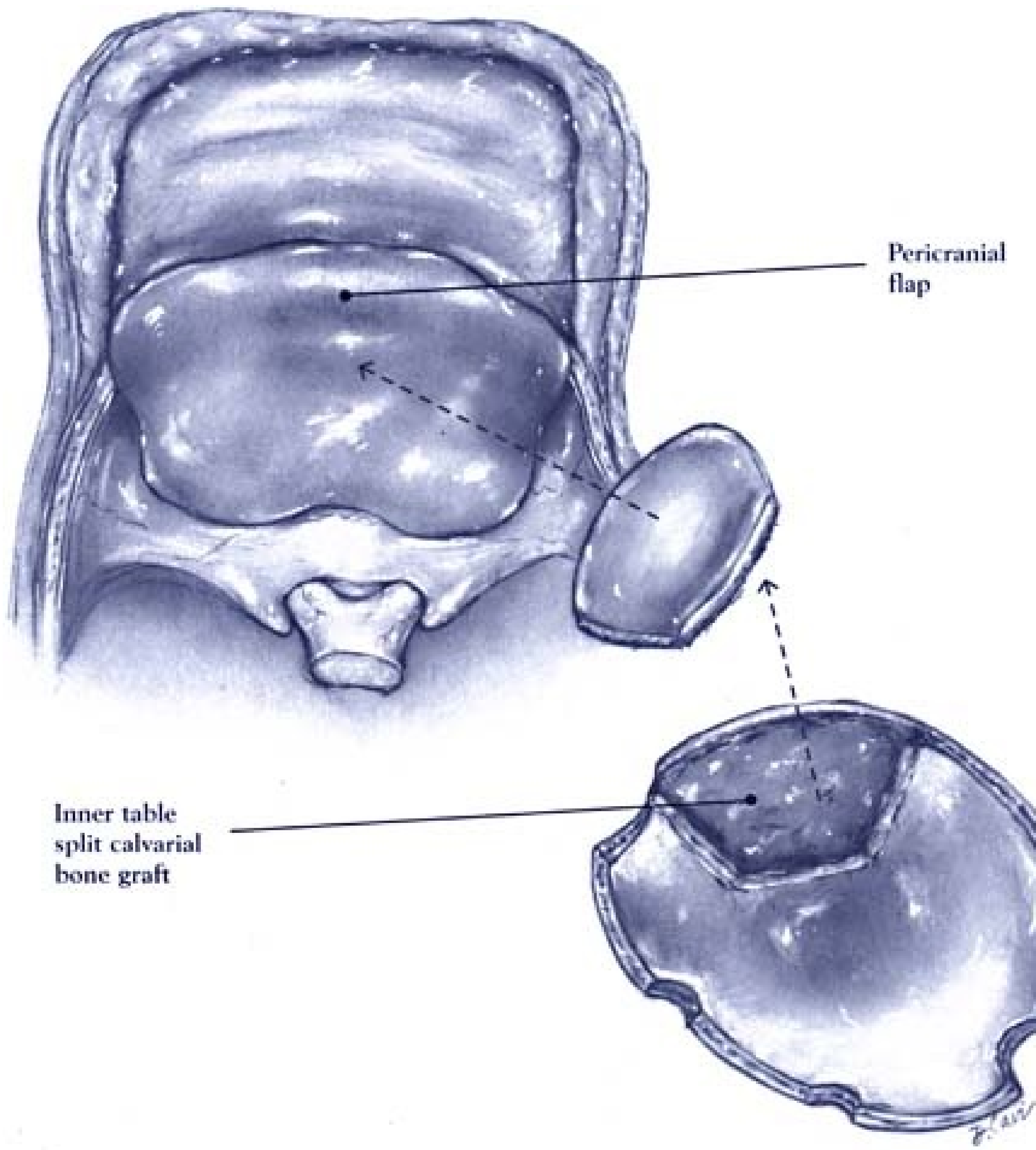


Figure 11

Drawing of split calvarial bone graft harvest and reconstruction of an anterior skull base defect with the lengthy pericranial flap and bone graft

with sutures to bone or basal dura. The split-thickness calvarial bone graft or titanium mesh is then placed between the pericranial flap and the dura to provide rigid support as needed (Figure 11). The pericranial flap also helps to obliterate the frontal sinus which is formally cranialized upon expansion of the frontal lobes. The frontal craniotomy bone flap is then secured with rigid titanium plate and screw fixation, and the scalp and facial skin incisions are closed in an anatomical multilayer fashion.

An important note is that the inferior frontal bone osteotomy should be wide enough so that replacement of the frontal bone flap does not constrict the blood supply to the pericranial flap. To prevent possible epiphora from transection of the nasolacrimal duct, Crawford lacrimal stents may be placed through the superior and inferior lacrimal puncta or a formal dacryo-cystorhinostomy may be performed.

Absorbable gelatin sponge pieces (Gelfoam®, Upjohn, Kalamazoo, MI, USA) may be placed over the visible pericranium exposed to the nasal cavity, and half-inch gauze packing, with or without topical antibiotic ointment (e.g. bacitracin), placed for hemostasis and to eliminate dead space and reduce the risk of postoperative tension pneumocephalus. The packing is removed on postoperative days 3 or 4. A nasogastric tube is placed through one nostril and is removed upon return of normal bowel sounds. A nasal pharyngeal airway stent is usually placed in the opposite nostril to divert air that could be forced intracranially upon extubation or in the postoperative period. The nasal pharyngeal stent is left in place for 5–7 days. Antibiotics are continued until the nasal packing is completely removed. The use of systemic steroids and anticonvulsants is determined by the extent of frontal lobe retraction or resection.

COMPLICATIONS

Intraoperative complications, such as optic nerve injury and retraction injury to the frontal lobes, can be significantly reduced by using wide surgical exposure and strategically designed craniotomy bone cuts that provide direct visualization of anatomical regions of the skull base. In the postoperative period, sudden changes in mental status may indicate intracranial bleeding or tension pneumocephalus (especially when preceded by a sneeze, cough, or valsalva). A CT scan should be obtained immediately to evaluate the etiology of the mental status change, with the choice and urgency of intervention based on CT findings and severity or progression of symptoms. Ocular motility problems are not common, even should the medial periorbita require removal to achieve adequate lateral surgical margins. A small cerebrospinal fluid leak may be present in the first few days postoperatively but usually resolves spontaneously A large or persistent cerebrospinal fluid leak; however; should be investigated and treated accordingly. Placement or use of existing lumbar catheters with spinal fluid drainage is the first line of therapy, and surgical re-exploration is typically reserved for large or persistent leaks.

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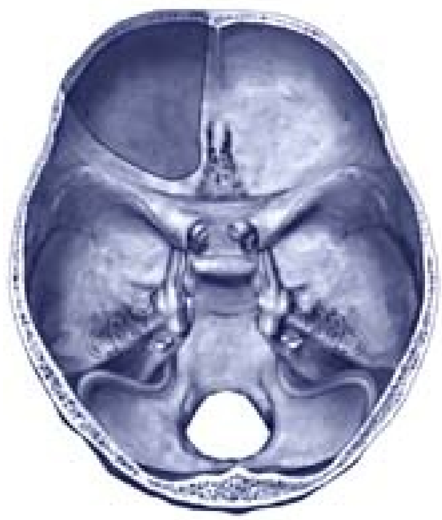
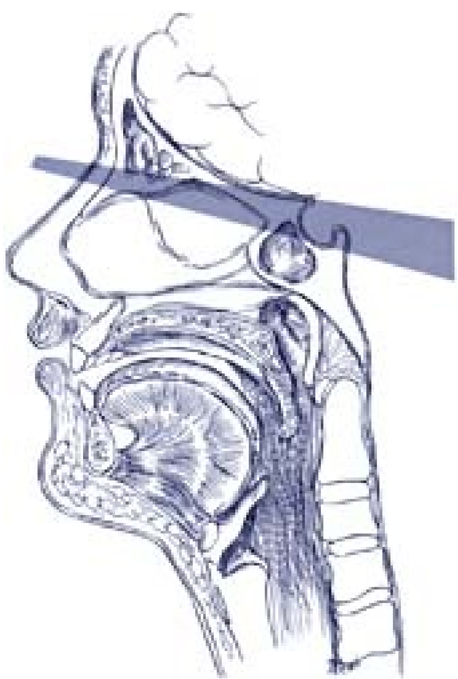
3
Transfacial approach to the infratemporal fossa, nasopharynx and middle cranial fossa

Bert W.O'Malley, Jr





INDICATIONS

The transfacial approach to surgical resection is indicated primarily for both benign and malignant tumors that arise extracranially that extend into or require dissection in the posterior maxillary sinus, infratemporal fossa, nasopharynx, pterygopalatine fossa, lateral sphenoid, clivus, mid-line middle cranial fossa, and the cavernous sinus (Table 1 and Figure 1). The facial translocation approach is one variation of this surgical strategy that involves displacing, but not actually resecting, anatomical segments of the facial skeleton, such as the zygomaticomaxillary complex, to provide wide and direct access to the infratemporal fossa and lateral mid-line skull base. For large tumors that arise in the parapharyngeal space and extend superiorly towards the skull base, a mandibulotomy (mandibular swing) may be included with the facial approach to improve inferior surgical exposure. Transfacial surgical approaches may, in some circumstances, obviate the need for craniotomy, as the excellent exposure of the middle cranial base allows partial craniectomy and resection of tumors extending into the cavernous sinus and anterior temporal lobe and medial sphenoid wing region. The wide surgical field created by this general approach provides direct, three-dimensional access to the region bounded laterally by the ipsilateral infratemporal fossa to the contralateral eustachian tube.

Posterior access includes the clivus, sphenoid sinus, and orbital apex. The transfacial or facial translocation procedure may also be combined with classic lateral infratemporal fossa and intracranial surgical approaches to allow maximal exposure for complete transcranial tumor resection. Upon completing tumor resection, the displaced units of the facial skeleton that are not invaded by tumor may be replaced to reconstruct cosmetic and functional deficits.

PATIENT EVALUATION

As in the majority of cranial base cases, pre-operative imaging is of critical importance. Both computed tomography (CT) and magnetic resonance imaging (MRI) scans are obtained to provide both bony and soft tissue detail which is critical in planning the appropriate surgical resection and in calculating the risks and possible surgical complications. The use of vascular imaging modalities may also be important for tumors that are vascular in origin or that abut or invade the internal carotid artery and cavernous sinus. A more detailed discussion of pre-operative imaging and cerebral blood flow studies is included in Chapter 2.

Table 1 Regions accessible by the transfacial approach

Infratemporal fossa

Nasopharynx

Pterygopalatine fossa

Clivus

Cavernous sinus

Medial orbit, orbital apex and fissures

Anterolateral middle fossa

Upper cervical spine

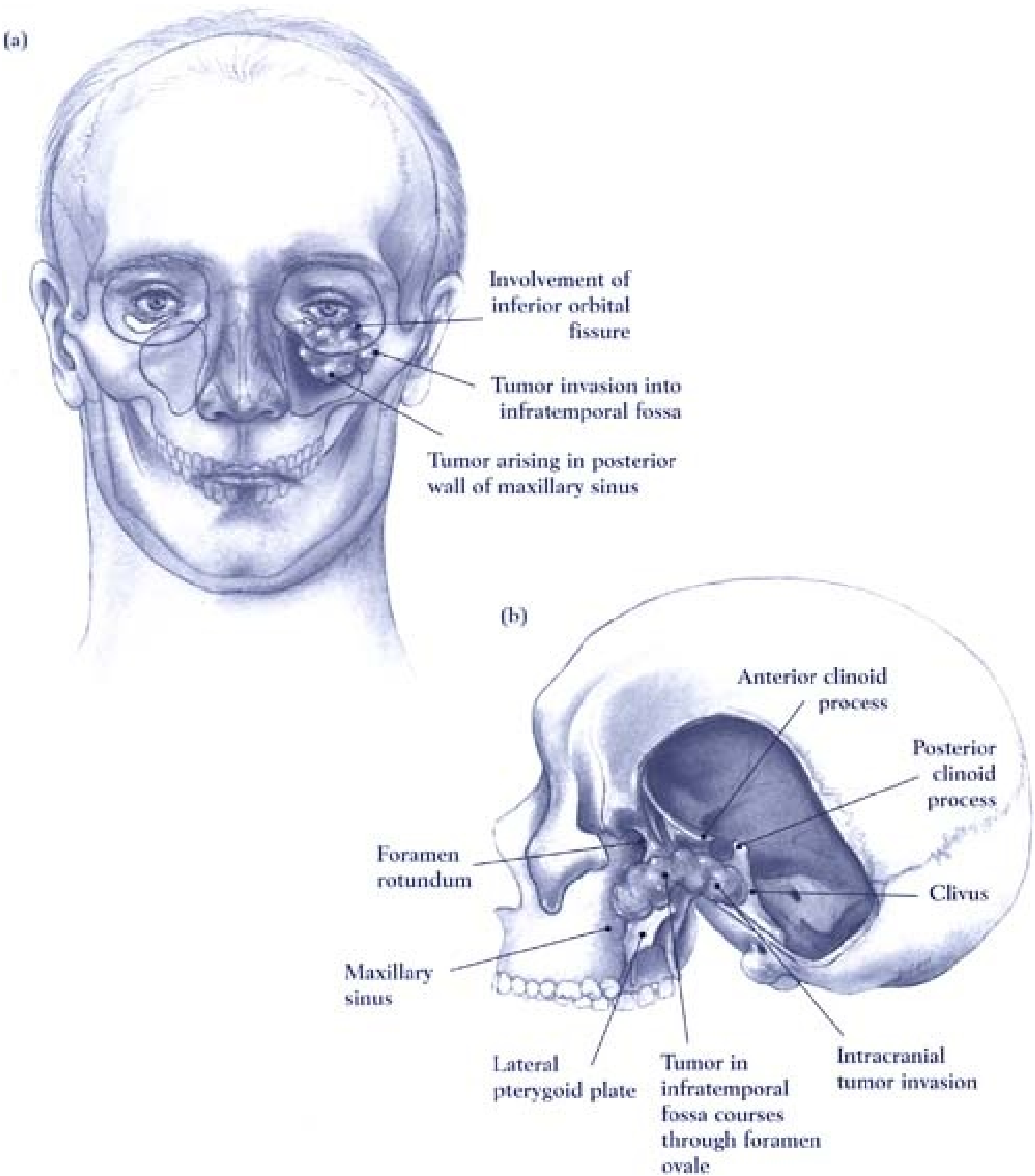


Figure 1

Tumor arising in the posterior maxillary sinus and invading through the infratemporal fossa to the middle cranial fossa. (a) Anterior view depicting the tumor origin; (b) lateral view showing the invasion into the middle cranial fossa and nearby anatomical structures

(a) (b)

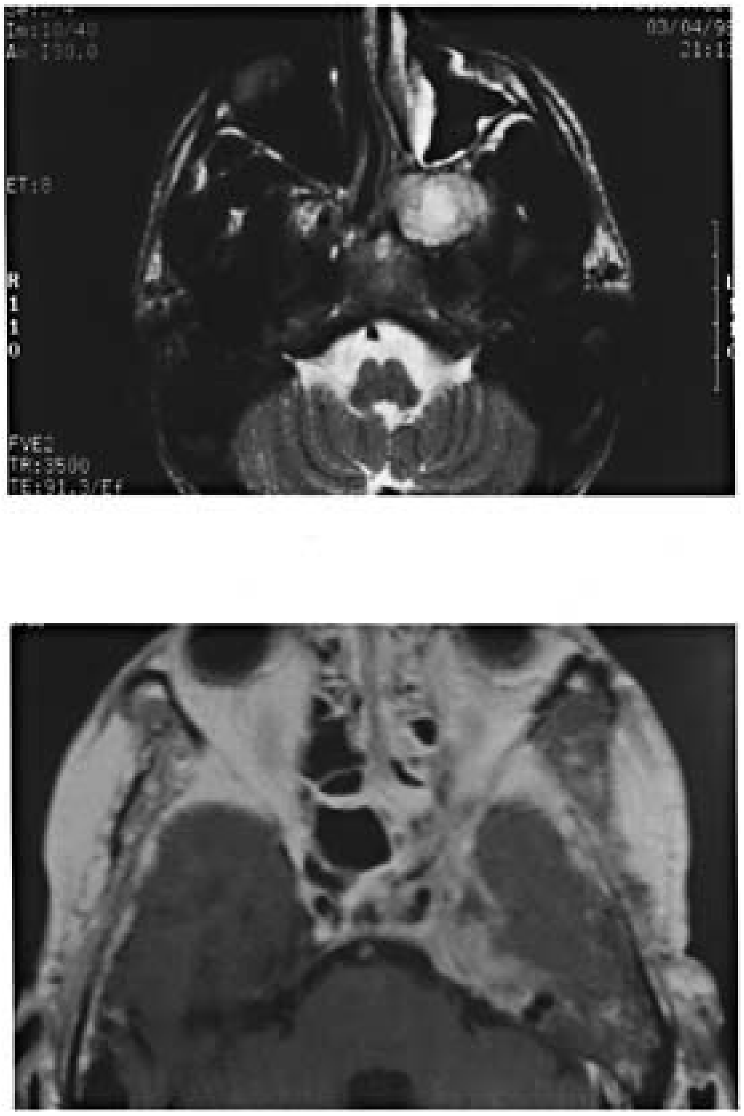


Figure 2

(a) Axial MRI scan depicting a metastatic squamous cell carcinoma of the infratemporal fossa; (b) tumor invasion along the trigeminal nerve into the middle cranial fossa

Transfacial surgical resection may be applied to a great variety of tumor histologies. The precise surgical technique should therefore be individualized. Each case must be considered on an individual basis and the choice or modification of transfacial approach selected accordingly. Examples of malignant tumors that could be candidates for these approaches are squamous cell carcinomas, adenoid cystic carcinomas, or adenocarcinomas that arise in the maxillary or ethmoid sinuses and extend into the infratemporal fossa or spread along the trigeminal nerve into the middle cranial fossa (Figure 2). Nasopharyngeal carcinomas and clival chordomas that extend laterally across the mid-line, or sarcomas of the infratemporal fossa or sphenoid region are also ideal for these approaches (Figure 3). Transcranial orbital apex or sphenoid wing meningiomas, extensive juvenile nasopharyngeal angiofibromas (Figure 4),

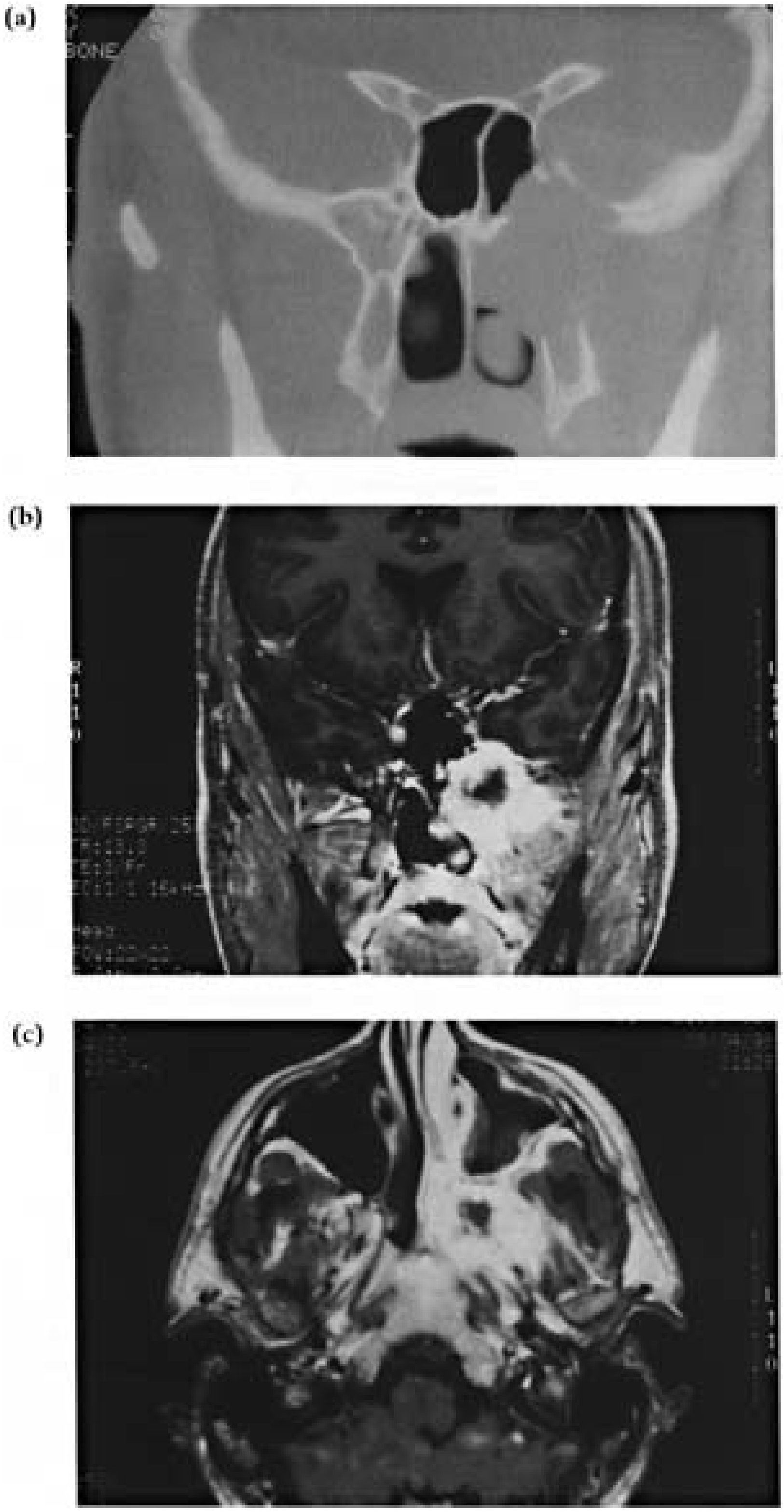


Figure 3

(a) Coronal CT scan of a sarcoma arising in the pterygoid and infratemporal fossa regions with erosion through the bony cranial base; (b, c) coronal and axial MRI scans of the extensive sarcoma

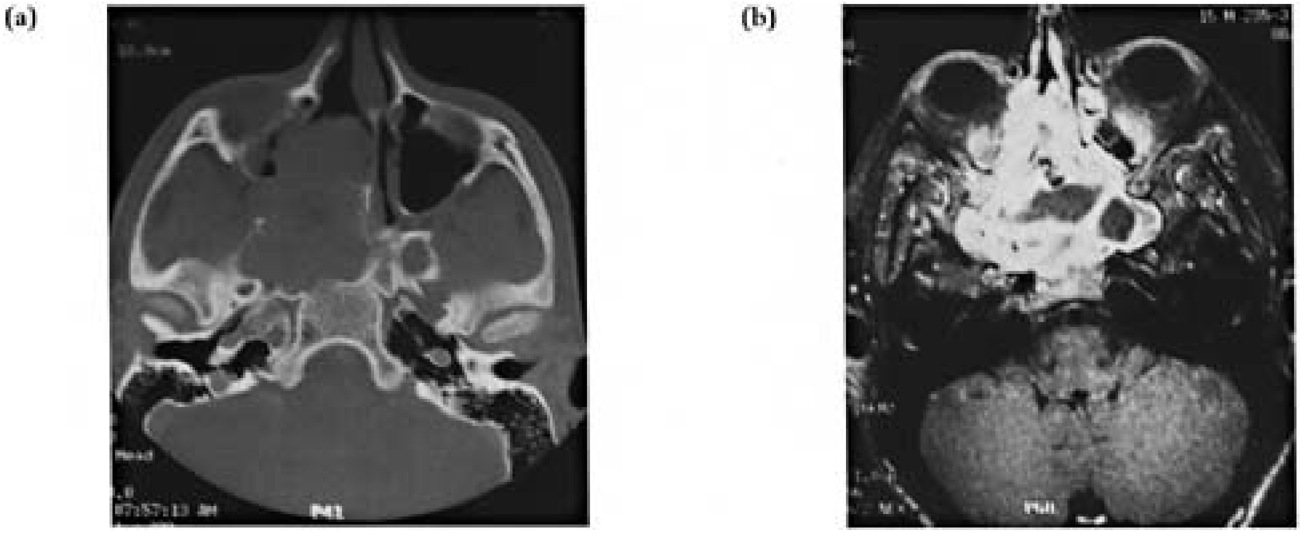


Figure 4

Axial CT (a) and MRI scan (b) of a large angiofibroma

and fifth-nerve schwannomas (Figure 5) are examples of aggressive benign tumors that could be removed transfacially. Large deep-lobe parotid tumors and parapharyngeal space paragangliomas and nerve sheath tumors that extend superiorly to the skull base would be good candidates for a combined facial translocation and mandibular swing approach. Given the broad range of tumor types and the clinical scenario, a thorough understanding of both the tumor histology and the extent of invasion will ensure the appropriate surgical approach and reconstruction, while taking into consideration the need for postoperative adjuvant radiation or chemotherapy.

PROCEDURE

Anesthesia and patient positioning

The patient is placed supine on the operating table and general endotracheal anesthesia is induced, followed by placement of urinary, arterial, and central venous catheters as needed. Automatic compression stockings are used as is the case for all patients undergoing lengthy skull base procedures. For the transfacial approach, patient head mobility is important for the various surgical steps and angles of skull base exposure. It is therefore recommended that the patient's head rest freely in a horseshoe headrest and not be fixed with Mayfield pins. Because of the need or desire to rotate or move the patient's head throughout the procedure, the endotracheal tube may be further stabilized by wiring it circumferentially to the teeth on the side opposite to the surgical approach. A circummandibular wire may also be placed to stabilize the endotracheal tube in the case of poor or absent dentition. When a combined intracranial approach is planned, neurophysiological monitoring (i.e. for somatosensory potentials) is arranged pre-operatively and scalp leads are affixed at the time of surgery outside the planned sterile area.

Facial incisions

The medial incision used for the transfacial approach is a variation of the classic lateral rhinotomy or Weber-Ferguson incision which is placed at the junction of the nose and cheek. The transfacial incision scar is more cosmetically acceptable as it resides along the aesthetic units of the nose and face. The incision is begun in the medial canthal region with a 'W' plasty centered apically at the medial canthus

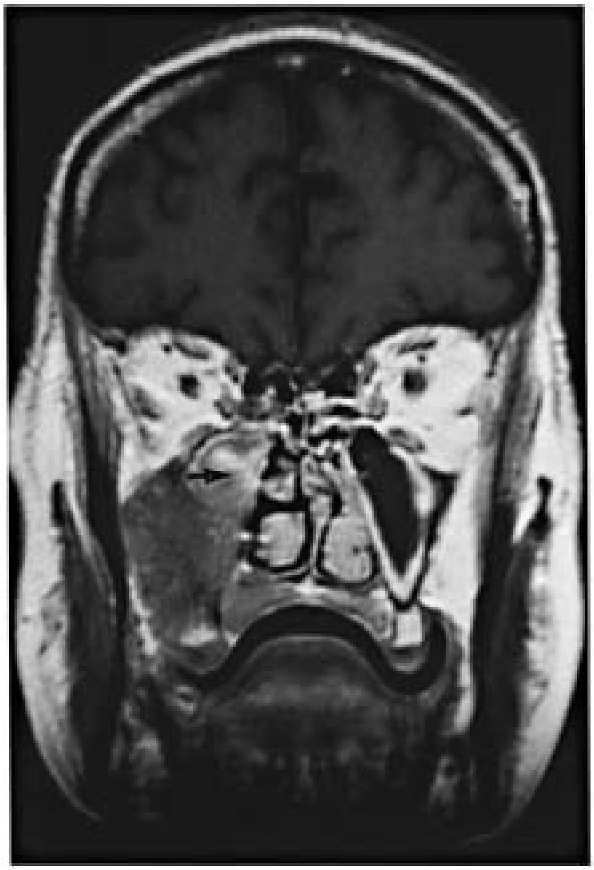


Figure 5

Coronal MRI scan of a fifth nerve schwannoma arising in the infratemporal fossa

(Figure 6a). The incision is placed approximately half-way between the nasal labial region and the nasal dorsum along a line that is part of the aesthetic unit of the nose and then curved inferiorly along the nasal ala. To break up the scar line along the ala, the incision can be carried a few millimeters into the nasal vestibule and then out along the ridge of the nasal philtrum and through the lip. A small triangular incision with the apex at the cutaneo-vermillion junction or 'white line' border of the lip is made to facilitate reapposition of this important aesthetic landmark and to improve the overall cosmetic result of this approach (Figure 6a).

A transconjunctival incision is performed posterior to the tarsus in the inferior fornix with transection of the medial and lateral canthal tendons (Figure 6b). The canthal tendons are marked with a silk or nylon suture on the skin flap and the bony site of attachment in the nasolacrimal crest can be marked with a bovie or small drill hole. Attention to the need for re-establishing an anatomic medial canthal position will maintain normal intercanthal distance and maintain important cosmesis. Suture reapproximation of the lateral canthus will reduce the incidence of postoperative lower lid retraction or ectropion. The facial incision is then carried through the lateral limit of the orbicularis oris. Stopping the incision at this lateral border provides maximal exposure while preserving the frontal branches of the facial nerve. Elevation of the anterior facial flap (Figure 7) is performed at the level of the maxillary periosteum and the infraorbital nerve is transected and marked with 6–0 nylon for reapproximation (if not involved with the tumor) at the completion of the case.

A coronal incision is then made and the temporalis muscle is exposed. A scalp flap in the temporal region is raised at the level of the superficial layer of the deep temporal fascia until the temporal fat pad is encountered. Upon identification of the temporal fat pad, the temporal fascia is sharply incised

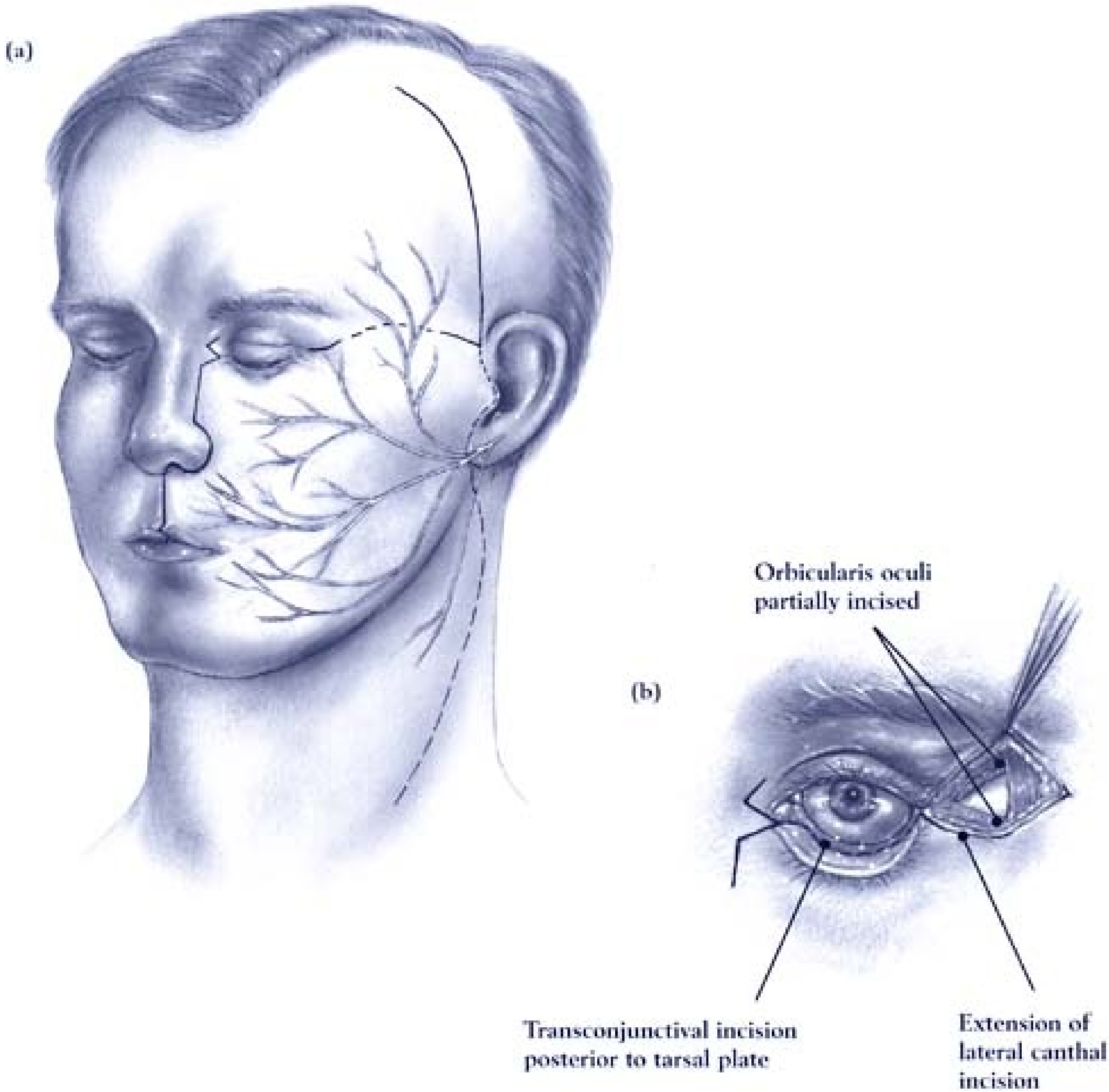


Figure 6

(a) Facial incisions for the transfacial approach. Dotted lines represent options for extensions of the incisions as needed; (b) periorbital and transconjunctival incisions made in the left eye

and the dissection proceeds within the fat pad to the zygomatic arch inferiorly and the lateral orbital rim medially. This dissection in the temporal fat pad assures protection and preservation of the frontal branches of the facial nerve. The zygomatic arch is exposed in a subperiosteal plane which connects medially to the anterior facial dissection at the malar eminence (Figure 7). Soft tissue elevation inferior to the zygomatic arch is performed under the level of the masseteric fascia in order to protect the zygomatic and buccal branches of the facial nerve. Once the facial and temporal skin and soft tissue flaps are raised, there remains a 3–4-cm bridge of skin and subcutaneous tissue through

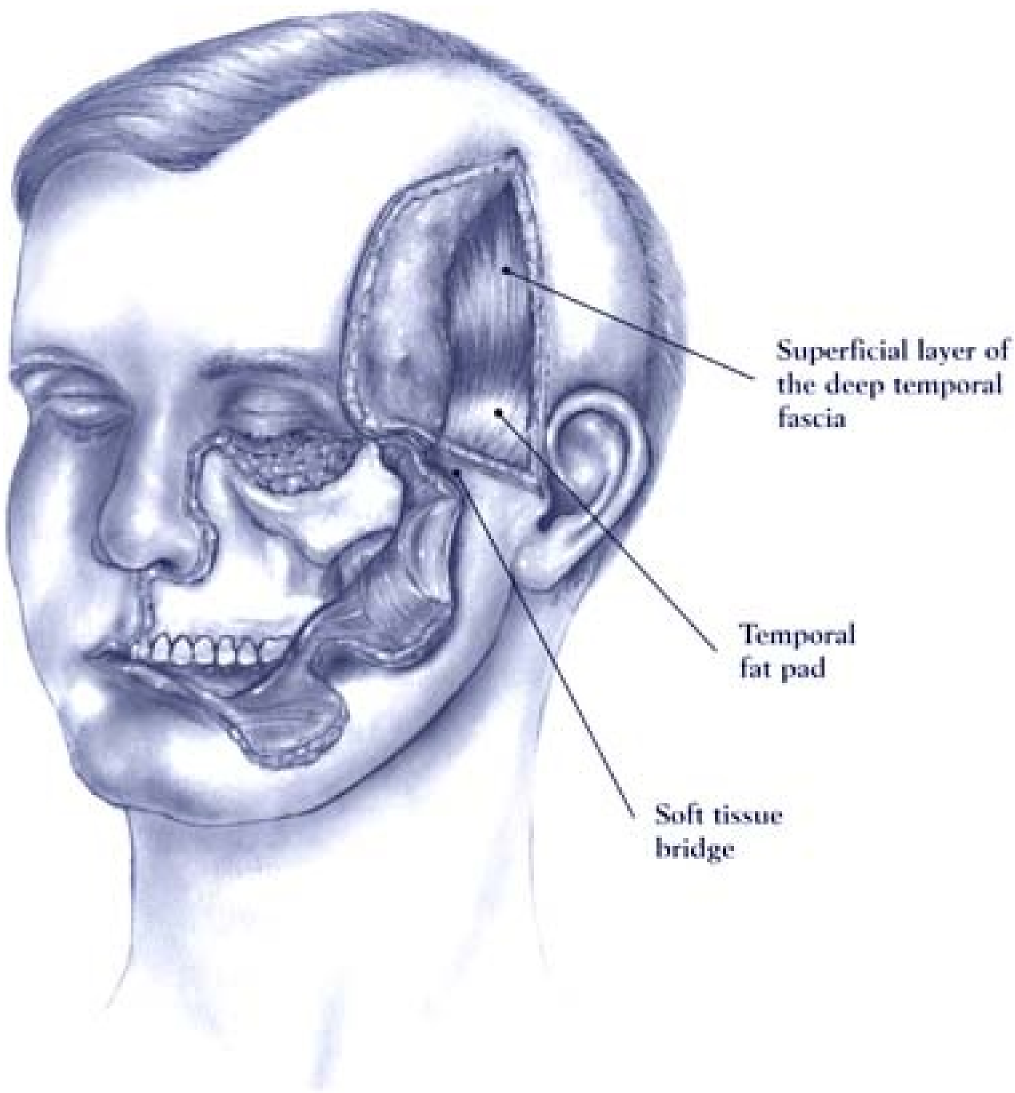


Figure 7

Exposure of the zygomaticomaxillary complex and temporalis muscle. The frontal branches of the facial nerve are preserved and protected in a soft tissue and skin bridge overlying the zygomatic arch

which course the frontal branches of the facial nerve. This tissue bridge protects the frontal branches of the facial nerve from transection or stretch injury.

For maximal possible exposure to the infratemporal fossa and middle skull base, the facial incision can be extended across the zygomatic arch to connect to the coronal incision (Figure 8). The facial and temporal skin and subcutaneous flaps will then retract widely and be easily secured outside the direct operative field, as if opening a book for viewing.

In order to achieve this exposure, the soft tissue bridge must be incised and the frontal branches of the facial nerve will be transected. Prior to cutting these four to six branches above the zygomatic arch; each branch is identified under loupe or microscope magnification and tagged with 7–0 nylon and a small piece of soft silastic tubing. The silastic tubing is then sharply cut in the middle to not only mark the branches but to allow for suture reapproximation at the end of the case (Figure 8). Although the frontal branches of the facial nerve will take 6–9 months to fully recover function, the

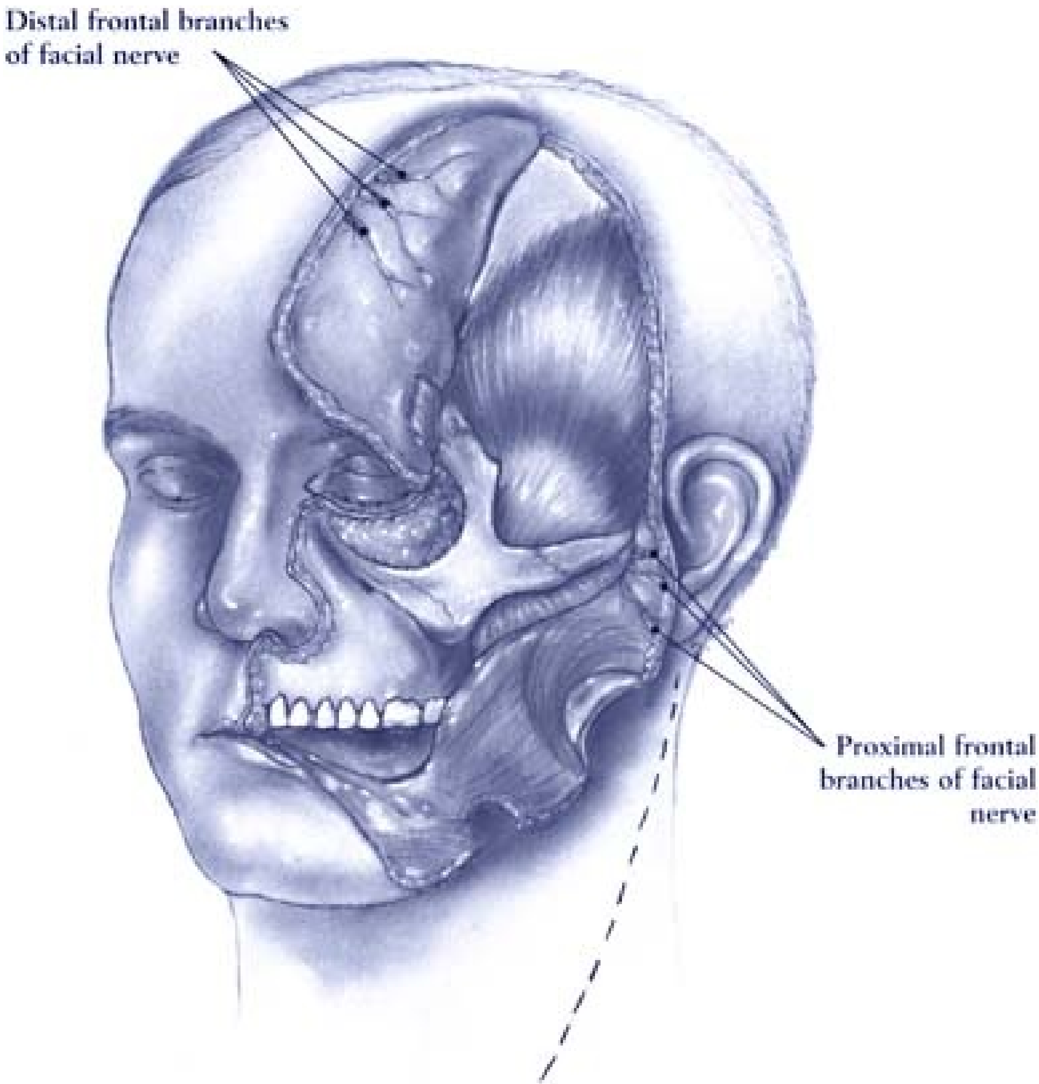


Figure 8

Extension of facial incision for maximal exposure. The frontal branches of the facial nerve are marked with suture and secured in silastic tubing to assist in reapproximation at the time of wound closure

zygomatic branches to the orbicularis oculi are preserved. Avoiding injury to the zygomatic branches will maintain innervation to the orbicularis oculi and provide adequate eye closure and protection until the frontal branches reinnervate.

Bony osteotomies
Upon raising the soft tissue flaps and exposing the underlying bony skeleton, a series of osteotomies is performed to mobilize an intact unit comprised of the zygoma and the supra-alveolar maxilla, including the orbital floor. This unit can be removed totally or in part if it is invaded by tumor. Figure 9 depicts the sites for anterior and lateral osteotomies to mobilize this orbitozygomaticomaxillary unit. The osteotomies are performed in a controlled fashion under direct vision using a reciprocating saw for the majority of cuts. Orbital soft tissue dissection is performed in the subperiosteal or subperiorbital plane to provide bony exposure, while protecting and avoiding injury to extraocular muscles and nerves, globe, and optic nerve and

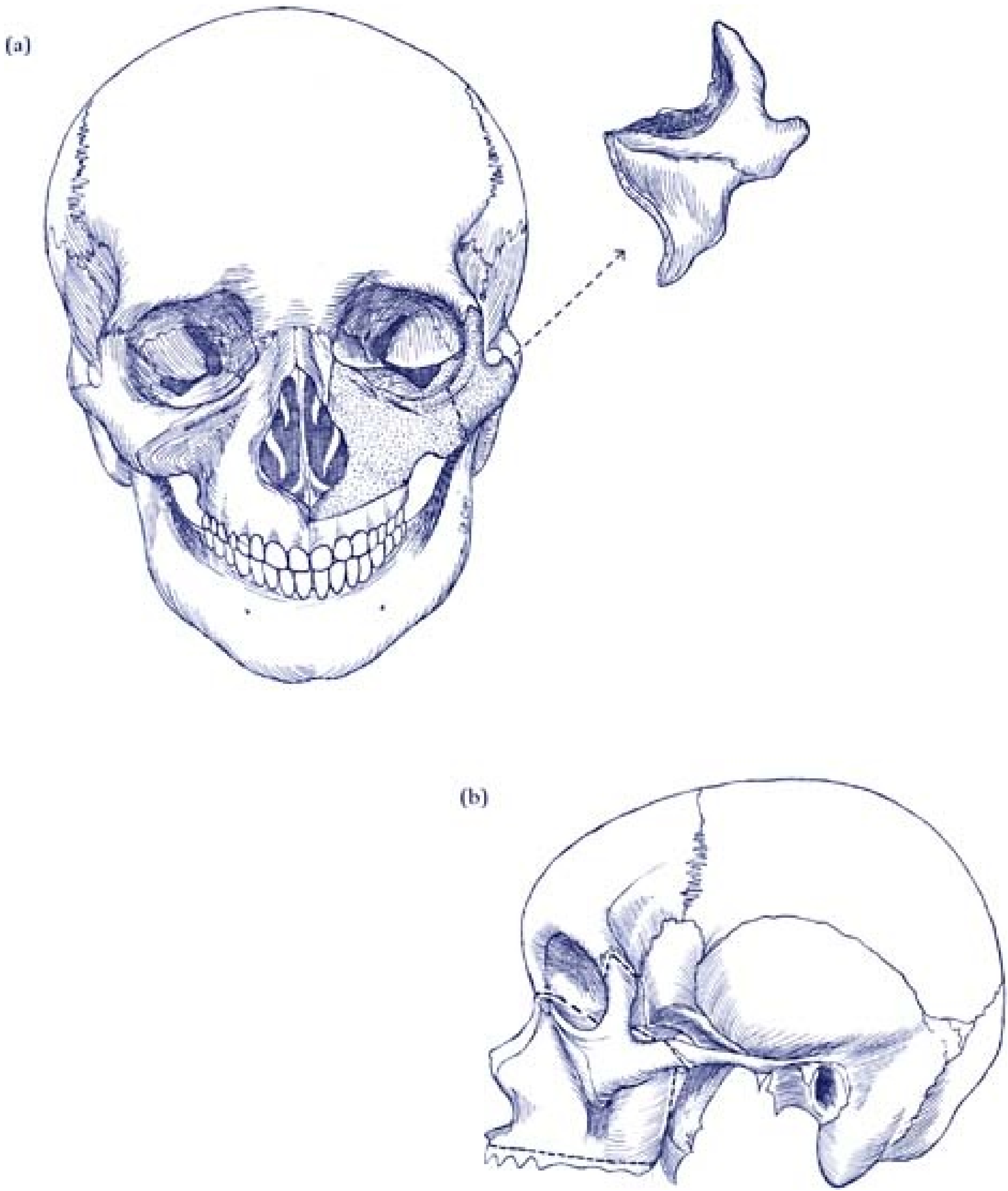


Figure 9

(a) Solid lines surrounding the shaded section indicate the placement of osteotomies to mobilize the zygomaticomaxillary complex. The dotted line at the junction of the maxilla and zygoma represents an optional osteotomy to limit the extent of bony complex mobilization or resection; (b) lateral view of standard osteotomies (dotted lines)

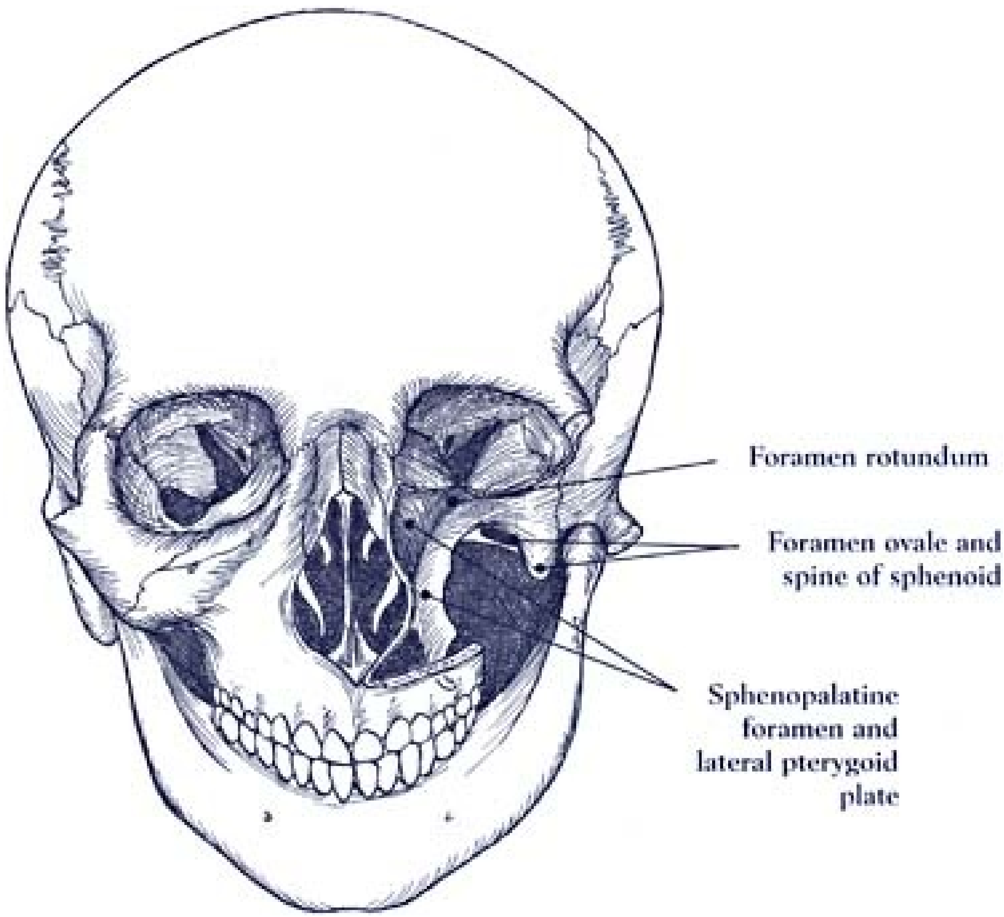


Figure 10

Anterior view of the bony anatomy that is exposed after removal of the zygomaticomaxillary complex vessels. There are two intraorbital osteotomies. The first originates from the posterior aspect of the inferior orbital fissure and extends laterally to include the extracranial component of the lateral orbital wall. The zygomaticofrontal suture line marks the superior limit for this first osteotomy. The remaining orbital osteotomy is along the posterior bony floor and extends to the lacrimal crest or lateral ethmoid region as needed. This bone cut is made with an oscillating saw with a short right-angle blade or curved osteotomes. A Lefort I and nasomaxillary osteotomy are then performed and the zygomatic arch is divided along the zygomaticotemporal suture line. A posterior lateral osteotomy is then made with the reciprocating saw along the pterygomaxillary suture line to complete the mobilization or resection, if needed, of the intact orbitozygomaticomaxillary unit. Upon removing this bony unit and then removing the posterior maxillary sinus, the pterygoid plates, posterior orbit, nasopharynx, and infratemporal fossa are visible and widely accessible (Figure 10). For extensive tumors that involve the floor of the maxillary sinus and bony palate, the Lefort I osteotomy is not performed, but instead osteotomies are made in the hard palate to the extent needed to encompass the tumor. These palatal bone cuts allow for an en bloc removal of the maxilla and/or zygoma as a surgical specimen. When the orbitozygomaticomaxillary complex cannot be saved, a more extensive reconstruction is required to rebuild the orbital floor and anterior maxilla defect.

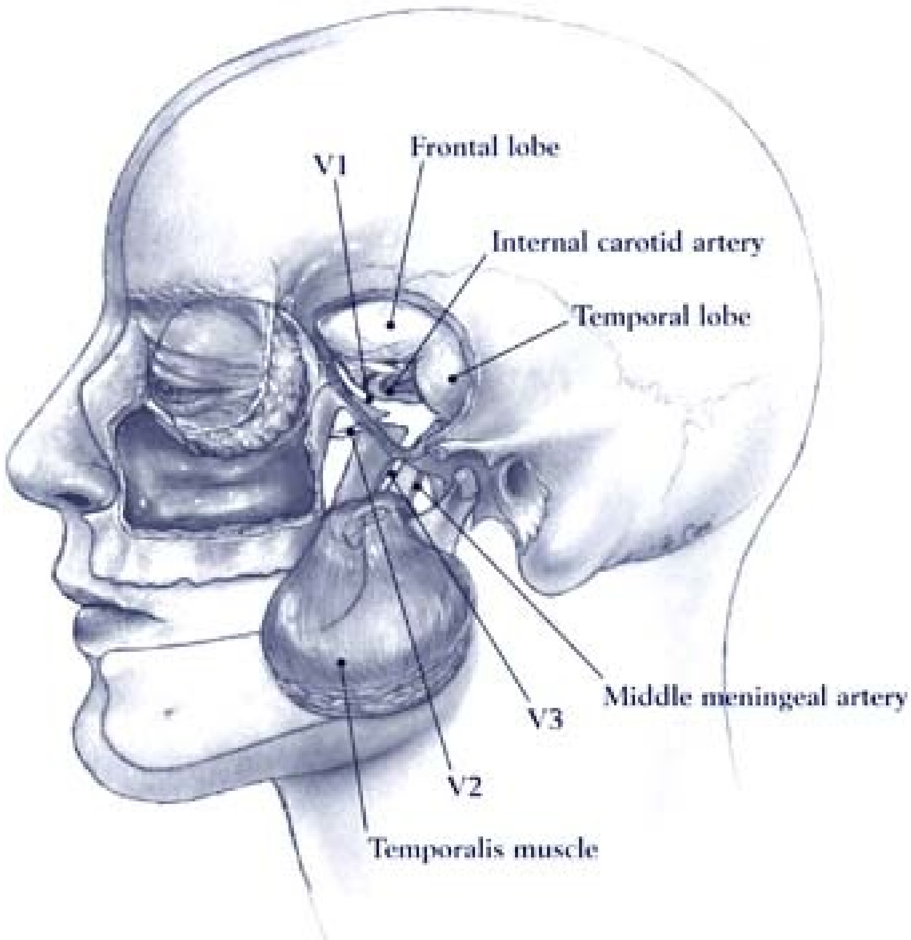


Figure 11

Anatomical relationships within the infratemporal fossa and view of the junction of the middle and anterior cranial fossa after craniectomy

Temporal and infratemporal fossa exposure

In order to gain access to the infratemporal fossa, the temporalis muscle is detached with bovie electrocautery or sharp dissection from the squamous temporal bone. The temporalis muscle is then rotated inferiorly while maintaining its attachment to the coronoid process of the mandible (Figure 11). Although the superficial temporal artery and middle temporal vessels will most likely be severed, the temporalis muscle will maintain its vascularity via the deep temporal artery, which arises from the internal maxillary artery medial to the mandibular notch. For increased exposure in the infratemporal fossa, the coronoid process may be cut to improve the inferior rotation of the temporalis muscle. Excellent access to the infratemporal fossa is now achieved and the lateral pterygoid muscle may be detached from its bony skull base attachment or resected as needed. Wide exposure of the frontal, lateral temporal, and infratemporal skull base allows for craniotomy or craniectomy as needed for tumor resection (Figure 11).

As each skull base tumor is different, the extent of exposure and tumor resection using the transfacial approach will vary for each individual case. If the tumor involves the nasopharynx, clivus, or sphenoid sinus, the pterygoid plates are removed and the ethmoid sinuses and posterior nasal

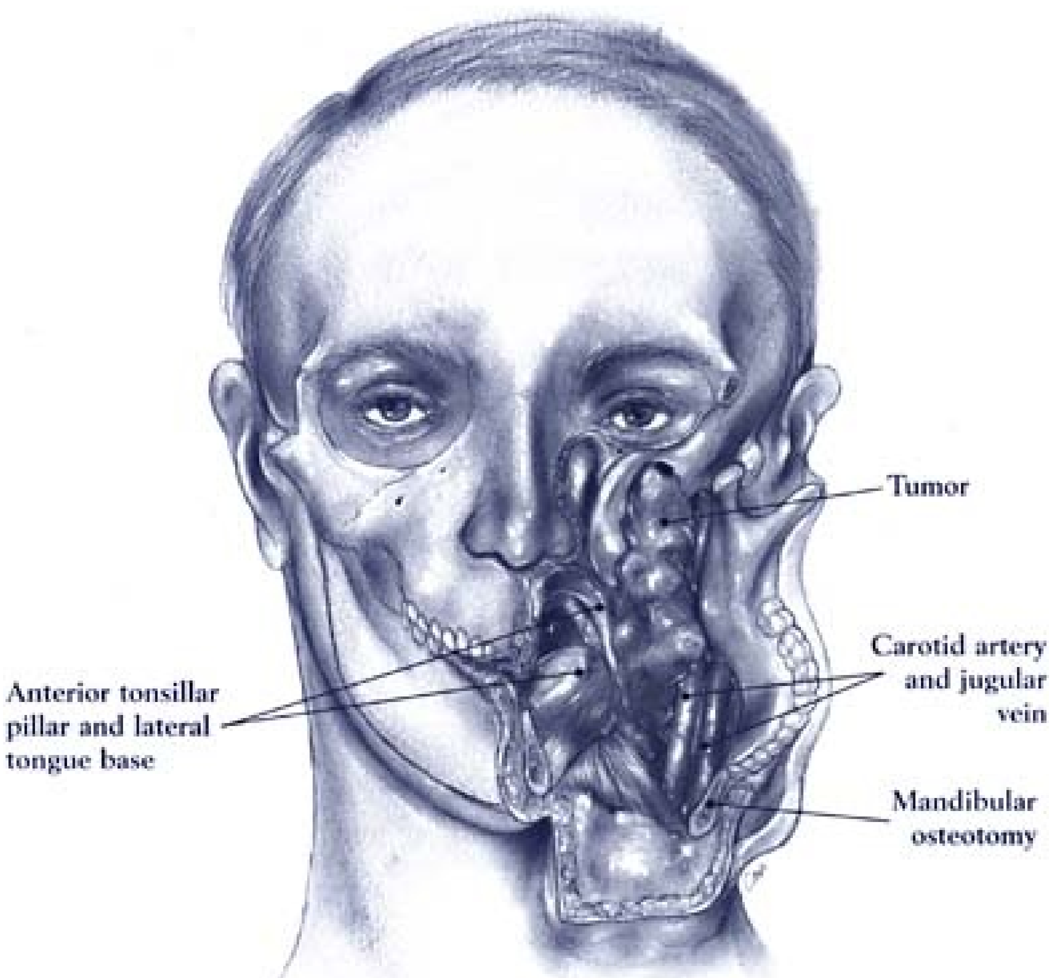


Figure 12

Mandibulotomy and lateral swing provide increased exposure for resection of tumors extending into the parapharyngeal space. Neck incision and dissection provide access to the carotid artery and jugular vein

septum may be resected to improve access to these regions. The pterygoid plates and muscles may be resected for tumors that invade the infratemporal fossa and eustachian tube. For tumors such as adenoid cystic carcinoma and squamous cell carcinoma which may track proximally along the Vth nerve, the foramen ovale and rotundum are exposed and made easily accessible with this approach (Figure 11). If the tumor follows the Vth nerve intracranially, or invades into or through the middle cranial fossa, anterior temporal lobe, or cavernous sinus, a subtemporal craniectomy alone or combined with formal craniotomy may be performed to gain access to these regions and critical structures. The transfacial approach also provides exposure to the inferior orbit, orbital apex, and lateral sphenoid wing for resection of tumors involving these regions.

For infratemporal fossa tumors that invade inferiorly and large deep-lobe parotid or parapharyngeal space tumors that extend superiorly to the skull base, the transfacial approach may be combined with a mandibulotomy and mandibular swing procedure. The mandibular swing procedure greatly increases inferior exposure and allows for dissection and control of the carotid artery and jugular vein (Figure 12).

General reconstruction of surgical defects

The reconstruction effort and procedures will also vary depending on the extent of approach and bony skeleton and tumor resection. The temporalis muscle is used frequently as a pedicled vascularized muscle flap to cover exposed dura or dural graft and separate the middle cranial fossa from the infratemporal fossa, nasal cavity and remaining paranasal sinuses (Figure 13a). The temporalis muscle can also be rotated to cover exposed carotid artery and bony middle skull base after infratemporal fossa dissection and tumor resection without accompanying craniectomy. Depending on the extent of surgical resection and craniectomy it is often possible to perform a split temporalis muscle graft which minimizes the cosmetic defect of soft tissue depression in the temporalis muscle fossa (Figure 13b). When the orbitozygomaticomaxillary bone unit is preserved, it is then reattached to the bony skeleton using rigid titanium plates and screw fixation techniques (Figure 14). Depending on the extent of orbital floor resection or bony maxilla resection for complete tumor removal, the replaced bony unit may be augmented with titanium mesh or free bone grafts.

When tumor resection mandates superior or total maxillectomy, the temporalis muscle flap may be used along with titanium mesh or free bone grafts for reconstruction of the inferior orbit and anterior maxilla (Figure 15). When using titanium mesh for this reconstruction procedure, a sterile skull is used intraoperatively to mold the mesh into a general template of the bony orbital, zygomatic, and maxillary bony defects. The pedicled temporalis muscle is then rotated medially to resurface the exposed titanium mesh or the orbital floor, and the remaining muscle and fascia, when preserved, may be rotated anteriorly to provide a vascular layer between the mesh and the overlying skin and subcutaneous tissue (Figure 16). This last step in anterior maxilla reconstruction is even more important to prevent facial skin breakdown and implant exposure in patients who have undergone or are expecting to receive radiation therapy.

For large malignant tumors of the maxillary sinus and infratemporal fossa, a radical maxillectomy is often required, with or without orbital exenteration. For these large surgical defects, a variety of reconstruction options are possible. The infratemporal fossa and exposed skull base or intracranial contents may be reconstructed and separated from the oral cavity and paranasal sinuses using the vascularized temporalis muscle and/or pericranial flap. The remaining maxillary and palatal defect may be reconstructed with a skin graft and prosthesis or a microvascular free tissue transfer procedure, using rectus abdominus or latissimus dorsi muscles. In cases where microvascular free tissue transfer is contraindicated or not feasible; a pectoralis of superior-based trapezius muscle or a myocutaneous flap may be used as alternatives. Pedicled trapezius or pectoralis muscle flaps have significant limitations when applied to skull base reconstruction, as these flaps are restricted in their superior and anterior rotation by tethering from the pedicle. These flaps also have a greater tendency to pull away from the skull base because of the constant gravitational pull from the soft tissue that surrounds the pedicle. In the majority of extensive surgical cases where brain, dura, or carotid artery are exposed, microsurgical free tissue transfer may prove the most effective means of wound reconstruction while reducing the risk of postoperative complications.

Other considerations in reconstruction

Lacrimal apparatus

As the lacrimal drainage system is disrupted as a result of this surgical approach and procedure, it is important to stent the nasolacrimal duct at the time of reconstruction and wound closure. The superior and inferior lacrimal puncta are identified, a series of dilators are inserted to increase the opening temporarily, and silicone stents are placed through both canaliculi and lacrimal sac. The two ends of the stents are tied in the nasal cavity and should remain in place for at least 6 weeks. Removal is performed in the clinic setting under direct vision using a nasal endoscope.

Infraorbital nerve
The infraorbital nerve is transected in all transfacial approaches and may be reapproximated to maintain sensory innervation to the upper lip and cheek at the end of the case. Preservation of the infraorbital nerve may be possible in many benign lesions of the infratemporal fossa and skull base, but careful consideration should be given in cases of malignancy as tumors such as adenoid cystic carcinoma and squamous cell carcinoma have a propensity to travel within the nerve sheath. Resection of this nerve with frozen section

(a)

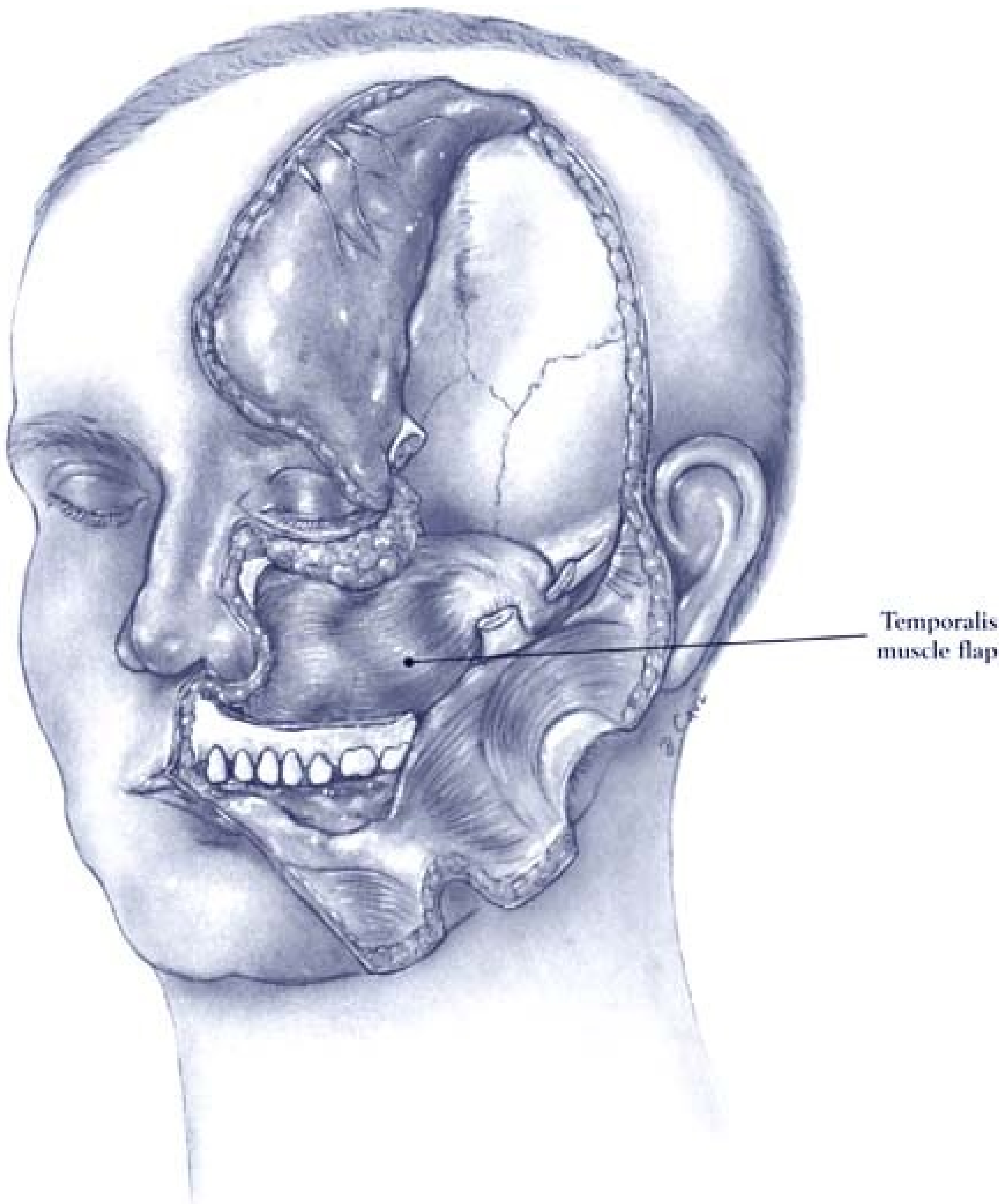


Figure 13

(a) Skull base reconstruction with full temporalis muscle flap; (b) optional split temporalis muscle flap for smaller skull base defects *(see opposite page)*

(b)

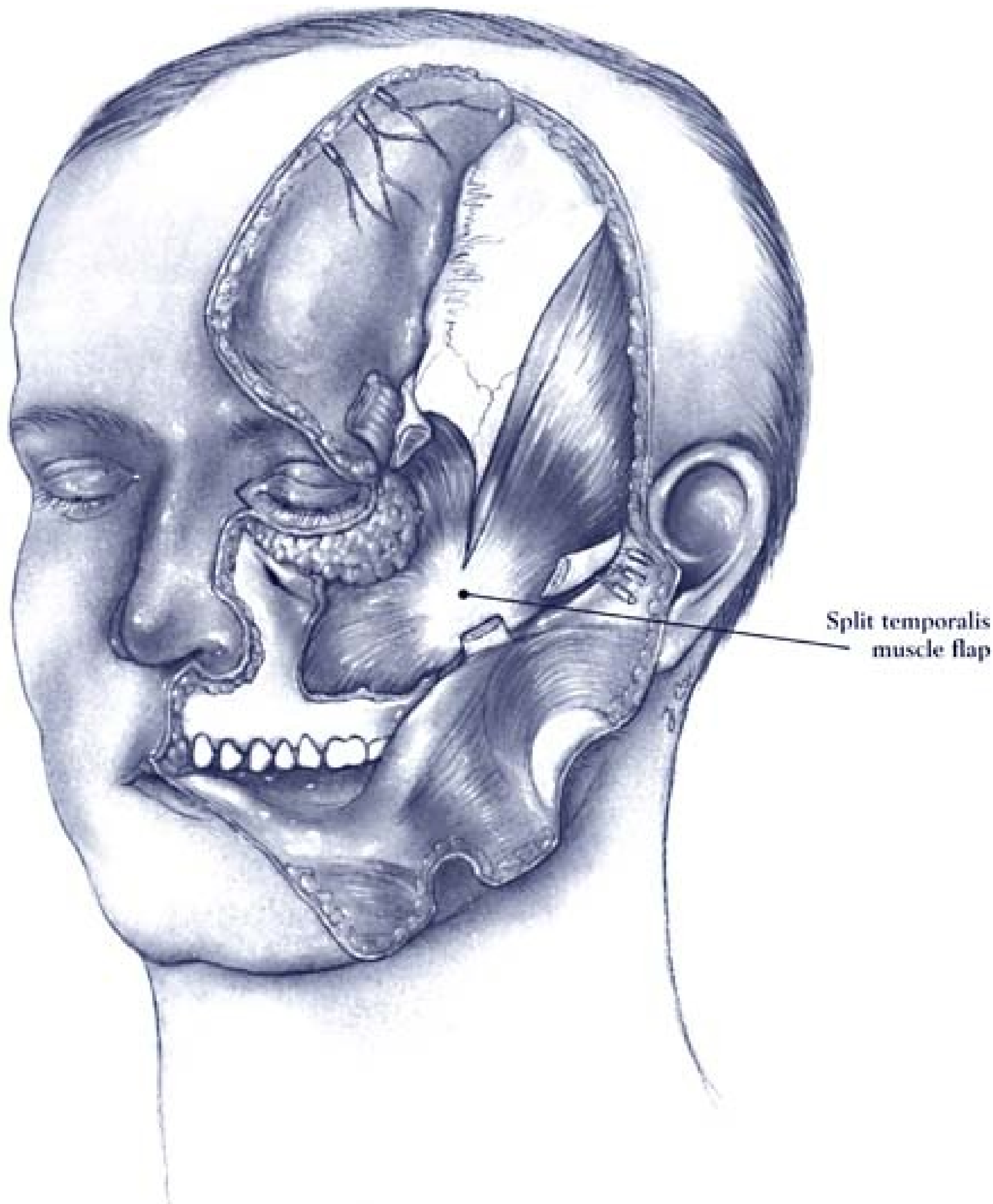


Figure 14

Replacement of zygomaticomaxillary complex and rigid fixation

Figure 15

Titanium mesh reconstruction of the skull base, orbit, maxilla and zygoma

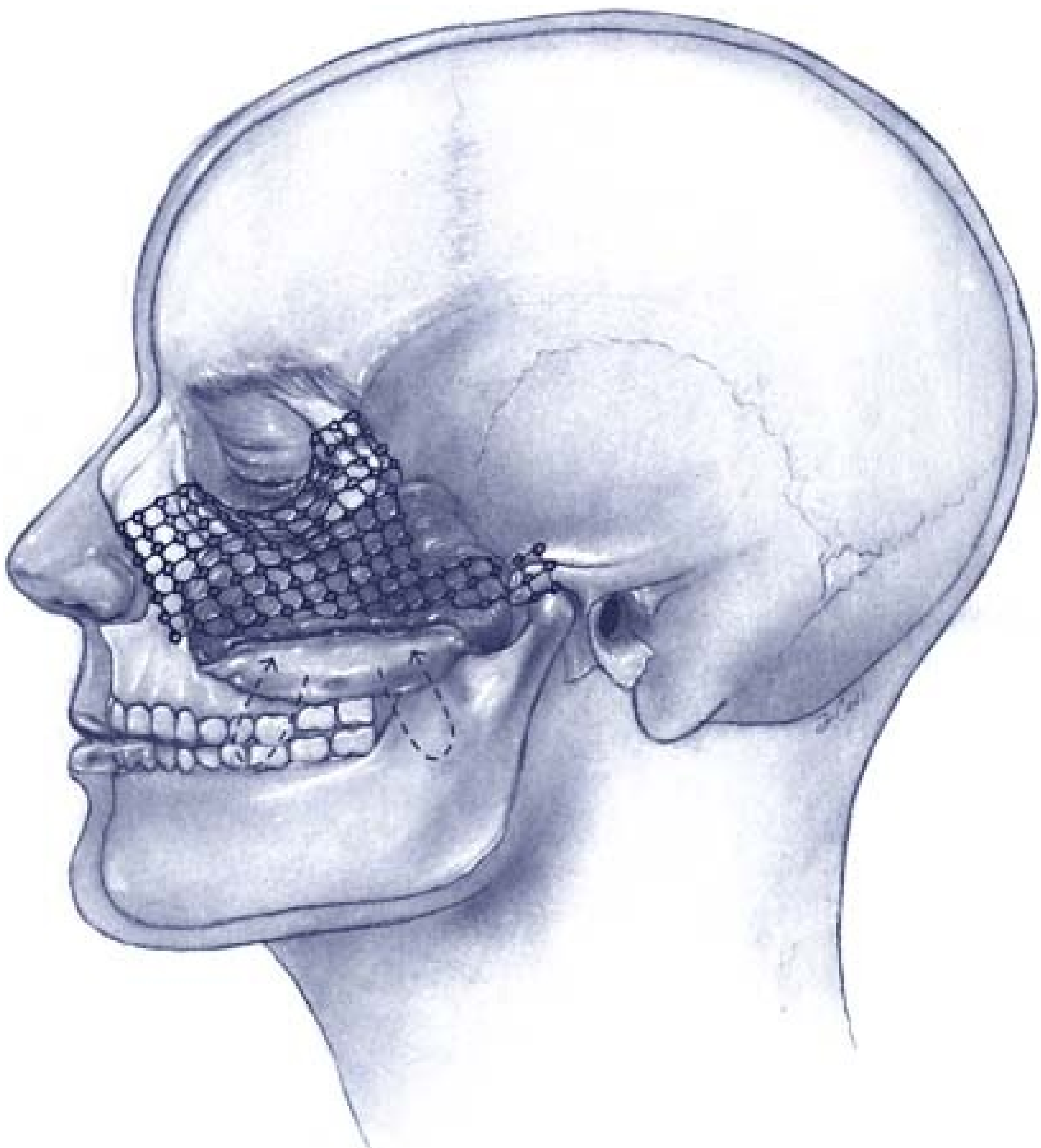


Figure 16

Temporalis muscle flap placed deep to the titanium mesh. The arrows represent the rotation of the temporalis muscle and fascia anterior to the mesh which provides a vascularized layer between the titanium mesh and soft tissue and skin flaps biopsy up to the foramen rotundum or the proximal may be important in both adequate cancer resection and planning for postoperative routine or stereotactic radiation.

Temporal fossa depression
When a temporalis muscle flap is used for reconstruction, a substantial contour defect may be present in the temporal fossa. This visible depression may be addressed with synthetic implants or hydroxyapatite bone cement reconstruction after full postoperative recovery and/or upon completion of radiation therapy.

COMPLICATIONS

Airway compromise is fortunately uncommon following surgical resection through the transfacial approach. However, in cases where mandibulotomy is performed and accompanying incisions in the floor of mouth are made to gain exposure to the parapharyngeal space, a tracheostomy is warranted. Otherwise, a soft nasopharyngeal trumpet may be placed for 4–5 days postoperatively to maintain the nasal airway, which may be compromised from palatal edema or from the bulk of the temporalis muscle flap when used to reconstruct the orbit and maxilla defects.

As in most cranial base procedures, sudden changes in mental status in the postoperative period may herald intracranial bleeding or tension pneumocephalus (especially when preceded by a sneeze, cough, or valsalva maneuver). An immediate CT scan should be obtained and appropriate intervention chosen depending on the etiology and severity or progression of symptoms. Small cerebrospinal fluid leaks may be present in the first few days postoperatively and usually resolve spontaneously. In cases where the cerebrospinal fluid leak persists after the first few days, bed rest and placement of a lumbar catheter with monitored spinal fluid drainage is the first line of therapy. Surgical re-exploration is typically reserved for large leaks or those that are refractory to conservative intervention.

Depending on the extent of intraorbital dissection or tumor resection and the need for extensive reconstruction of the orbit and maxillary defect, early complications may include some degree of ocular dysmotility from direct injury to ocular muscles or nerves or muscular entrapment as a result of the reconstruction procedures. Late orbital complications include enophthalmos or hypoglobus that result from atrophy or resection of orbital fat or inadequate replacement or reconstruction of the orbitozygomaticomaxillary complex.

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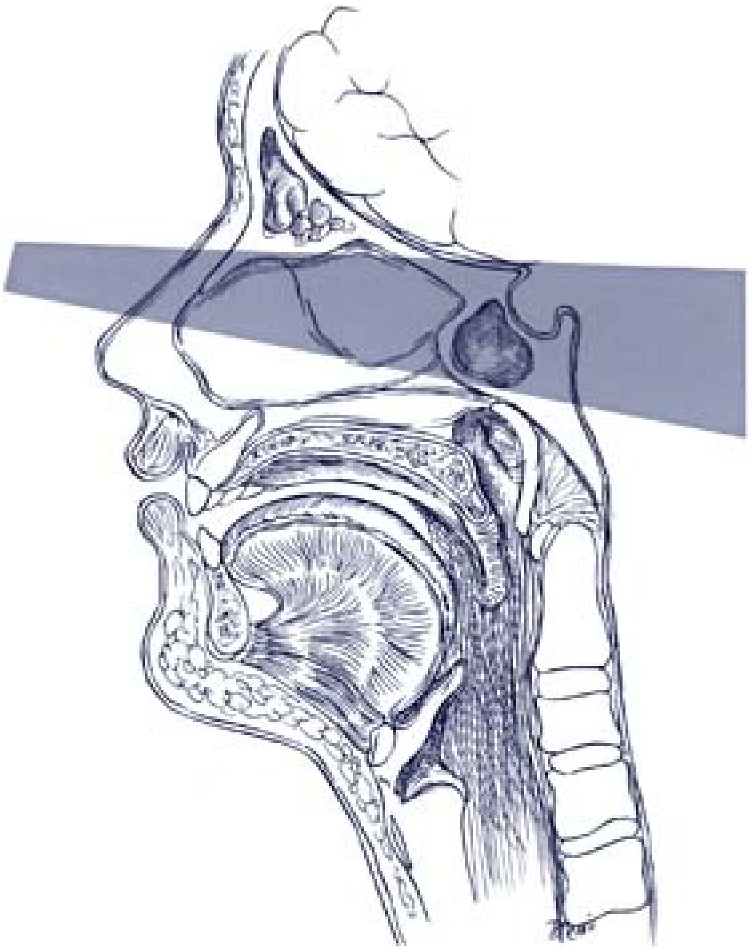
4
Transsphenoidal approach to the mid-line cranial base

Bert W.O'Malley, Jr, John K.Niparko and Michael J.Holliday



INDICATIONS

The transseptal transsphenoidal (simply transsphenoidal) approach to the skull base offers a less invasive alternative to frontal craniotomy for access to mid-line lesions that are based in the sphenoid sinus, upper clivus, sella, and medial parasellar regions (Table 1). The transsphenoidal approach is used principally for adenomas of the pituitary gland, whether hormonally active or non-secreting. For smaller microadenomas confined to the sella, complete removal is typical. For larger lesions that extend beyond the sella; tumor debulking via the transsphenoidal route facilitates decompression of the optic chiasm and restoration of the visual fields, although complete removal is less predictable. Figure 1 depicts the various presentations of pituitary adenomas. Residual tumor may be treated with postoperative adjuvant radiotherapy. Although surgery is the primary modality for both symptomatic and asymptomatic pituitary tumors, prolactinomas may be amenable to an initial trial of medical therapy with dopamine receptor agonists, and growth hormone-secreting tumors may be inhibited with somatostatin analogs.

In addition to pituitary tumors, mucoceles, Rathke's pouch cysts, sphenoid-based meningiomas, craniopharyngiomas, and upper clival tumors can be partially or completely accessed and resected with the exposure provided by this approach. Other less common infiltrative and inflammatory disorders that may involve the pituitary and require surgical biopsy for diagnosis include primary epidermoids, histiocytosis X, sarcoidosis, and granulomatous disorders. Both traumatic and spontaneous cerebrospinal fluid leaks that localize to the sphenoid sinus are also readily accessible via this approach.

PATIENT EVALUATION

All patients should have a thorough physical examination including nasal and sinus examination and an evaluation of cranial nerve function. For pituitary adenomas, visual compromise may occur when the tumor extends above the plane of the diaphragma sellae. Assessment of visual acuity, visual fields, and ocular motility should be routine, with emphasis on detailed examinations in patients with macroadenomas and suprasellar extension. In general, cranial nerves II, III, IV, and VI are not affected until significant parasellar tumor extension occurs. However, acutely expanding or developing lesions, such as hemorrhage within an existing adenoma or infarction (pituitary apoplexy), may also induce palsies of cranial nerves III, IV, and VI and may present as a surgical emergency Slowly expanding tumors or acute changes secondary to intra-tumor

Table 1 Regions accessible by the transseptal transsphenoidal approach

Sphenoid sinus
Pituitary fossa
Upper clivus
Middle clivus
Medial parasella
Suprasella

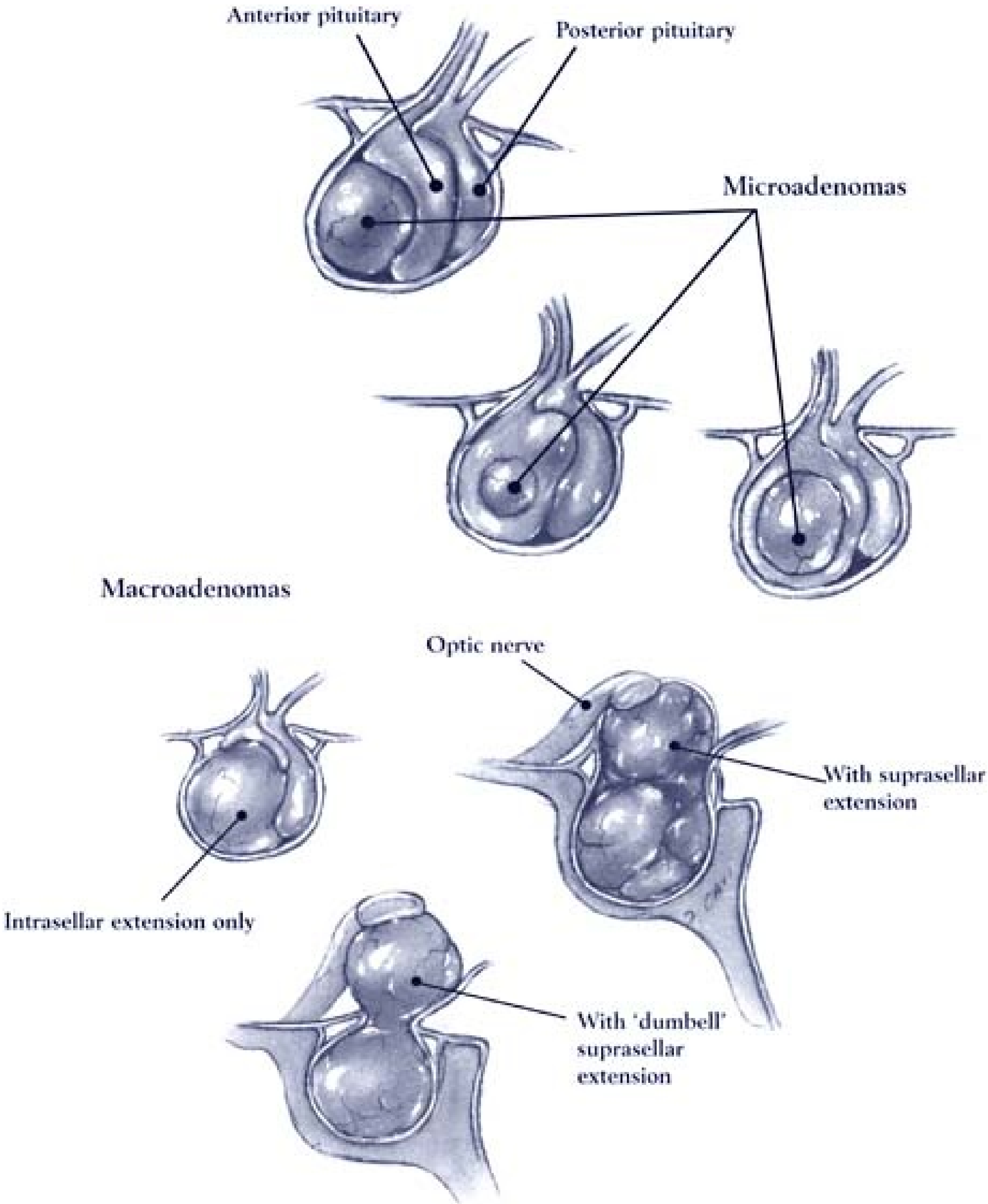


Figure 1

The various presentations and growth patterns of both pituitary microadenomas and macroadenomas

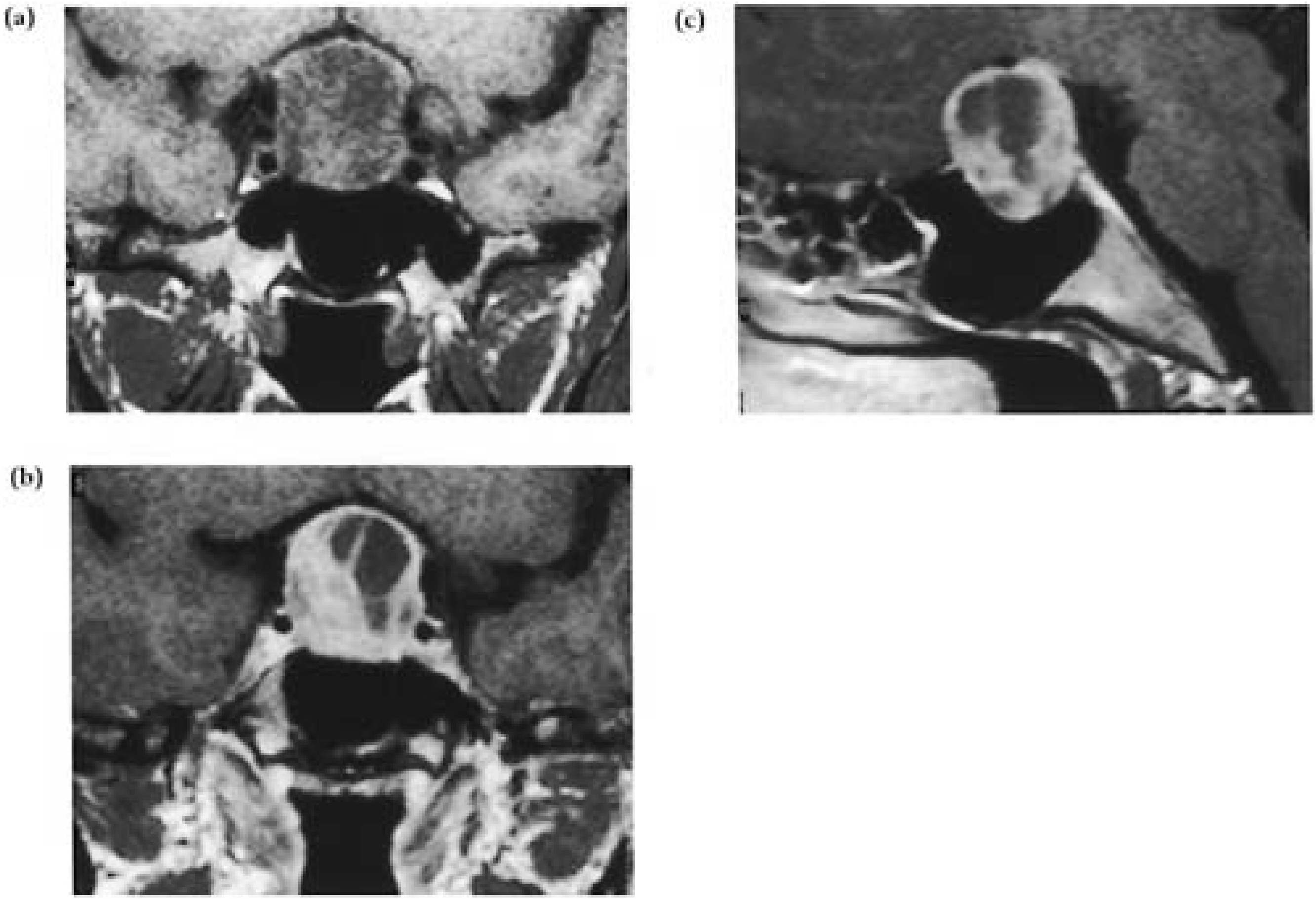


Figure 2

(a) Coronal T1-weighted MRI of pituitary tumor with suprasellar extension; (b) coronal T2-weighted MRI of pituitary tumor demonstrating cystic changes. Note the flow void of cavernous carotid arteries bilaterally; (c) sagittal T2-weighted MRI demonstrating well-pneumatized sphenoid sinus with good pre-sellar aeration, permitting identifiable hypophyseal impression within the sphenoid sinus

hemorrhage may injure cranial nerve II at the optic chiasm and result in loss of the temporal visual fields in each eye (bitemporal hemianopsia). It is unusual for the trigeminal nerve (V) to be involved in pituitary or parasellar tumors. Parasellar neoplasms such as meningiomas or schwannomas, however, may initially present with palsies of cranial nerves III, IV, and VI and paresthesias or anesthesia in the distribution of cranial nerve V.

Magnetic resonance imaging (MRI) is the mainstay of a neuroradiology evaluation for sellar and parasellar tumors or lesions. An MRI scan defines the tumor size and involvement with brain or other surrounding tissues (Figure 2). It also depicts characteristics such as cystic changes or hemorrhage within the lesion and differentiates inflammatory lesions from tumors. Axial and coronal MRI also provide information on the position of the carotid artery in relation to the lesion. For tumors that extend to or encompass the carotid artery, conventional angiography or magnetic resonance angiography may prove helpful in discerning the level of carotid artery involvement. Tumors that demonstrate significant involvement of the carotid artery and cavernous sinus region, however, are usually managed from primary intracranial or combined intra-and extracranial approaches. Although MRI may be sufficient for evaluation and surgical planning, only computed tomography (CT) can provide a detailed assessment of the bony anatomy and osseous patterns of the nasal vault, paranasal sinuses, and sellar to sphenoid relationship (Figure 3). These relationships may prove helpful in the

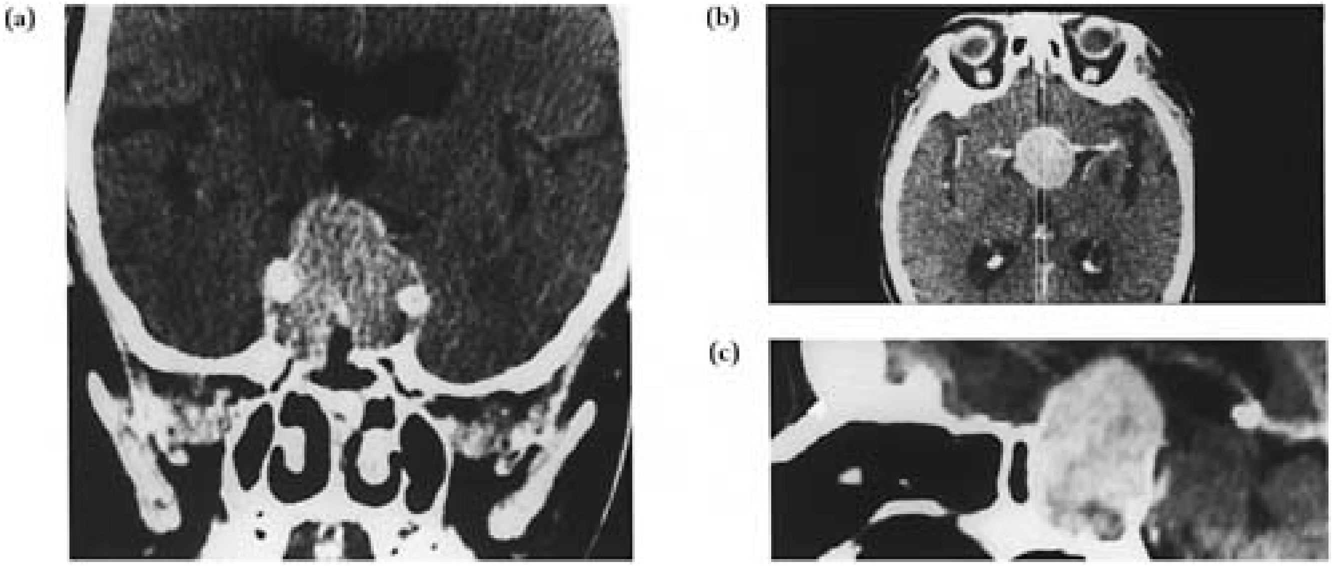


Figure 3

(a) Coronal CT showing large pituitary adenoma with suprasellar extension; (b) axial CT demonstrating relationship of pituitary tumor to skull base; (c) sagittal CT reconstruction demonstrating pituitary tumor and its relationship to the surrounding bony anatomy of the sphenoid sinus and clivus

preoperative surgical planning. In the majority of cases, the sphenoid sinus develops with pre-sellar aeration where only the anterior bony sellar floor is defined. Extensive post-sellar pneumatization exposes a majority of the bony sella in the posterosuperior aspect of the sinus and facilitates wide visualization and access. Conchal pneumatization (no air cell development defining the sella turcica), however, may limit pituitary fossa access and require a more extensive resection or drilling of the posterior wall of the sphenoid sinus.

For any tumor or lesion involving the pituitary fossa or gland, a complete endocrinology evaluation and work-up are paramount. Determination of anterior pituitary function is made with direct serum assay of the pituitary hormones: prolactin, growth hormone, and thyroid stimulating hormone. When an adrenocorticotropin (ACTH) secreting pituitary tumor and Cushing’s disease are suspected, dynamic cortisol testing and central-to-peripheral serum ACTH ratios assist in making the diagnosis. Provocative stimulation tests are also frequently performed to determine anterior pituitary reserve and document hypopituitarism that necessitates hormonal replacement therapy. Screening for posterior pituitary disorders includes evaluation of serum osmolality and sodium levels as well as urine osmolality and specific gravity.

ANATOMICAL CONSIDERATIONS

The sella turcica (hypophyseal fossa) houses the pituitary gland and is situated at the central mid-line skull base between the cavernous sinuses and posterosuperior to the sphenoid sinus (Figure 4). The parasellar regions and cavernous sinuses house critical neurovascular structures that may be invaded by primary pituitary or parasellar neoplasms. The cavernous sinuses extend from the superior orbital fissure anteriorly to the petrous portion of the temporal bone posteriorly. The cavernous sinuses drain into the superior and inferior petrosal sinuses. Each cavernous sinus receives blood from the superior and inferior ophthalmic veins, the superficial middle cerebral vein, and

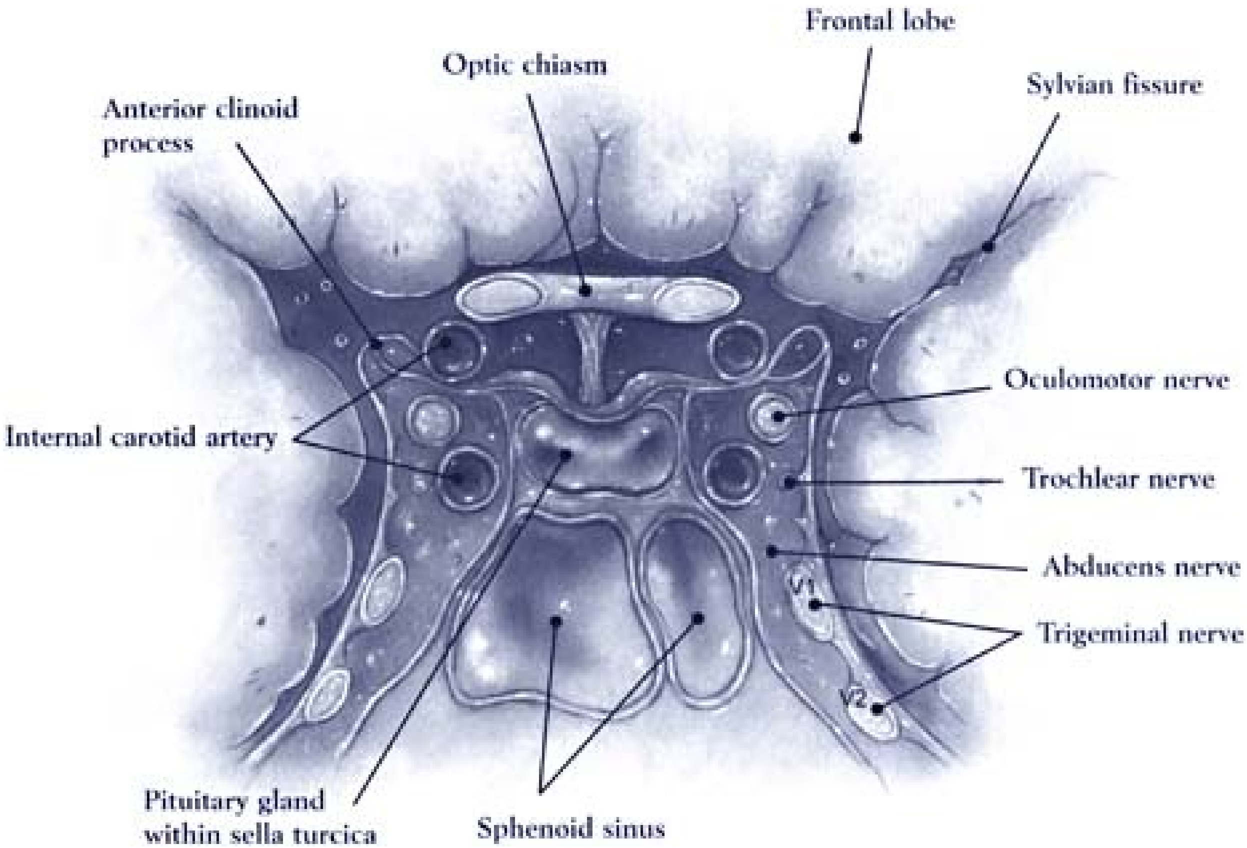


Figure 4

Coronal drawing of the anatomical structures surrounding the pituitary gland at the level of the posterior sphenoid sinus. A cross-section of the cavernous sinuses is depicted with the relationships of the various nerves in the lateral wall of the cavernous sinus and the abducens nerve with the carotid artery

the sphenoparietal sinus. The right and left cavernous sinuses communicate via intercavernous sinuses that pass anterior and posterior to the infundibulum (stalk) of the pituitary gland.

The oculomotor (cranial nerve III), trochlear (cranial nerve IV), and ophthalmic and maxillary divisions of the trigeminal nerve (cranial nerve V1 and V2) are situated from superior to inferior in the lateral wall of the cavernous sinus. Within each cavernous sinus are the internal carotid artery and its sympathetic plexus as well as the abducens nerve (cranial nerve VI) (Figure 5). Superior to the cavernous sinus lies the extracavernous distal segment of the internal carotid artery, and the optic nerve (cranial nerve II) is situated superomedial.

PROCEDURE

Anesthesia and patient positioning

The patient is placed in the supine position on the operating table with the neck slightly extended to 10–15°. There are three basic choices for patient and surgeon positioning. The

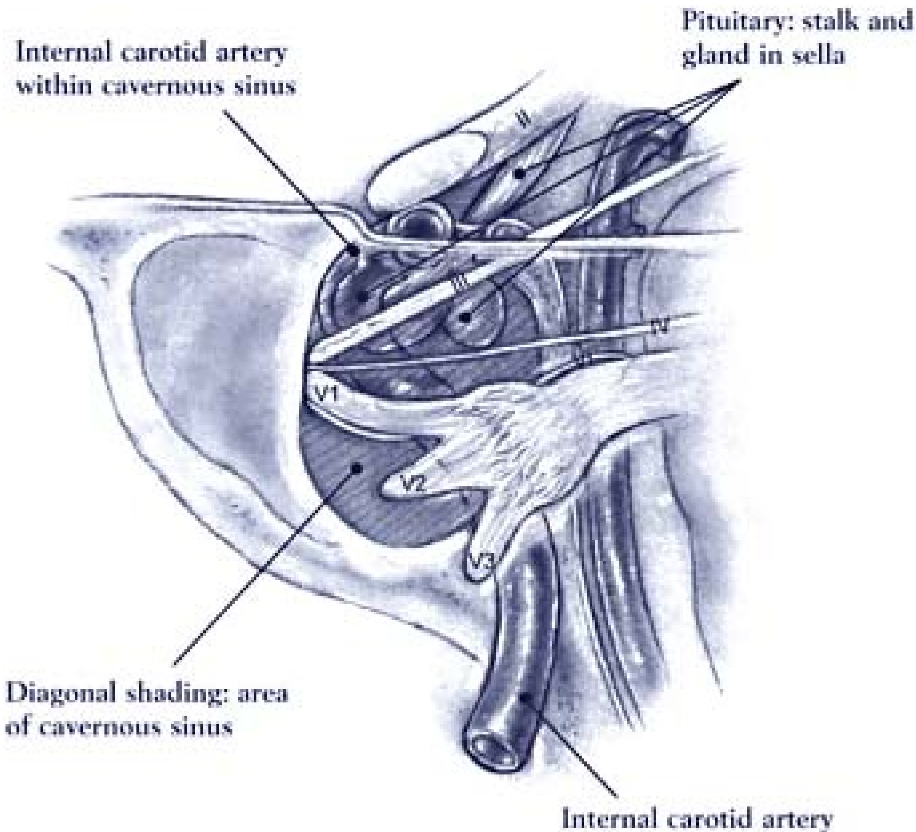


Figure 5

Sagittal drawing of the nerves within or surrounding the cavernous sinus and depicting their relationship to the carotid artery. The diagonal-line shading demarcates the area occupied by the cavernous sinus

two most common are the original Cushing's method where the surgeon stands behind the patient's head, and the alternative choice where the surgeon stands to the patient's right. Less common is the semi-sitting position with the surgeon positioned to the patient's right. In general, the head is not fixed with pins but rests on a Mayfield horseshoe or conventional headrest that allows neck extension. Pin fixation limits head manipulation to facilitate visualization or instrumentation. If fluoroscopy is to be used to confirm location, the C-arm of the X-ray imaging device can either be brought into the operating field at the time of need or can be positioned below the head of the operating table prior to beginning the procedure. A plain film lateral radiograph needs no particular prior preparation.

General anesthesia with orotracheal RAE® tube intubation is preferred for ideal operating conditions. The endotracheal tube is fixed to the mid-line chin and a gauze throat pack is placed to protect the airway from any bleeding during the operative procedure. An orogastric tube and urinary arterial, and central venous catheters are placed as needed after induction of anesthesia. Arterial blood pressure and electrocardiography are closely monitored throughout the procedure and hypertension is avoided to minimize mucosal or venous bleeding. Topical nasal mucosal vasoconstriction is achieved initially from placement of cottonoids soaked in either a total of 4 ml of 4% cocaine hydrochloride or topical nasal decongestant solution. Low concentration lidocaine with a diluent of 1:100 000 or 1:200 000 epinephrine is then injected submucosally into the membranous nasal septum, bilateral septal subperichondrium, floor of the nose, and the sublabial region to facilitate hemostasis.

Surgical incisions and mobilization of the cartilaginous nasal septum
The initial incision is made in the sublabial region. It is important to leave an adequate cuff of normal alveolar mucosa to facilitate suturing and closing of the sublabial

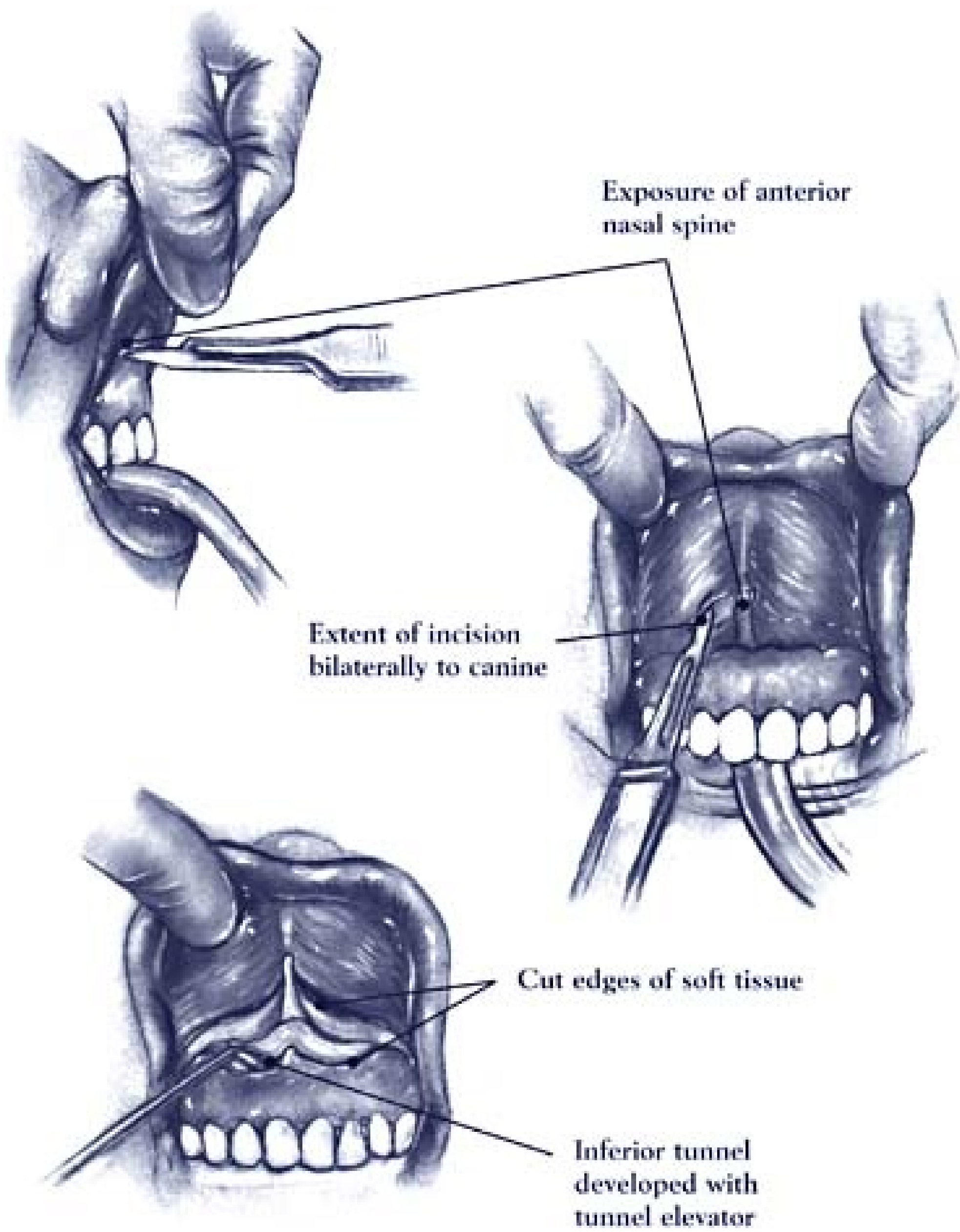


Figure 6

Initial incisions and dissection for a sublabial transsphenoidal approach to the pituitary fossa incision at the completion of the surgical procedure (Figure 6). A subperiosteal dissection using an elevator is performed and the nasal piriform aperture, nasal spine, and caudal septal cartilage are exposed. A caudal nasal septal incision may also be made to facilitate identification of the nasal spine, the raising of septal tissue flaps, and the correction of septal deformities, if present (Figure 7). Under direct visualization, a wide subperichondrial septal tunnel is developed over one side of the entire septum between the nasal dorsum and maxillary crest. Inadequate elevation of

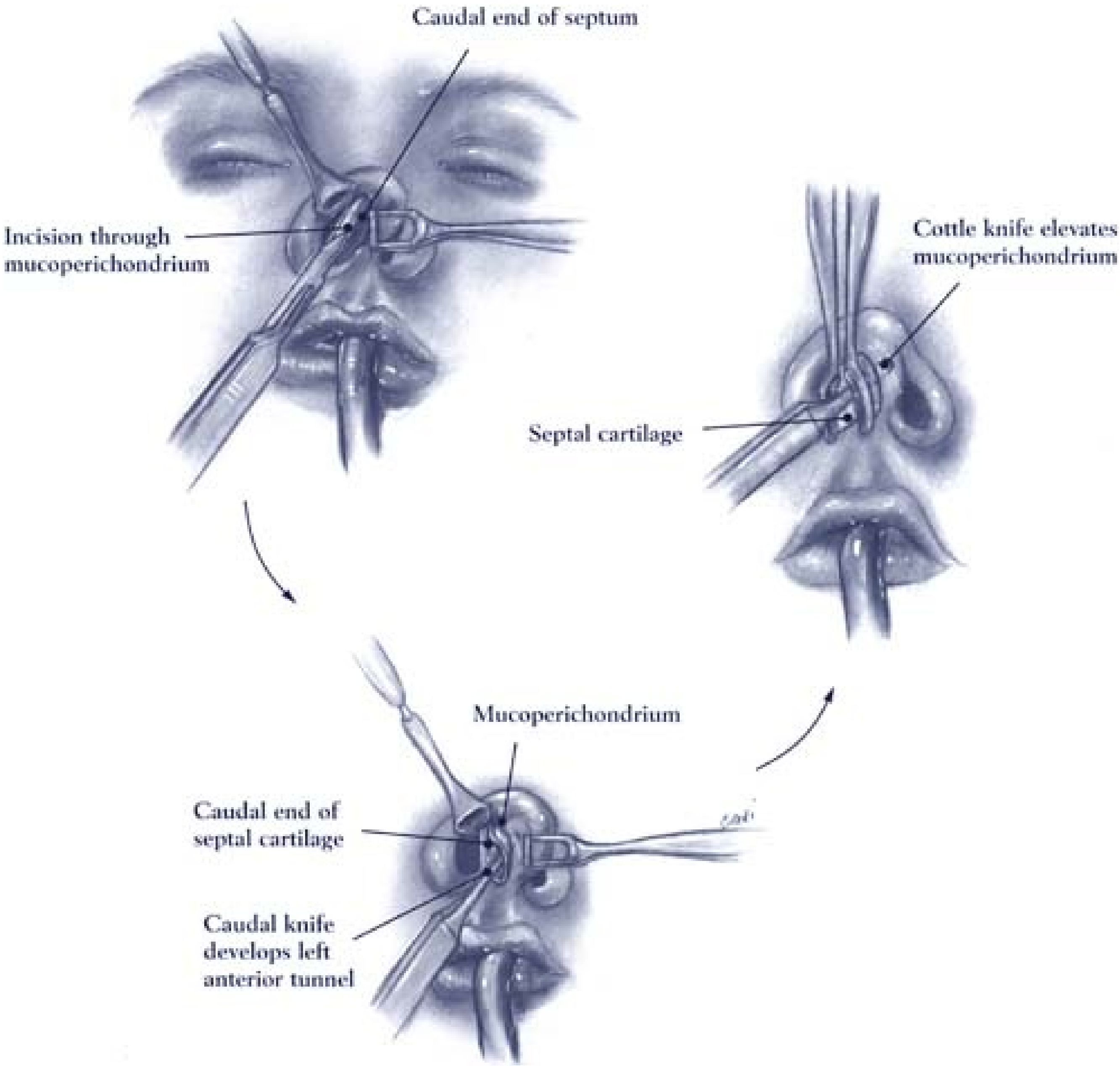


Figure 7

Intranasal incisions are made in the caudal septal mucosa and perichondrium. Submucoperichondrial dissection is used to develop an anterior septal tunnel

the septal tunnel will prevent wide retraction of the cartilaginous septum away from the mid-line, thereby limiting exposure to the sphenoid and sella. Bilateral submucosal tunnels are developed on the nasal cavity floor (Figure 8). The cruciate fibers supporting the caudal septum are incised to join the septal and nasal floor tunnels. The septal cartilage is then disarticulated from the osseous maxillary crest and posterior bony septum. The cartilaginous septum is then swung to the lateral nasal vault, providing wide exposure to the residual bony septum. It is

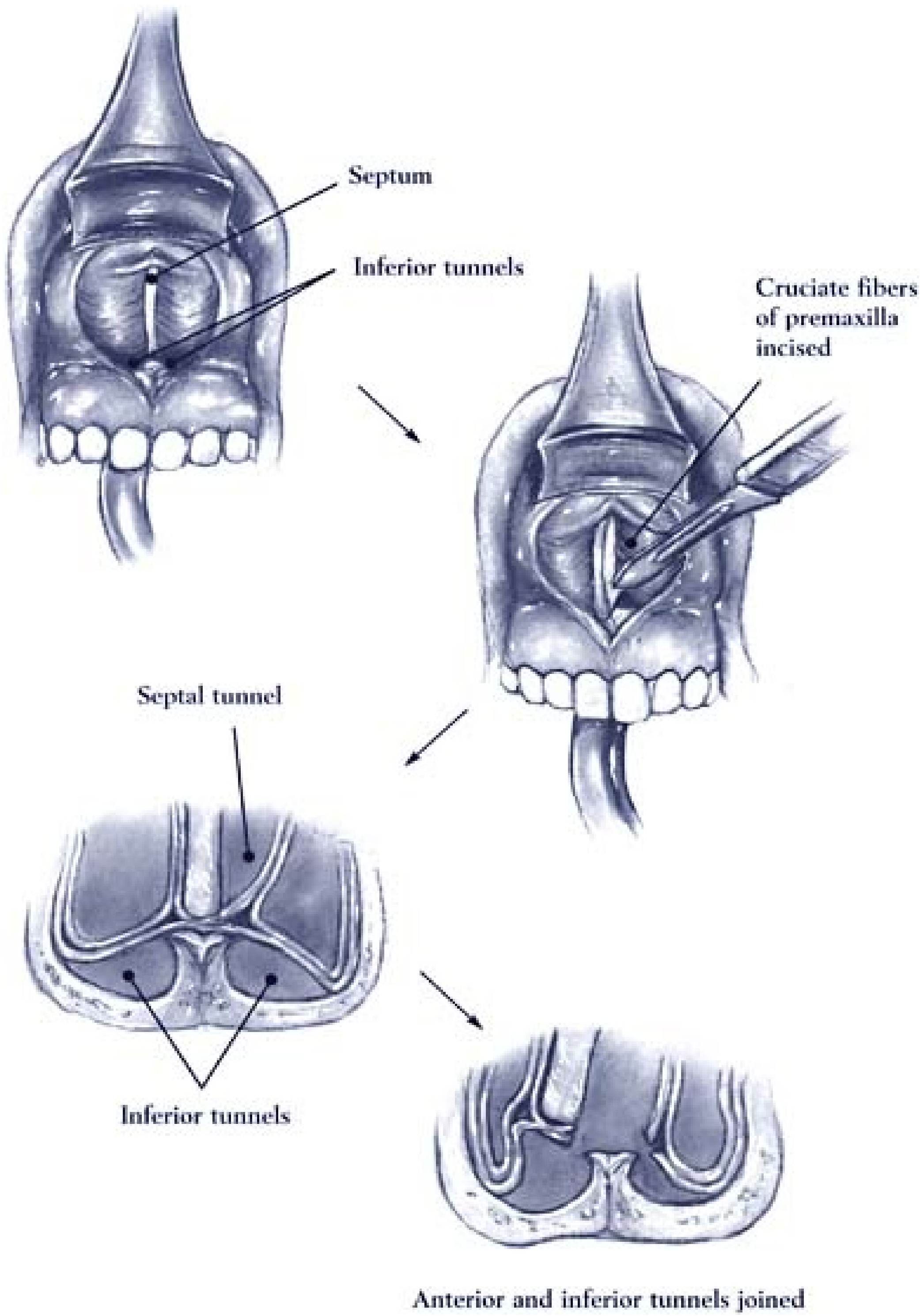


Figure 8

Inferior submucoperichondrial tunnels are developed and the cruciate fibers of the premaxilla are incised to connect the anterior and inferior tunnels important to leave the cartilaginous septum hinged on dorsal attachments to prevent postoperative saddle nose deformity. A self-retaining Hardy retractor is placed to maintain surgical exposure. Rarely, a narrow piriform aperture in the pediatric population may limit the degree of opening of the self-retained retractor and, hence, obstruct deep exposure. Although usually unnecessary, the aperture can be widened with rongeurs or by drilling with a cutting burr.

Resection of the sphenoid rostrum and identification of the sella turcica and bony impressions of the carotid artery and optical nerve

After placement of the Hardy retractor, the microscope is brought into the surgical field to enhance the visualization for the remaining aspects of the procedure. The nasal septal tunnels are now extended posteriorly onto the sphenoid rostrum, which is identified and widely exposed. The Hardy retractor is re-positioned to place the blades directly against the lateral flare of the sphenoid rostrum. Failure to identify the rostrum most commonly results from inadequate dissection of the septal tunnels inferiorly along the nasal floor and therefore placement of the retractor in a position angled superior to the rostrum. This improper dissection and placement of the retractor may lead to inadvertent entry into the anterior cranial fossa through the cribriform plate. To avoid this potential pitfall, the surgeon should inspect each side of the nasal cavity to confirm that the tunnel septal flaps are elevated down to the floor. The retractor is then inserted at a 25° angle from the nasal floor. The bony septum is removed using superior and inferior bony osteotomies made with either a chisel or double-action scissors. Care is taken to maintain large segments of the bony septum so that they can be used to reconstitute the anterior wall of the sella or sphenoid on closure. These bone grafts may be used to stabilize free tissue grafts placed within the sella or sphenoid.

Removal of the bony septum provides direct access and visualization of the sphenoid rostrum (Figure 9). Resection of the anterior nasal spine is rarely necessary and may result in postoperative columellar retraction, shortening of the nasolabial angle, creation of septal deviations from the mid-line and excessive bleeding at surgery. Orientation to the rostrum is provided by visualizing the sphenoid ostia, which are bony openings of approximately 4-mm diameter that allow sphenoid sinus drainage anteriorly into the nasopharynx. The ostia are located at the junction of the upper third and lower two-thirds of the rostral bony face, approximately 8–10 mm on either side of the mid-line. Once the rostrum is completely exposed, circumferential osteotomies are made with a punch or small osteotome to create a bony window that is further mobilized and removed (Figure 9). This bone segment may also be used to reconstitute the rostrum or support sinus grafts at the time of closure. The sphenoidotomy is extended superiorly with a Kerrison punch to open the thickened ridge of bone in the mid-line of the rostrum. The opening is further enlarged by removing the lateral margins of the rostrum. The surgeon should maintain exposure in the central aspect of the sinus to avoid entering the lateral wall of the sphenoid and adjacent internal carotid artery and optic nerves.

Mid-line and posterior exposure within the sphenoid sinus requires removal of the intersinus septae. There are usually multiple, asymmetrically developed septae that may be resected with a rongeur or drill with cutting or diamond burrs. The sphenoid sinus mucosa is then completely elevated and removed. Removal of the mucosa may reduce the risk of postoperative mucocele formation after placement of fat or tissue grafts.

The sella turcica is visualized most commonly as a bulging convexity of the posterosuperior aspect of the sphenoid sinus. There is a visible impression of the internal carotid arteries along the inferior aspect of the lateral wall of the sphenoid sinuses bilaterally. Superiorly, the carotid impression joins the bony impression of the optic nerve and forms a recess. The carotid impression also marks the lateral extension of the cavernous sinus. The clivus is located just below the bony convexity of the sella turcica and its superior margin forms the base of the sella. Wide mid-line exposure not only enables instrumentation and removal of lesions in the sphenoid sinus, sella, parasellar region, and clivus but also reduces the risk of complications by providing visualization of the carotid artery and optic nerve bony impressions which flank the cavernous sinus and pituitary gland.

Removal of pituitary neoplasms

The remaining aspect of this chapter will focus on the surgical steps for removing pituitary neoplasms as they are

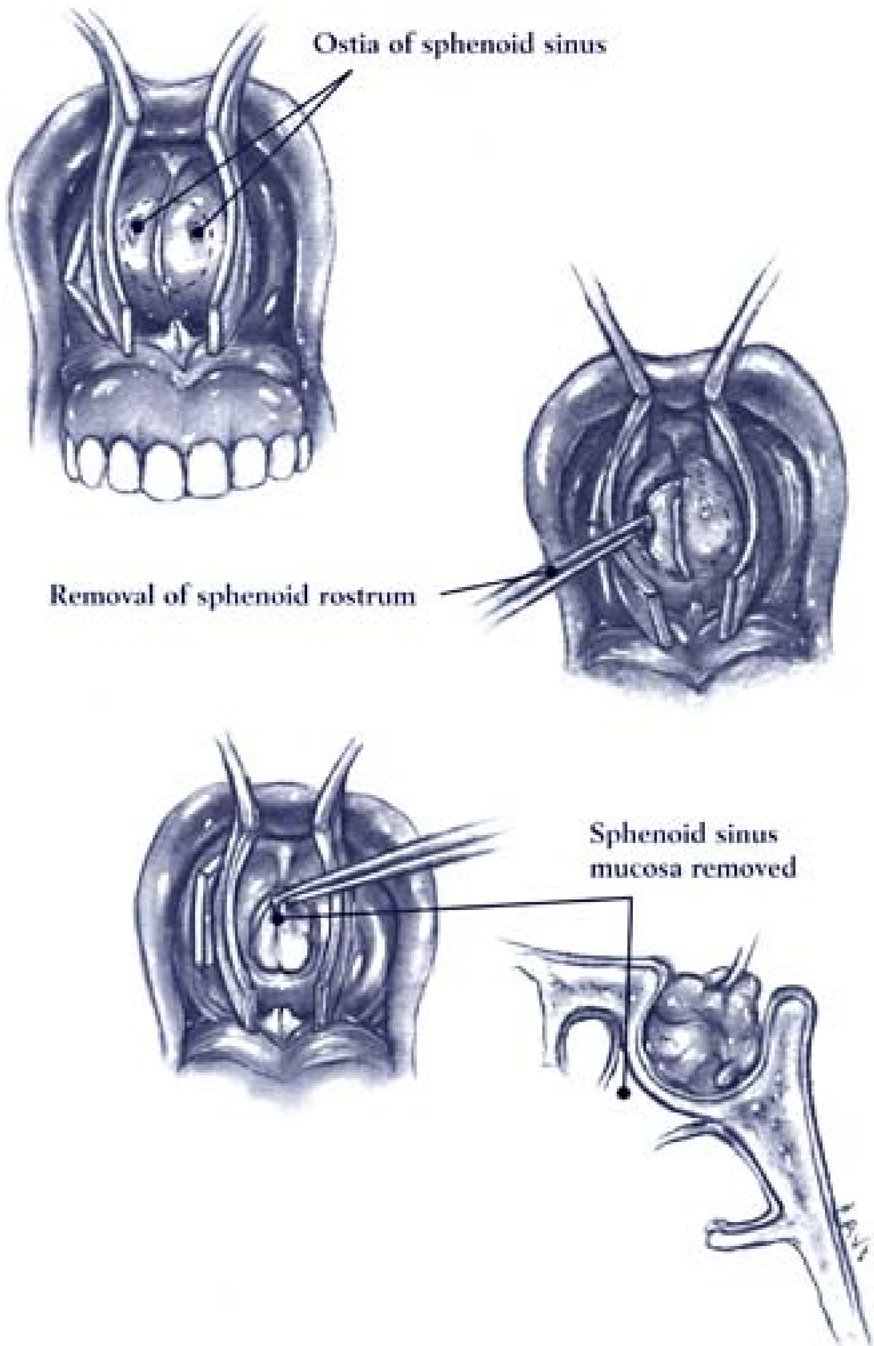


Figure 9

The sphenoid sinus rostrum is identified after removal of the nasal septum. The periosteum is elevated laterally to expose the sphenoid sinus ostia. Osteotomies are made in the rostrum, and an intact bony plate is removed if possible. A Kerrison punch is used to widen the osteotomy and the sphenoid mucosa is removed as needed

the most common lesion for which the transsphenoidal approach is chosen. The convexity of bone that forms the anterior wall of the sella turcica is entered in the mid-line and the bony wall is removed with a Kerrison punch or Cottle elevator (Figure 10). Care is taken not to extend the bony removal too far laterally so as not to risk entering or tearing the cavernous sinuses. For microadenomas or cases with a normal pituitary fossa, the bony anterior wall may be

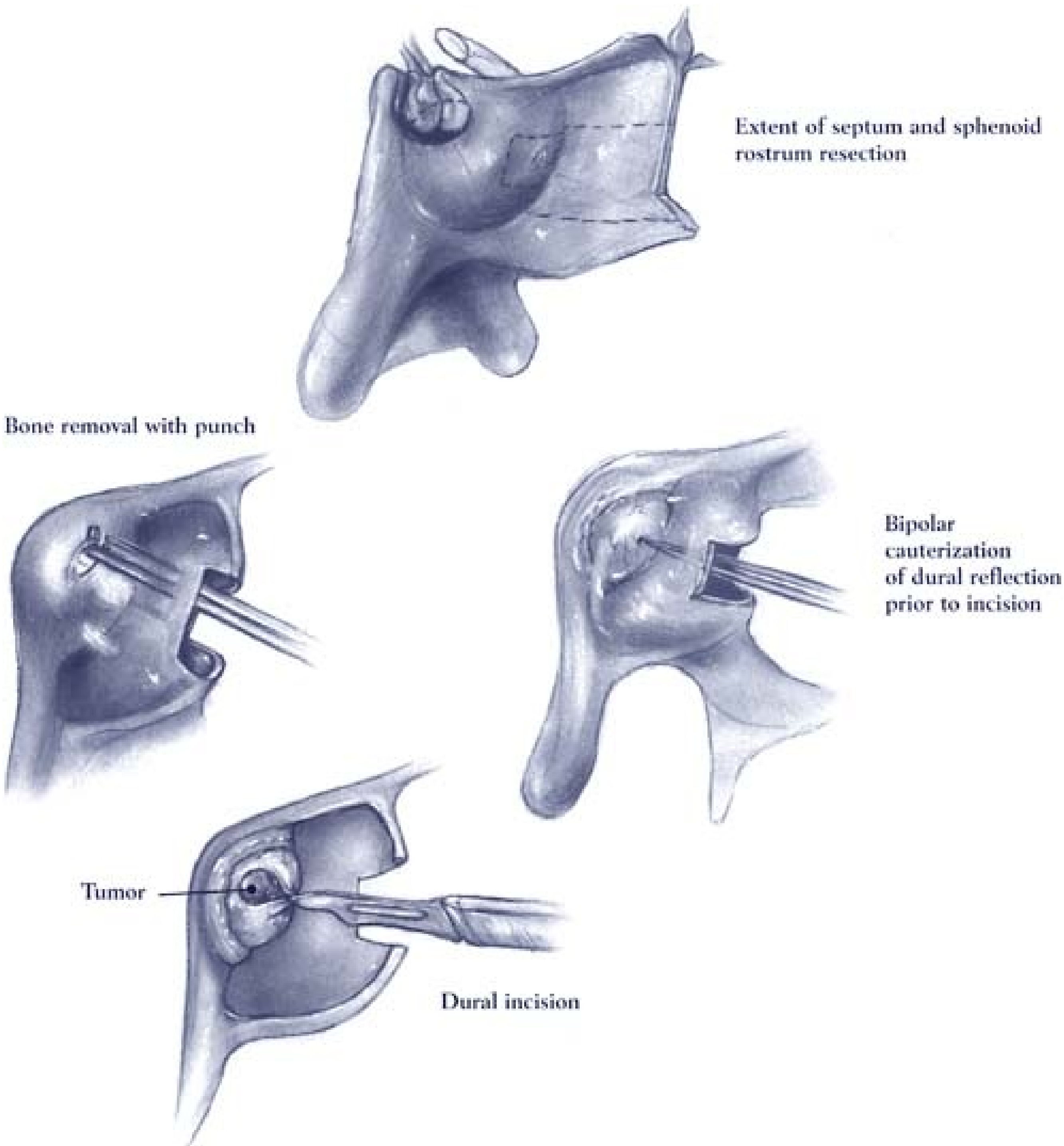
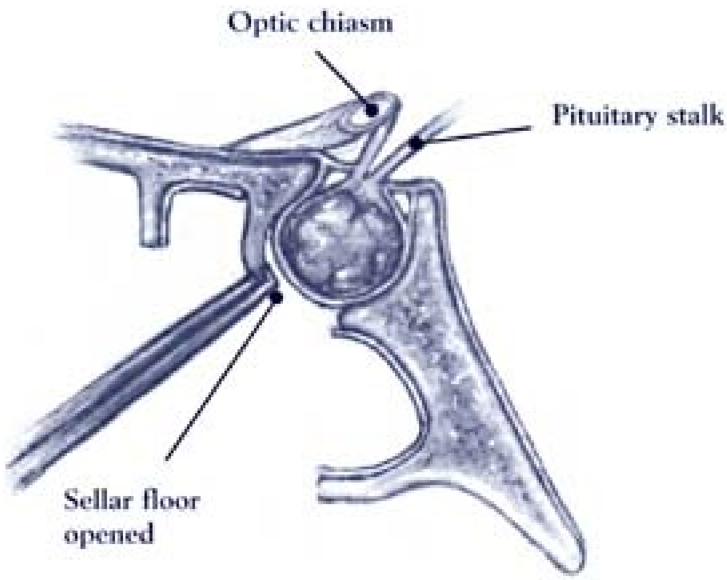


Figure 10

Sagittal view showing entry through the sella turcica and dura covering of the pituitary gland



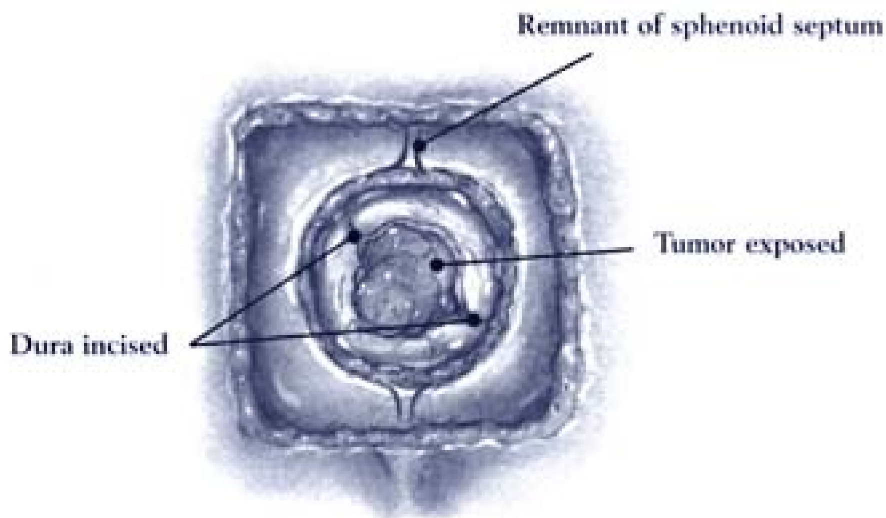


Figure 11

Sagittal and coronal drawings of the wide exposure that provides visualization and access to a pituitary neoplasm

too thick for easy removal with rongeur or elevator. In these cases, a drill with an extended handpiece and diamond burr or a mallet and chisel with direct microscopic visualization to create a bone window may be used to remove the anterior bony wall and expose the dura overlying the pituitary gland. The dura is cauterized with bipolar cautery and then opened in a cruciate fashion. The pituitary neoplasm is visualized (Figure 11) and a biopsy is sent for confirmation of the presence of tumor.

Upon dural entry, transverse intercavernous (dural communicating) sinuses may cause bleeding. Compression with cotton balls and bipolar cautery are usually sufficient to control the bleeding. The pituitary neoplasm (adenoma) is removed with stepwise curettage from anterior to posterior and left to right directions (Figure 12). One should begin the dissection inferiorly, avoiding superior dissection too early so that premature diaphragma sella herniation with increased risks of cerebrospinal fluid leak or optic chiasm insult are avoided. Suprasellar tumor usually descends after removal of the sellar component. To facilitate this process by increasing the intracranial pressure, one may compress the jugular veins or ask the anesthesiologist to provide sustained ventilatory pressure. The residual normal pituitary gland is identified either in the posterior sella or just below the diaphragma sellae. Normal pituitary is less commonly displaced laterally. Bleeding may occur upon lateral curettage, but is usually controlled with gentle compression with absorbable gelatin sponge Gelfoam“.

Wound closure

Unless there is a visible or suspected intraoperative cerebrospinal fluid leak from dissection in the region of the diaphragma sella, no grafts are placed into the pituitary fossa. If bleeding persists at the time of closure, a small piece of Gelfoam“ may be placed within the sella and gentle pressure applied with cottonoid pledgets. When a cerebrospinal fluid leak is present, either a free fat, or temporalis muscle, or fascia lata graft is harvested and placed within the anterior sella defect and onto the diaphragma (Figure 13). A small piece of bony sphenoid intersinus septum or posterior nasal septum may be wedged into the defect to support the grafts or prevent herniation of a prominent diaphragma. Placement of a large tissue graft within the sella is generally not required and may be misinterpreted as residual tumor by postoperative CT or MRI examination. With respect to the sphenoid sinus, a fat graft is placed when a cerebrospinal fluid leak is present or suspected and remaining rostrum or nasal septum bone may be wedged into the anterior opening to support the graft.

The Hardy retractor is removed and the cartilaginous nasal septum is rotated back to mid-line and situated upon the maxillary crest. The mucosal flaps are reapproximated to the cartilaginous septum and nasal floor. Gelfoam“ packing may be placed in the spheno-ethmoid recess to stabilize the mucosal flaps of the sphenoid rostrum and to prevent herniation of fat or muscle graft into the nasal cavity. The sublabial incision is closed with 3–0 chromic gut suture and the caudal nasal septal incision (if present) is closed with 4–0 chromic gut suture. Doyle nasal splints are placed bilateral to support the nasal septum in the mid-line position and are secured with 3–0 nylon suture.

Endoscopic resection of pituitary neoplasms

With trends towards less invasive surgery, the use of endoscopy for primary or adjuvant cranial base surgical approaches is gaining popularity and acceptance. For tumors of the pituitary gland especially, endoscopic transnasal-transsphenoidal resection is a viable option. Proponents of endoscopic pituitary surgery report less complications, including facial swelling, septal perforations, nasal septal deviations, numbness of the upper incisors, and saddle nose deformities from dorsal septal collapse. Probably the most significant benefit is that the endoscopes provide improved lateral visualization within the sphenoid sinus. This lateral visualization may help with the identification of the carotid artery and optic nerves, as defined by the bony impressions on either side of the sella turcica.

Endoscopic pituitary surgery is performed under general anesthesia with the patient supine and the head elevated 10°. In the majority of cases, the operation can be performed through one nostril, for which the choice depends on the width of the nasal cavity sphenoid sinus size, and laterality of the pituitary tumor. The nose is decongested topically and then further vasoconstriction is achieved by infiltrating the mucosa over the rostrum of the sphenoid, middle turbinate, and posterior septum with lidocaine hydrochloride 1 % with epinephrine 1:100 000. Using a rigid 0° endoscope, the sphenoid ostium is identified; and its position may be confirmed by the use of C-arm fluoroscopy. The middle turbinate can either be outfractured or even removed to provide increased exposure to the sphenoid rostrum. The sphenoid ostia is identified and then fractured inferomedially. A microdebrider or Kerrison rongeurs are used to widen the sphenoidotomy and remove the sphenoid rostrum. The posterior bony nasal septum may also be ronguered to provide wider visualization to include the contralateral sphenoid sinus cavity. The 0° or 30° endoscope is then inserted into both sides of the sphenoid sinus for identification of the optic and carotid protuberance, the opticocarotid recess, clival indentation, and anterior wall of the sella (Figure 14). The intersinus septum may be removed if needed, and the sella and dura are exposed and entered in the standard fashion. For the resection of

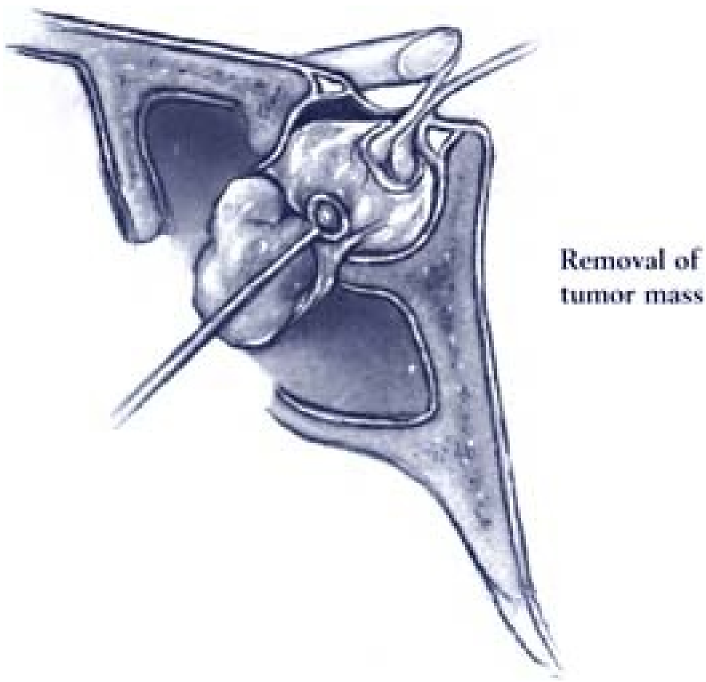


Figure 12

Removal of a pituitary neoplasm using ring curettes. Care is taken not to rotate the curette within the fossa to minimize injury to the optic nerve or cavernous sinus vascular or neural structures

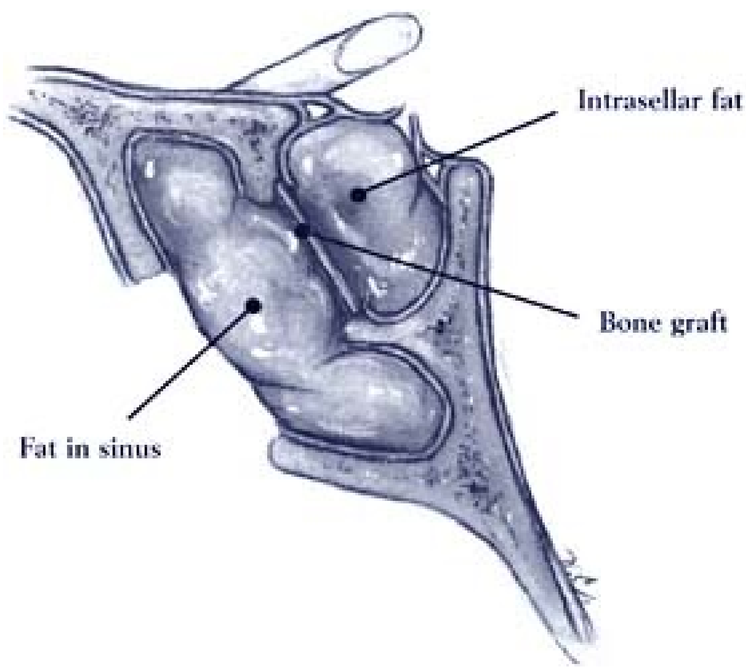


Figure 13

In cases where a cerebrospinal fluid leak is identified or suspected, layered free tissue grafts are used to seal the leak. A free bone graft from the posterior nasal septum or the sphenoid intersinus septum is used to reconstruct the superoposterior sphenoid sinus wall

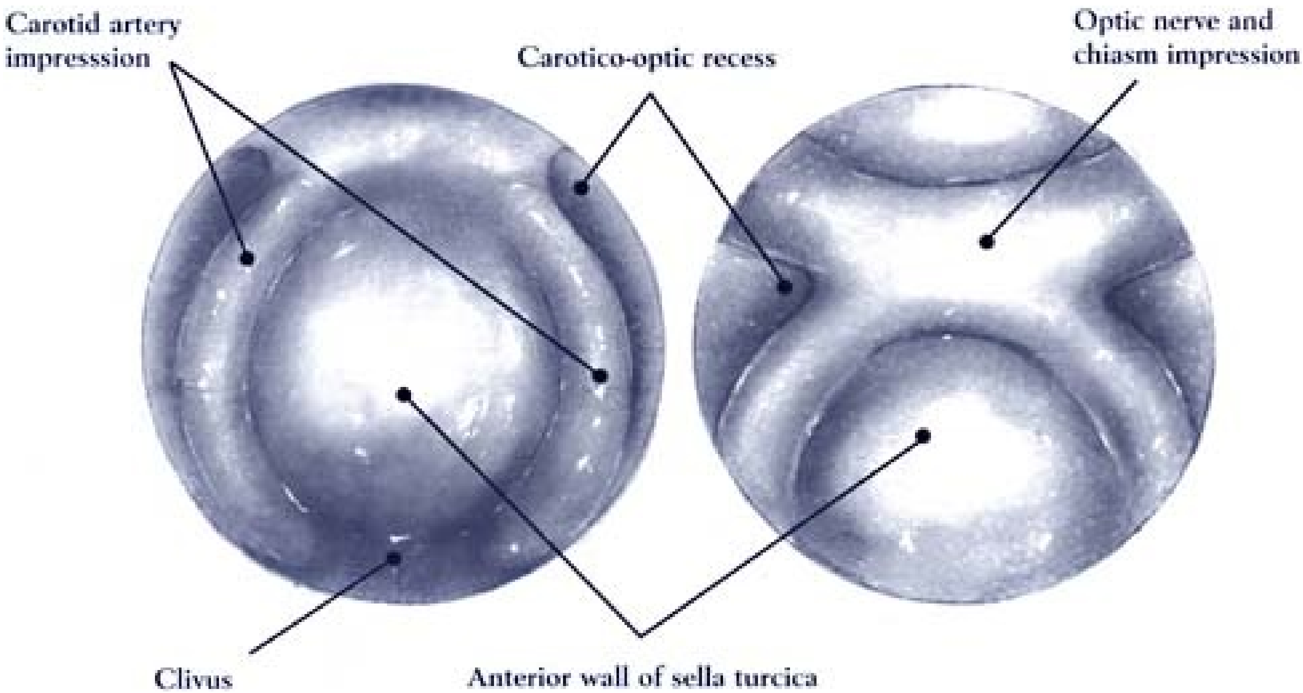


Figure 14

Anatomy of the anterior sella and carotico-optic recess, as visualized with 0° and 30° sinus endoscope

macroadenomas, the insertion of the 30° endoscope allows the surgeon to follow both intra- and extrasellar extension of the tumor and to identify and preserve the arachnoid membrane. The ability to enter the sella with the endoscope and directly visualize tumor and normal pituitary gland is a major advantage over the operating microscope (Figure 15). This increased visualization may allow more complete tumor resection while limiting potential complications associated with blind curettage of the superior and lateral sella contents.

Postoperative management

Intensive care monitoring and management in the initial postoperative period are generally advocated, especially for patients at high risk for complications. Patients with pituitary neoplasms and Cushing's disease fall into this high-risk category. Hospital stay ranges from 3–5 days for uncomplicated pituitary procedures. During the first 24–72 h, close attention is paid to urinary output and specific gravity as well as serum electrolytes to rule out the onset of diabetes insipidus. Nasal saline drops three to four times daily are started on postoperative day 1 and continued for 1–2 weeks. Doyle splints are removed on days 3–7, either at the time of discharge or upon outpatient follow-up.

For patients with CT or MRI evidence of chronic sinusitis, perioperative broad-spectrum antibiotics are given and patients may be discharged home with 1–2 weeks of oral antibiotics. Patients with no history of sinus disease or infections may receive oral antibiotics until the Doyle splints and any nasal packing are removed on days 5–7. Nasal splint removal may be performed on an outpatient basis as needed. By postoperative day 1, the patients should be able to

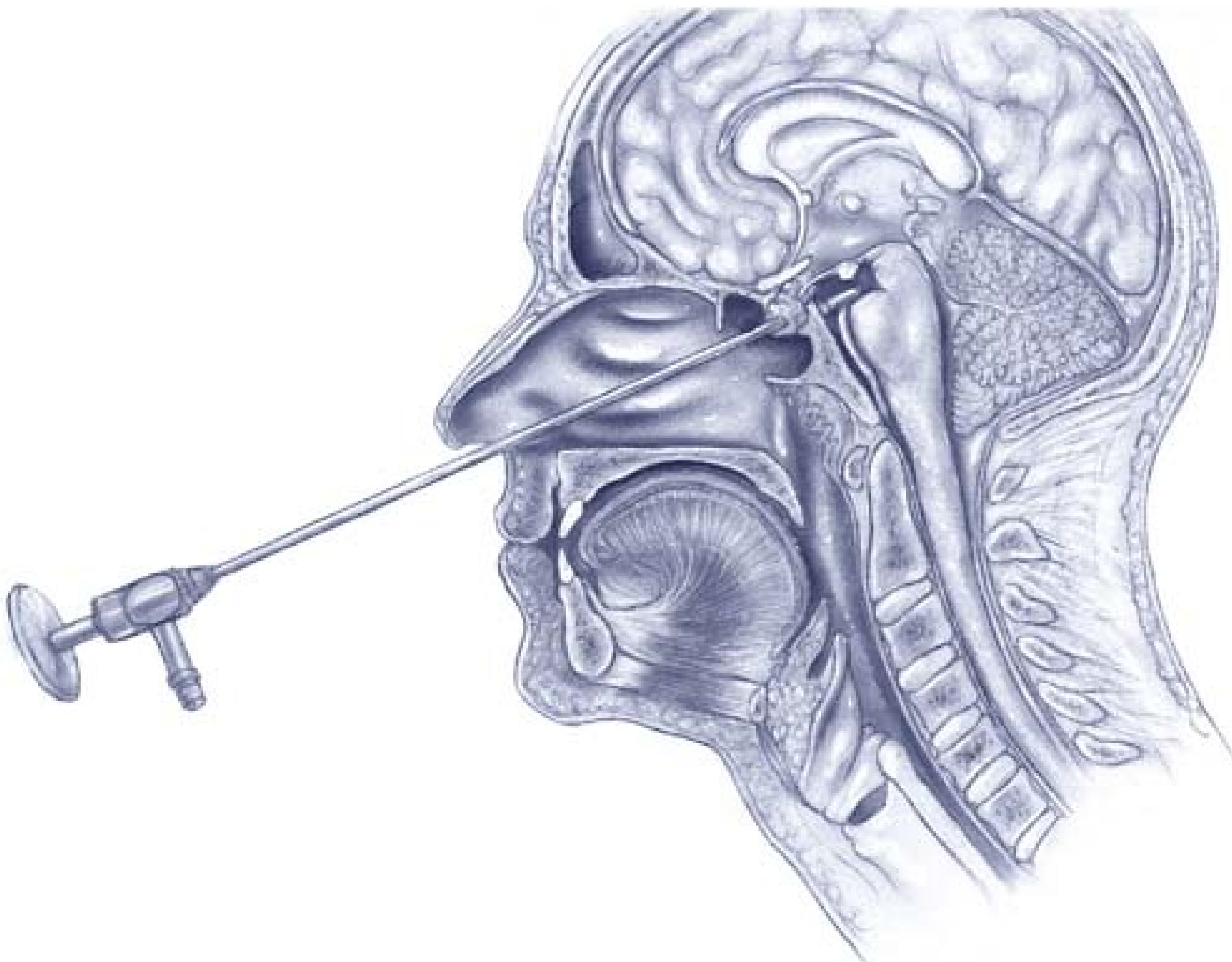


Figure 15

Sagittal drawing depicting the placement of the endoscope within the pituitary fossa to visualize and access residual tumor

ambulate and low-dose subcutaneous heparinization may be discontinued unless a high-risk situation (such as with Cushing's disease) exists.

For patients whose pituitary tumors have resulted in secondary adrenocortical failure, intravenous hydrocortisone is administered both intra-and postoperatively. On the day of surgery, patients are typically dosed with 100 mg of hydrocortisone over a 24-h period. The daily dose of hydrocortisone is then tapered from 80 to 30 mg over the subsequent 6 days to a maintenance dose of 25 mg by day 7. For patients with thyroid or gonadotropic hormone deficiencies, replacement dosing on postoperative day 1 is continued, as determined by the preoperative regimen.

Endocrine testing is performed at approximately 1 week after surgery for those patients with hormone disorders and then testing is repeated in 2–3 months.

COMPLICATIONS

Cerebrospinal fluid leak

A persistent or visible cerebrospinal fluid leak, as manifested by clear rhinorrhea within the first 24–48 h after surgery, can usually be controlled with lumbar drainage for 3–4 days. Should the cerebrospinal fluid leak persist, reoperation is necessary. Surgical incisions are reopened and any fat and fascia grafts are removed to identify the fistula. The defect is then covered with fresh fascia and the sphenoid sinus is packed with fat graft. Lumbar drainage is maintained for 3–5 days. The incidence of meningitis with cerebrospinal fluid leak is rare and occurs in less than 1% of patients who undergo isolated pituitary operations. The treatment for meningitis is systemic intravenous antibiotic therapy with culture specificity if an organism is identified in cerebrospinal fluid cultures.

Diabetes insipidus

Diabetes insipidus may manifest within the first 48 h after pituitary or parasellar surgery. Indications for the onset of diabetes insipidus include increased urinary output greater than 2500 ml/24 h after the first postoperative day, a specific gravity below 1005, and an elevated serum sodium. The treatment is desmopressin acetate given intramuscularly or through nasal topical administration after the first week of recovery. When it does occur, diabetes insipidus is usually transient and resolves within the first few months after surgery.

Other complications

Significant bleeding from the cavernous sinus or from injury to the carotid artery is rare but, when it occurs, it may be rapidly fatal. The treatment for major bleeding is packing with Avitene® backed cotton balls of the anterior sella, sphenoid sinus, and nasal cavity followed by supportive systemic measures. Emergent angiography with embolization may be an option if the patient continues to bleed and remains unstable.

Ocular nerve palsies (primarily cranial nerves II and VI) after transsphenoidal tumor resection are rare; but the incidence increases with the extent of parasellar involvement by the pituitary tumor or other neoplasm. Optic nerve injuries are equally rare. Systemic steroids may be administered and the palsies are usually transient.

ADDITIONAL READING

Historical interest

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Other

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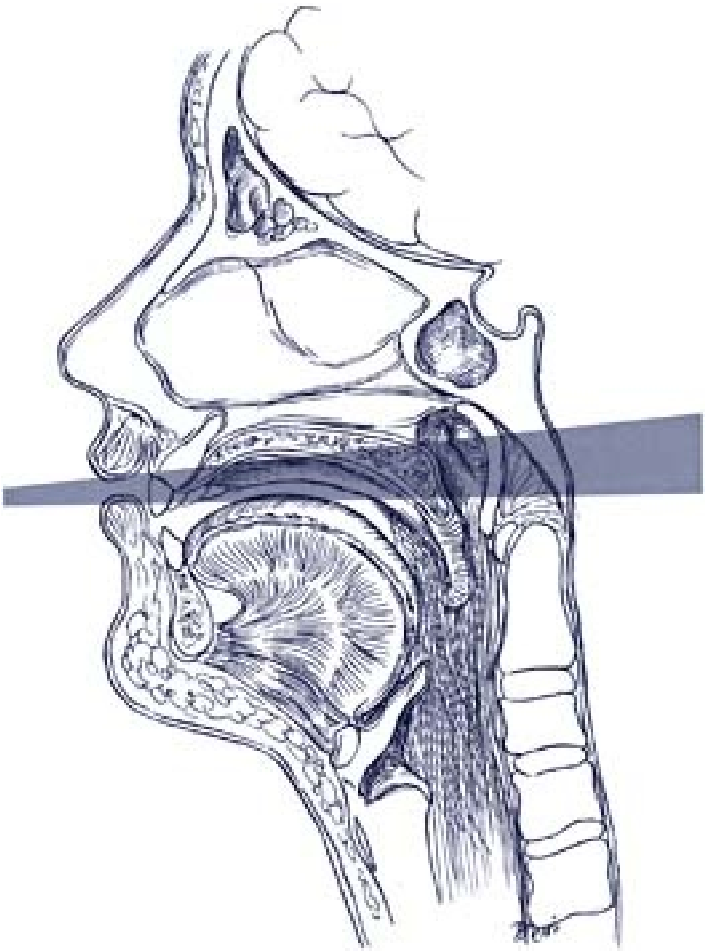
5
Transoral approach to the mid-line skull base

Bert W.O’Malley, Jr and Michael J.Holliday



INDICATIONS

The transoral approaches to the skull base provide access to the clivus, anterior craniocervical junction, and upper anterior cervical spine and spinal canal (Table 1). The range of accessibility spans from the mid-clival region to the third cervical vertebra for standard transoral procedures (Figure 1). The most common neoplasm for which this approach is employed is the clival chordoma and less common are primary sarcomas and metastases. The transoral approach provides adequate access and visualization for removal of both the extradural and intradural components of clival chordomas. Depending on their location and orientation with respect to the brain stem and spinal cord, primarily intradural neoplasms such as schwannomas, epidermoids, and meningiomas may also be amenable to transoral procedures. For non-neoplastic lesions such as inflammatory disorders of C1–C2, this approach may be used to decompress the anterior cervical spinal cord. Rheumatoid arthritis is the most common inflammatory disorder involving the odontoid process and its supporting ligamentous structures. Chronic inflammation can result in deformation of the odontoid peg or atlanto-axial subluxation and brain stem or cord compression, with resultant neurological sequelae. Other lesions that can be approached transorally include aneurysms of the mid-to lower basilar artery and neurenteric cysts. The transoral approach may be used for addressing the basilar impression, as well as secondary Arnold-Chiari malformations resulting from genetic syndromes or trauma. With respect to traumatic injuries, fusion of high cervical fractures may be performed transorally. Depending on the extent of cervical instability caused by either the lesion or the resection, the transoral procedures may require an immediate second-stage procedure of posterior cervical fixation.

ANATOMICAL CONSIDERATIONS

The transoral approach provides a safe and readily applied access to the basi-occiput and its important bony and soft tissue structures. This avenue gives excellent exposure to predominantly the anterior mid-line basi-occiput. Transoral exposure is limited laterally by the retracted soft tissues, the vertebral arteries running within the foramen of the cervical transverse processes, and the carotid arteries at the uppermost extent (Figures 1 and 2). The layers that are divided include the pharyngomusculomucosal layer of the pharynx, the pharyngobulbar fascia (anterior atlanto-occipital membrane) above the arch of the atlas and the anterior longitudinal ligament below the arch, the bony vertebral bodies and clivus of the basi-occiput, a fascial layer deep to the vertebral bodies (membrana tectoria), and the underlying dura.

PATIENT EVALUATION

All patients should have a complete physical examination with emphasis on oral cavity anatomy, cranial nerve function and respiratory status. With respect to the oral cavity, existing trismus and limitation of mandibular excursion may prevent adequate transoral exposure. In these cases,

Table 1 Regions accessible by the transoral approach

Middle clivus

Lower clivus

Anterior craniocervical junction

Anterior cervical vertebrae (C1–C2)

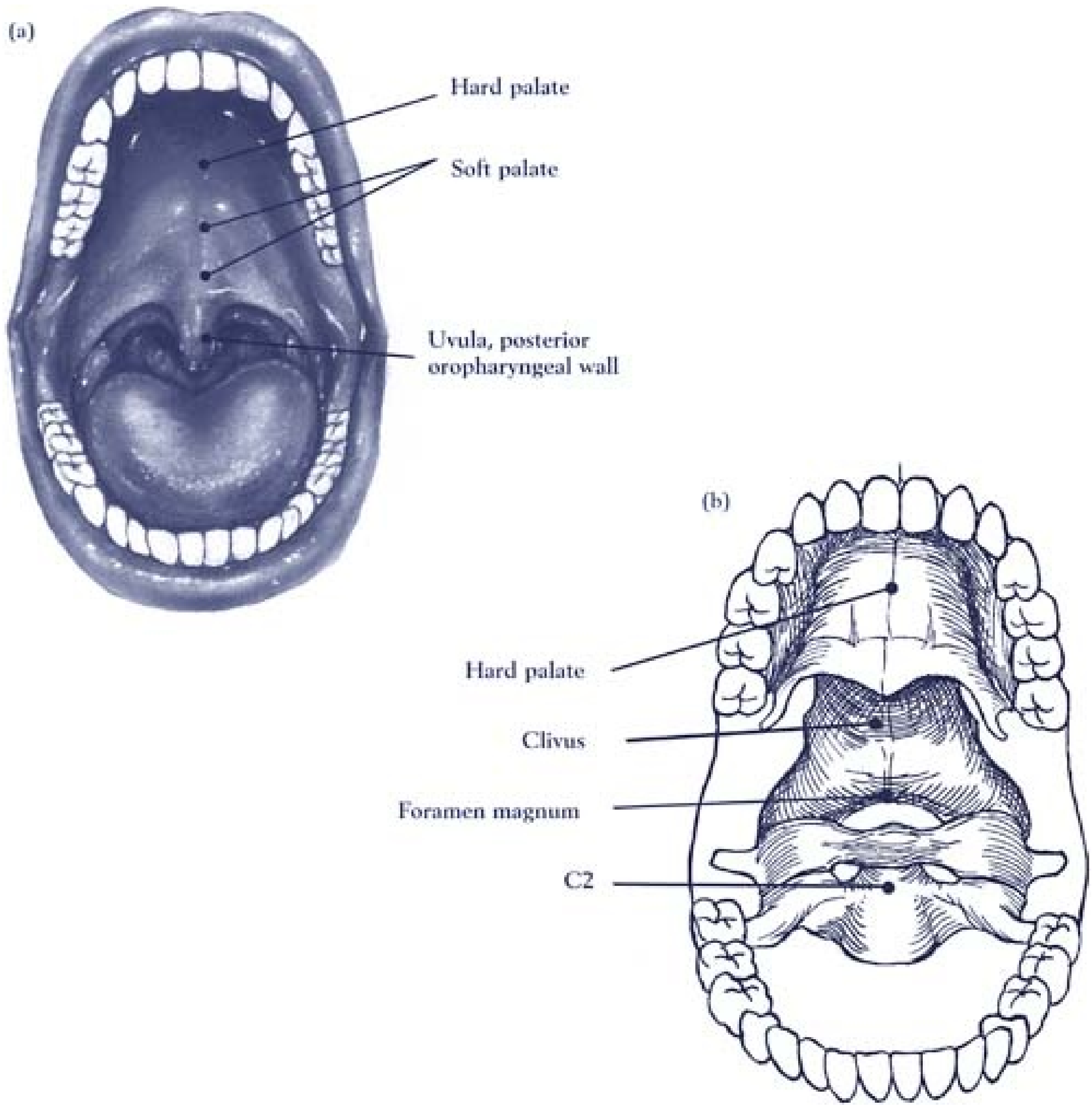


Figure 1

Transoral view showing the soft tissue landmarks (a) and the underlying bony structures (b)

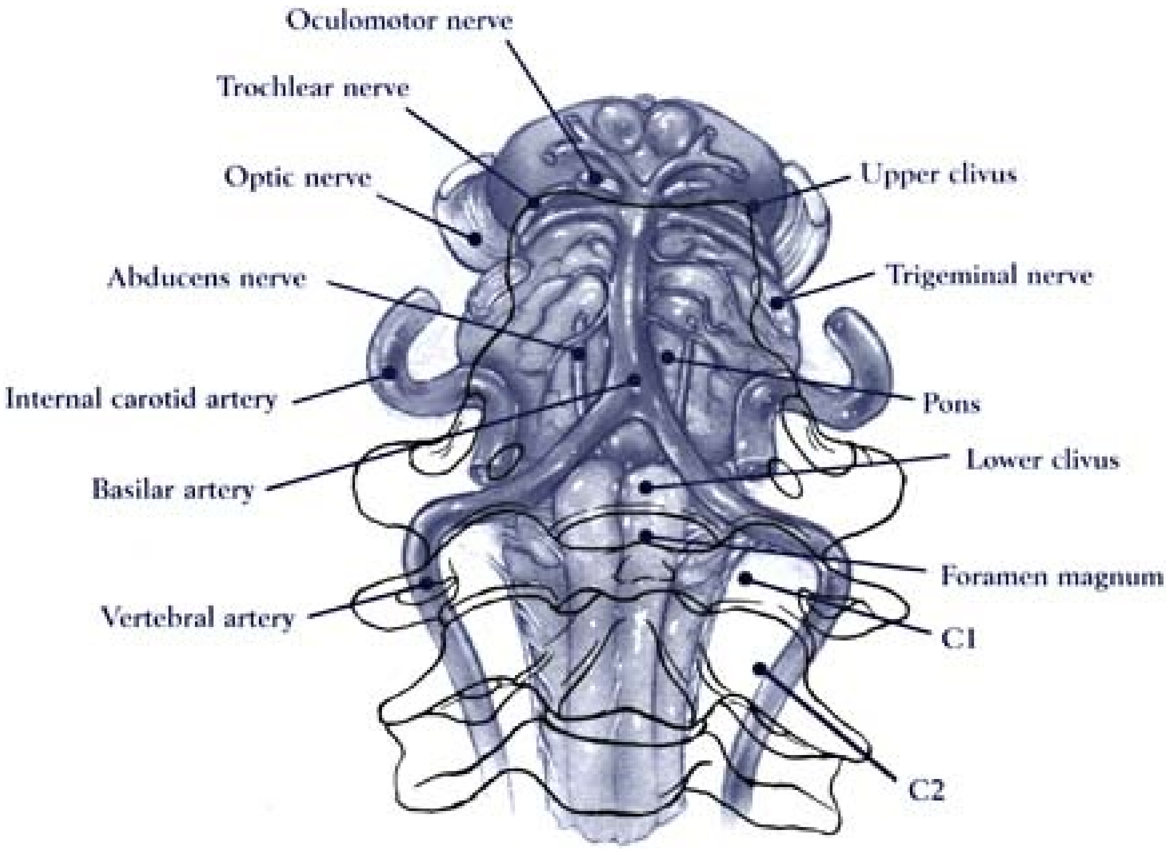


Figure 2

Bony anatomy (overlay) and underlying vascular and brain stem structures additional procedures such as the Lefort I osteotomy and palatal drop or the mid-line mandibulotomy may improve surgical exposure and access to the mid-line skull base lesion. Limited opening of the oral cavity also affects the induction of anesthesia and method of intubation. In such patients, planning for either fiberoptic-guided oral intubation or tracheotomy is important. Depressed respiratory function may exist preoperatively as a result of direct brain stem compression by the inflammatory, neoplastic, or traumatic lesion. Respiratory function may improve with removal of the offending process and decompression of the brain stem. Pulmonary function tests, with vital capacity assessment, help to estimate pulmonary reserve. Patients with vital capacities below 1 liter have an increased risk of long-term respiratory failure requiring ventilatory support.

(a)

(b)

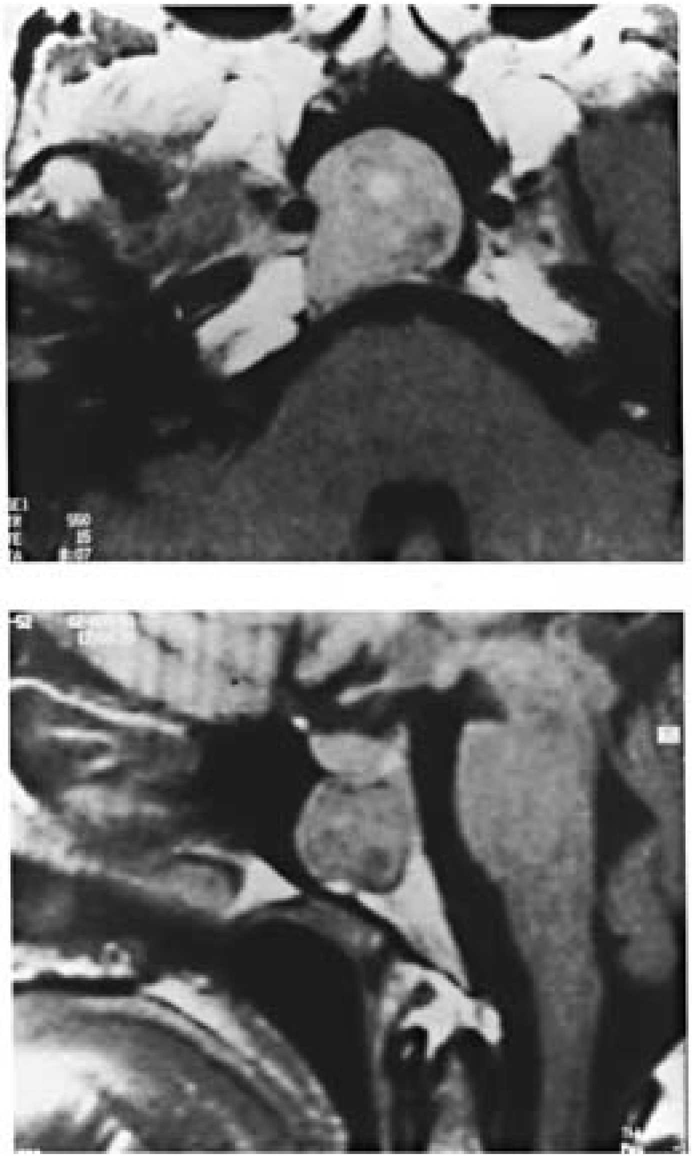


Figure 3

MRI scans of clival chordoma accessible via transoral transpalatal approach. (a) Axial view; (b) coronal view

As with all skull base processes, radiographic imaging is critical in diagnosis; preoperative planning; and postoperative management. Because of complex bony and soft tissue involvement by clival and upper cervical lesions, both magnetic resonance imaging (MRI) and computed tomography (CT) are advised (Figure 3). These imaging modalities localize pathology, define the limits of extension, and provide a greater understanding of the mechanism of compromise of the central nervous system. Lesions of the craniocervical region, such as bony degeneration and subluxation, may also be evaluated with cervical-spine plain film radiographic imaging.

Angiography can be helpful if the lesion is suspected of being vascular or if the process approximates or involves the vertebral basilar arterial system, the carotid artery, or the cavernous sinus. Vertebral angiography may also prove useful in demonstrating rotation of the vertebral artery into the planned surgical field. This potential surgical pitfall can result from rotation of the atlas on C1.

PROCEDURE

Anesthesia and patient positioning
For most cases; general anesthesia delivered via orotracheal intubation is advocated. The endotracheal tube is retracted along with the tongue base using the Dingman or Crowe-Davis oral retractor. Although there are proponents of nasotracheal intubation, it is the authors' experience that a nasotracheal tube limits the surgical view and lateral access and therefore hinders the procedure. For patients with craniocervical instability or limited oral opening, fiberoptic-guided oral intubation or tracheotomy may be required. The decision for tracheotomy depends upon the extent of airway compromise and swallowing function that are predicted to be present postoperatively Swelling of the base of the tongue as a result of prolonged or excessive tongue retraction during the procedure may be a cause of airway obstruction and need for extended intubation or tracheotomy. Release of the tongue retractor for approximately 5 min every 30 min will significantly reduce postoperative tongue swelling and allow for extubation. For patients undergoing extensive intradural procedures where wound exposure to pulmonary secretions increases the risk of infectious complications or who are predicted to have slow or limited recovery of respiratory function, a tracheostomy is performed. Tracheostomy is also recommended when the approach requires a mandibulotomy.

The patient is placed in the supine position with the head extended, slightly elevated, and fixed in a Mayfield head holder. When the transoral approach is followed by an immediate posterior cervical fixation, the patient may be placed in traction at the onset of the first stage. For lesions causing anterior brain stem compression that require combined transoral approaches followed by posterior decompression and fusion, an immediate second stage may shorten hospitalization and morbidity of intubation and brace requirements. Although not advocated by the authors, there are surgeons who position the patient laterally when combining the two surgical stages. The lateral positioning obviates the need to move the patient after the first procedure. With this positioning, the surgeon remains seated throughout the case and views the anatomy from a perspective of a 90° rotation. One possible advantage of the lateral position is that drilled bone dust and blood do not pool in the surgical field and obstruct visualization. In the authors' experience, however, the lateral positioning makes the procedure more tedious and actually extends the surgical time.

Intra-operative neural monitoring enhances safety for resection of lesions involving the neuraxis, particularly when pathology extends to the dura. Although somatosensory evoked potentials provide a sensitive and easily applied method of monitoring long tracts, motor columns may be injured without changes becoming evident. The use of antidromic potentials offers a method of monitoring more anteriorly located motor tracts. Because of the time delay in computer averaging and technical issues with lead problems and placement, neither of these monitoring methods can or should be totally relied upon.

Surgical incisions and exposure
After routine preparation of the face and sterile draping; a transoral retractor (Dingman or Crowe-Davis retractor) is placed in the oral cavity. The tongue and mid-line orotracheal tube are depressed with the retractor to provide visualization of the oropharynx. The soft palate, uvula, and oropharyngeal/nasopharyngeal posterior wall are infiltrated with 1% lidocaine hydrochloride with a diluent of 1:100 000 epinephrine for hemostasis. The selection of incisions and need for palatal division or bony resection depend upon the location of the tumor and extent of planned resection. Because most lesions of the craniocervical junction lie anterior to the neuraxis, a transoral view enables skull base exposure from the sphenoid-clival junction superiorly to the rostral aspect of the third cervical vertebral body inferiorly. Soft palate

mid-line or curvilinear incisions may increase exposure to the superior aspect of this region, but division or rongeuring of the hard palate is usually not necessary. Once the pharyngeal mucosa is incised and the muscular layers divided, the Crockard transoral retractor is placed and the anterior tubercle of C1 provides a palpable landmark (Figure 4). For extensive lesions involving the foramen magnum and upper spheno-clival region, the soft palate will require mid-line or curvilinear division and the hard palate may require osteotomies or partial resection.

The lateral extent of exposure is limited to a 3-cm width centered on the mid-line when vertical mid-line oropharyngeal/nasopharyngeal mucosal and muscular

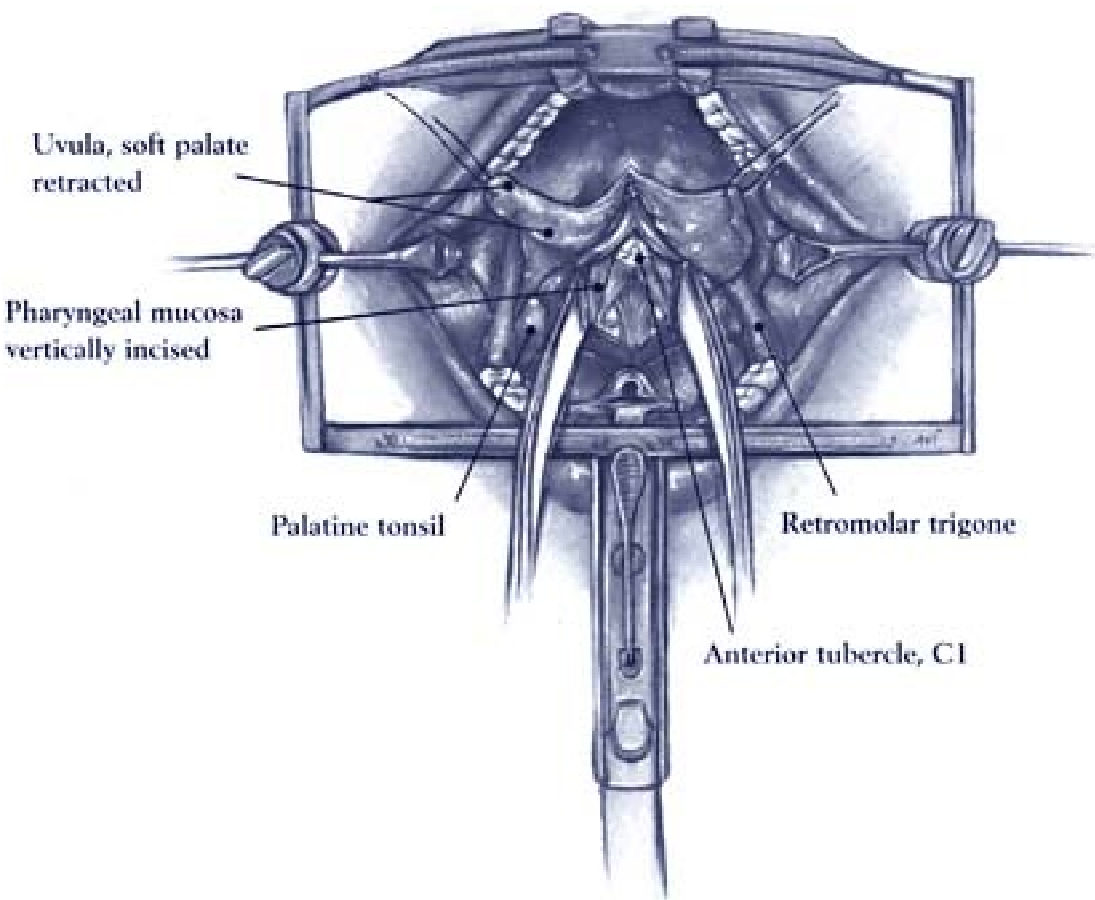


Figure 4

Placement of Dingman oral retractor and incision and retraction of the soft palate. Subsequent incision of the oropharyngeal mucosa and underlying musculature and placement of the Crockard retractor expose the underlying cervical vertebra

incisions are used. This lateral exposure may be increased using bilateral overlapping and laterally based soft tissue flaps. With this technique, the superficial flap includes the mucosa and submucosa and the deeper flap is comprised of the muscle and prevertebral fascia. Performing lateral-based flaps improves lateral exposure to 5–6 cm from mid-line and the overlapping layers help to reduce the incidence of leakage of cerebrospinal fluid or contamination with oropharyngeal secretions.

There are three basic options that can be further modified to fit the desired access. The first option is to simply retract the soft palate superiorly and incise the pharyngeal mucosa and muscles and prevertebral fascia (Figure 5). This approach would be adequate for lesions at lower C1–C3. The second option is to incise the soft palate and uvula in the mid-line and retract the left and right palatal flaps laterally to provide increased exposure rostrally. The oropharyngeal and nasopharyngeal mucosa and muscles are then incised in the mid-line and retracted laterally. This approach improves access and visualization in the upper C1–C2 region and mid-to upper clivus (Figure 5). The third option is to incise the soft palate and uvula and then rongeur or drill the posterior hard palate to further increase rostral exposure and visualization. This allows access to the superior clivus and sphenoid and lower sella region (Figure 6).

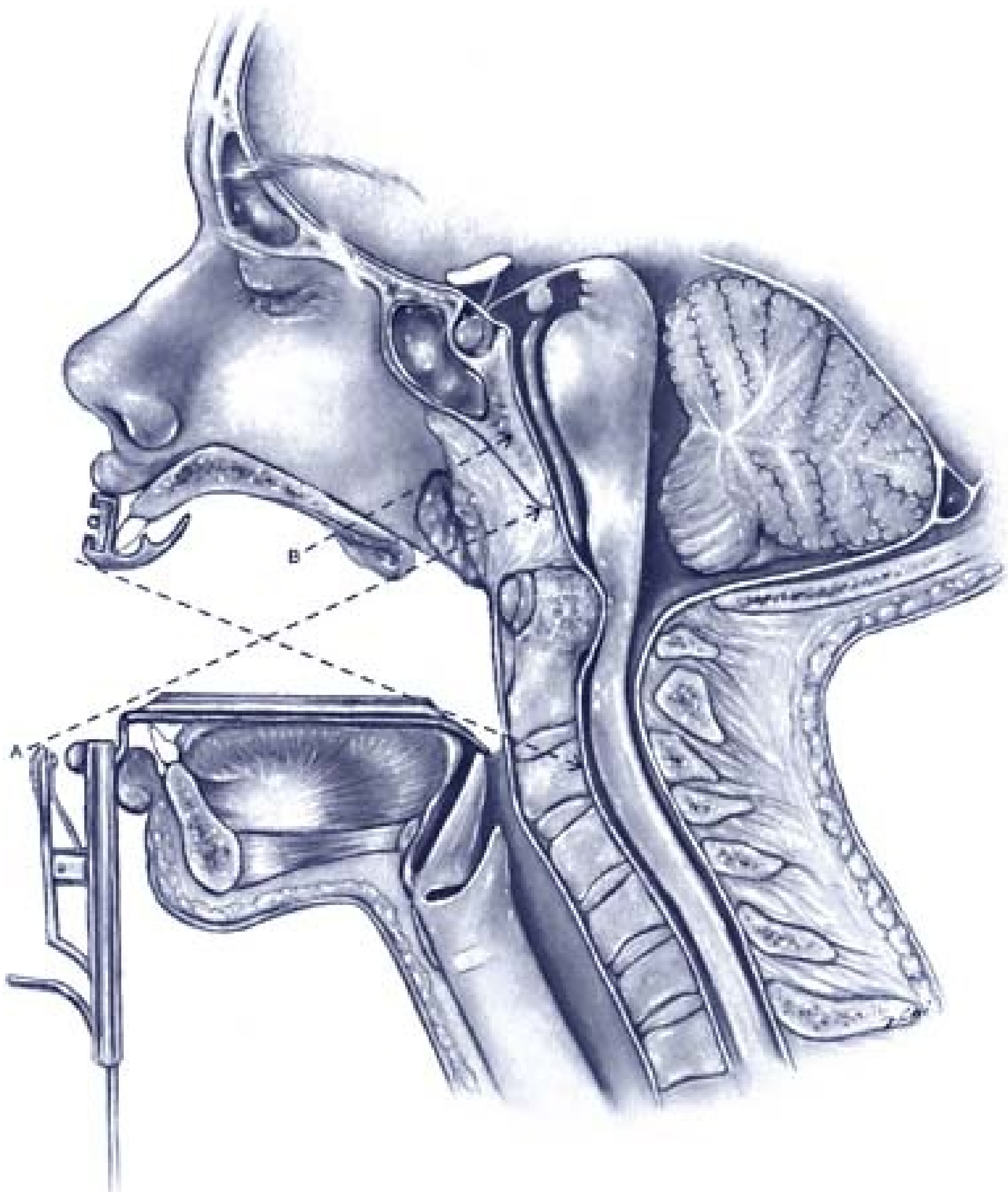


Figure 5

Sagittal drawing depicting the lines of sight (dotted lines) and extent of surgical exposure with retraction of the soft palate (A), or after incision and retraction of the soft palate (B), to expose an inflammatory or neoplastic process causing brain stem compression

Removal of anterior vertebral arches and odontoid process
The anterior tubercle of C1 can be palpated submucosally to help with orientation and placement of the pharyngeal incision. After incising the pharyngeal mucosa, the operating microscope is brought into the field. Under microscopic visualization, the prevertebral muscles and fascia are incised and dissected off the anterior arches of C1–C3, as needed, and extended superiorly to the clivus. Clival chordomas are typically exposed with the initial incision and dissection of the pharyngeal soft tissues;

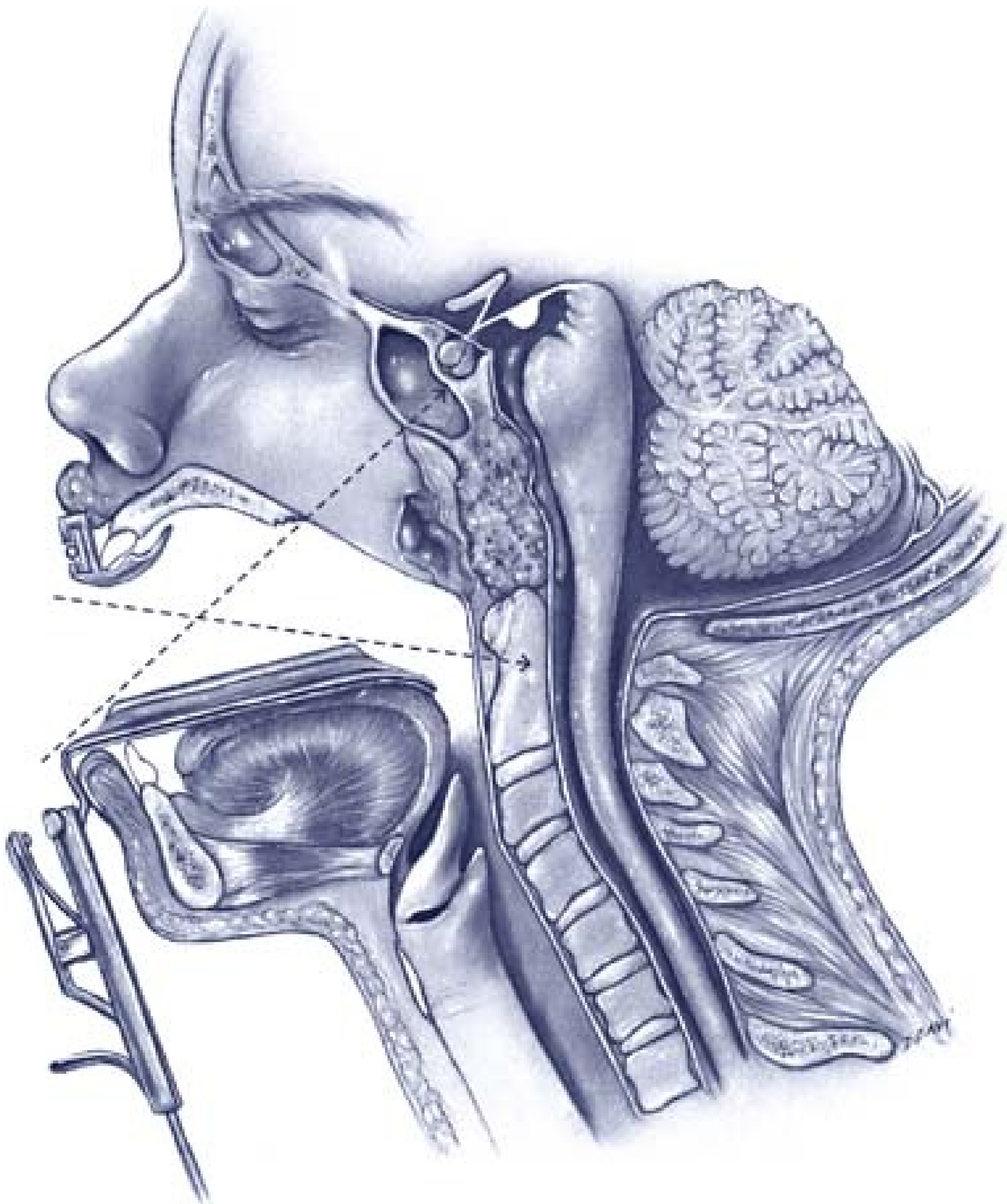


Figure 6

Sagittal drawing depicting the lines of sight (dotted lines) and extent of surgical exposure after soft palate incision and rongeur or osteotomy of the hard palate to expose a clival neoplasm

however, lesions of the odontoid process or intradural lesions require removal of the C1 arch and possibly the odontoid process itself. The anterior arch of C1 is removed by high-speed drilling using a diamond burr and suction irrigation, leaving a thin posterior cortex. After thinning C1, a diamond burr or curette is used to complete the resection of the posterior cortex and expose the odontoid process. Deep to the arch, the vascular pannus layer is encountered and is removed with cauterization to maintain hemostasis. Removal of the odontoid can be performed by drilling the mid-line and scalloping the odontoid to leave a thin posterior concavity of cortical bone that is removed using curettes or fine rongeurs. The distal tip of the odontoid is grasped with forceps and the alar and apical ligaments that are attached to the odontoid are identified and divided (Figure 7).

After removal of the odontoid, the transverse ligament and the posterior longitudinal ligament are divided to expose the dura. Adequate dural decompression is indicated by mobility of the dura which pulsates with the cardiac rhythm. Inadequate dural decompression usually results from residual bone in the lateral gutters of the exposed field. For intradural lesions, removal of the C1 arch and odontoid process is followed by a mid-line dural incision. The vertebrobasilar artery system and brain stem (anterior surface of the pons and medulla) or pathology surrounding these structures are now visible.

Surgical dissection and resection
After developing adequate exposure, the surgical resection will depend upon the nature of the pathology. Chordomas may be soft and easily removed by suction and gentle dissection. However, variations of consistency and composition are not uncommon. Chordomas may be gelatinous with islands of cartilage or may have multiple fibrous septated compartments. With this presentation, it is often difficult to distinguish the fibrous septations from reactive scar and fascia which often leads to a false assumption of complete tumor removal. Meningiomas and schwannomas at the basi-occiput are debulked with ultrasonic resection and the tumor capsule is removed with microsurgical dissection. Chondrosarcomas, on the other hand, vary from gelatinous to soft myxoid to cartilagenous. The firm cartilagenous sarcomas may require removal with a curette, high-speed drill, ultrasound, or laser dissection.

The ultrasonic dissector is an excellent tool to debulk the tumor and removal begins in the center and extends laterally and posteriorly, preserving the capsule or outer portion. Although the schwannoma usually has a well-defined capsule that facilitates dissection, other neoplasms may require piecemeal removal. Once the majority of the tumor is removed, fine dissection allows tumor removal from the important neural and vascular structures. For malignant neoplasms, it is the authors’ preference to resect the tumor up to the dura but not violate the dura, if possible. The dura provides a good barrier to the spread of tumor. It is therefore best to avoid opening or resecting dura in order to avoid spillage of malignant cells into the subarachnoid space. The exception to this general rule of leaving intact dura is the case where classical en bloc resection of the malignant tumor with definitive free margins is feasible.

Wound closure
Once the neoplasm has been removed, any dural tears or defects, if present, should be closed directly or reconstituted with grafts or flaps, as needed. Adequate dural closure will significantly decrease the risk of meningitis. For clival defects, a free fat graft may be harvested from the abdomen and used with fascia grafts in layers to close the defect. Thrombin fibrin glue may be used to help support the grafts and seal the closure.

Below the foramen magnum, there are two distinct soft tissue layers deep to the pharyngeal mucosa. The deepest layer consists of the superior constrictors, and the more superficial layer is the pharyngobasilar fascia. Each of these layers is closed with interrupted vicryl suture. The pharyngeal mucosa is then closed with chromic gut suture. A watertight closure helps to prevent leakage of cerebrospinal fluid and wound breakdown from exposure to oral secretions. The soft palate and uvula incision is closed in three layers.

For patients with preoperative craniocervical instability or those with resection of the odontoid and supporting ligaments, craniocervical fixation is maintained until a posterior fusion is performed. A lumbar drain may be placed either preoperatively or at the conclusion of the case before the patient awakens. Controlled lumbar drainage may minimize the risk of postoperative leak. A nasogastric tube is placed to manage stomach secretions and prevent reflux irritation or bathing of the surgical wound and for postoperative alimentation. Some patients may start clear liquid oral intake almost immediately after surgery and do not need a nasogastric tube. Patients with lower cranial nerve defects may benefit from percutaneous gastrostomy tube placement to support alimentation.

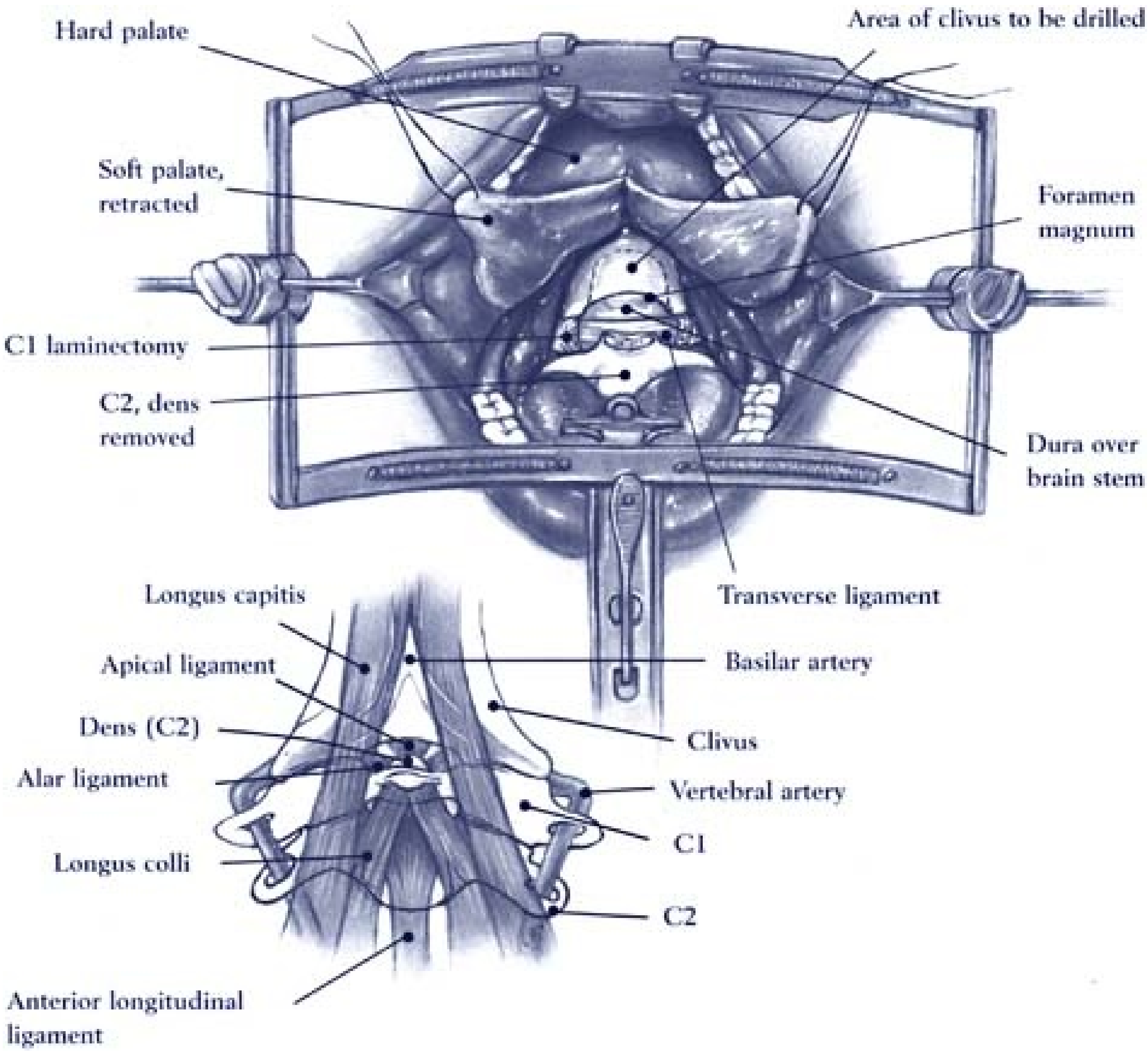


Figure 7

Drawing of the bony and soft tissue structures deep to the oropharyngeal mucosa (lower) and surgical view after resection of the arch of C1 vertebra and odontoid process of C2 vertebra (upper)

Postoperative care

Airway management is critical in the postoperative care of patients undergoing transoral approaches. If a problem with respiratory effort or management of upper respiratory secretions occurs postoperatively, the endotracheal tube and ventilatory support are maintained. For uncomplicated cases, the patient may be extubated in the intensive care unit after postoperative assessment of cardiovascular, respiratory, and neurologic status confirms the ability to extubate. For cases complicated by pharyngeal or tongue edema, the endotracheal tube may be removed after physical examination, fiberoptic laryngoscopy, and lateral cervical X-ray have confirmed the lack of obstructive swelling. For patients undergoing a delayed second-stage craniocervical fixation procedure within a few days of the transoral procedure, intubation and ventilatory support may be maintained until completion of the second stage.

Systemic broad-spectrum antibiotics, including anaerobic coverage such as a cephalosporin and metronidazole combination, are administered at the time of surgery and continued for at least 72 h postoperatively. Antiemetics and H2-blockers are administered and oral rinses with saline or Peridex rinses are performed every 4 h. Systemic or topical steroids are usually not necessary or advantageous unless the disease state warrants their use.

COMPLICATIONS

Airway compromise from pharyngeal edema may persist for several days and the patient should be remain intubated with ventillatory support until the edema has resolved. Risk of obstructive edema of the base of tongue is significantly reduced by intermittent release of the tongue retractor throughout the transoral procedure. Persistent pharyngeal edema may indicate the presence of infection and a CT scan can help to diagnose abscess formation.

Leakage of cerebrospinal fluid may result from inadequate dural and pharyngeal closure. A tight closure of the pharyngeal constrictor and mucosal layers should prevent this from occurring. Leakage of cerebrospinal fluid or wound breakdown carries a high risk of pneumocephalus and meningitis. The patient, nursing staff, and family should be educated about avoiding nose blowing and valsalva maneuvers in the postoperative period to reduce the risk of pneumocephalus and meningitis.

Bleeding may occur during the operation from epidural vessels, venous sinuses, or from injury to the vertebro-basilar arterial system. Cauterization may be used to control bleeding from the smaller vessels. Bleeding from injury to the vertebral artery at the vertebral foramen may be controlled with bone wax or Surgicel® or Avitene® packing.

ADDITIONAL READING

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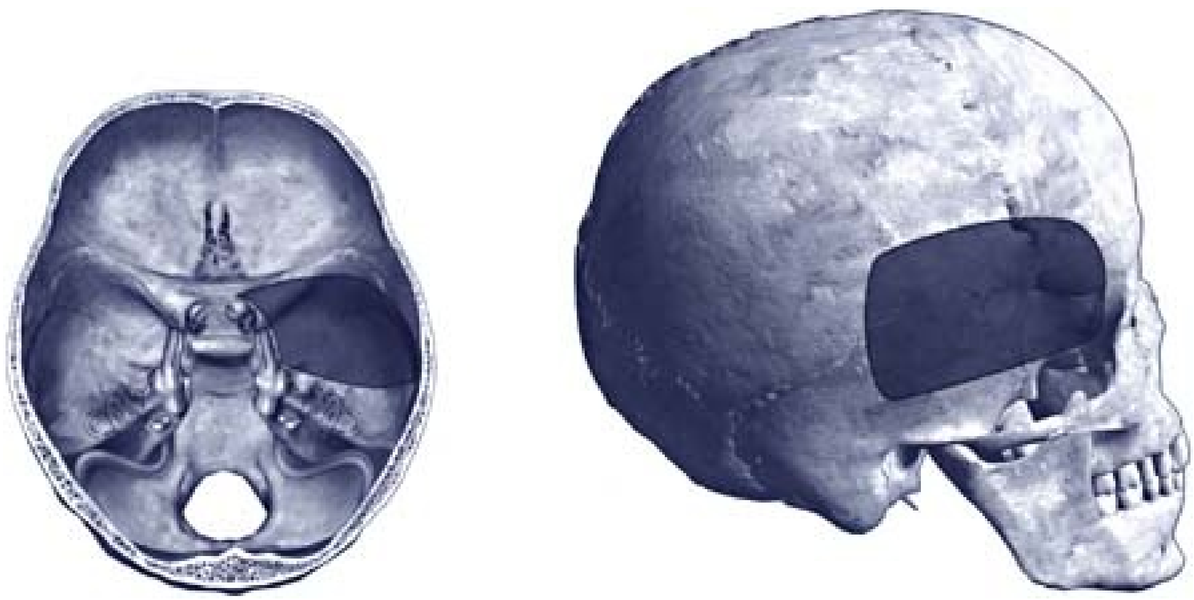
6
The pterional approach and its extensions

Donlin M.Long and Michael J.Holliday



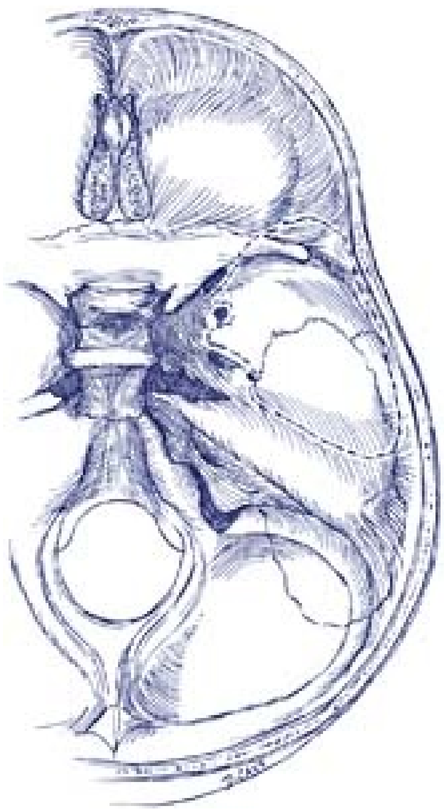


Figure 1

Access permitted by the pterional approach with its extensions includes the lateral anterior and middle cranial fossae, parapituitary area (parasella), orbit and optic canal, anterior clinoid, sphenoid ridge, and cavernous sinus

INDICATIONS

The pterional craniotomy and its modifications are essential to adequate exposure of lesions of the deep anterior skull base. These approaches provide lateral exposure of the anterior and middle cranial fossae, parapituitary area (parasella), orbit, optic nerve and canal, anterior clinoid, sphenoid ridge, and cavernous sinus (Figure 1). With the appropriate extensions, the pterional approach enables access to the entire lateral base of the skull from the ear canal forward. These extensions may include the addition of a middle fossa and infratemporal fossa approach to access structures in the middle and posterior cranial fossae or the addition of an orbital extension to access tumors superior and posterior to the orbit and under the frontal lobe. These approaches usually give full exposure of lesions of the sphenoid wing, including the pituitary fossa, optic nerve, cavernous sinus and petrous carotid artery, which are common sites of skull base involvement with meningiomas. The overall dissection takes the surgeon between the frontal and temporal lobes through the sylvian fissure (pterional approach), with additional exposure under the frontal lobe with minimal brain retraction (orbital extension). Bone removal from the floor of the anterior cranial fossa is performed to minimize brain retraction.

Typical lesions addressed with this type of approach include sphenoid wing meningiomas, large pituitary adenomas extending out of the sella, aneurysms of the carotid-ophthalmic junction and anterior arterial circulation, craniopharyngiomas and orbital tumors.

Figure 2

Intimate relationship of the cranial nerves within the region of the anterior middle cranial fossa

PATIENT EVALUATION

Clinical evaluation of the patient with tumors situated in the anterior and middle cranial fossae should include a thorough cranial nerve examination. This includes documentation of the visual acuity and ocular motility facial sensation and strength of the mastication muscles. These examinations will determine any preoperative neural deficits of cranial nerves II, III, IV, V, and VI which course through this region of the skull base (Figure 2)

Radiologic evaluation includes magnetic resonance imaging and computed tomography. Each offers invaluable information which is helpful during surgery. CT and MRI scans should provide information regarding the extent of the tumor and its relationship to the frontal and temporal lobes; to the orbit, optic nerve and cavernous sinus, and to the pituitary and sella (Figure 3). The tumor can often be differentiated from the surrounding brain if the tumor is enhanced with the aid of the intravenous paramagnetic agent gadolinium. Flow void signals will indicate the relationship of the tumor to the internal carotid artery, specifically the cavernous and petrous portions of the artery (Figure 4).

CT imaging provides information regarding the tumor-bone interface. Various degrees of bone erosion may be present. The numerous neurovascular foramina located in the floor of the anterior and middle cranial fossa should be evaluated in a systematic fashion to determine the degree of tumor involvement. These include the optic canal, superior and inferior orbital fissures, carotid canal, foramina spinosum and ovale. Evaluation of the bony structures, such as the anterior and posterior clinoid processes, sphenoid ridge, sphenoid sinus; sella, and orbital walls, helps the surgeon to localize the tumor (Figure 5).

Patients with tumors intimately involving the carotid artery should undergo either angiography or magnetic resonance angiography to determine the functional status of the anterior arterial circulation. For tumor types which require aggressive surgical resection and sacrifice of the carotid artery assessment of collateral arterial circulation is assessed via angiography and balloon occlusion testing. The latter test is usually performed with some form of functional neurologic evaluation after carotid occlusion; usually with clinical neurologic exam, EEG, xenon CT scanning, or SPECT scanning.

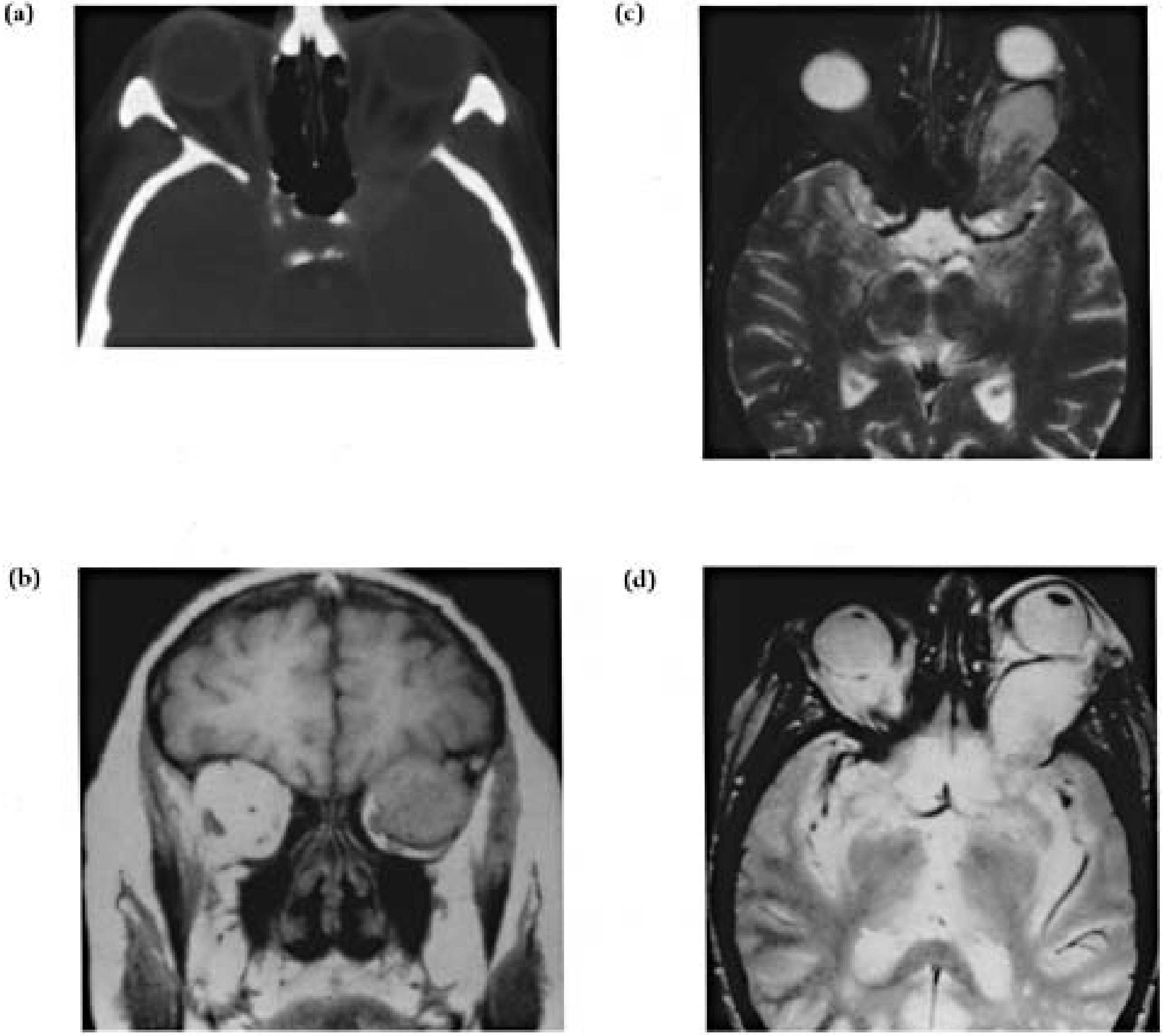


Figure 3

(a) Axial CT scan of orbital apex tumor (schwannoma) with bone erosion of sphenoid bone and intracranial extension; (b) T2-weighted axial MRI of orbital apex tumor showing medial displacement of the orbital contents; (c) T1-weighted coronal MRI showing extent of left orbital involvement by the tumor; (d) T2-weighted axial MRI scan demonstrating tumor enhancement and the plane between the tumor and orbit. Such a lesion is accessible via a pterional approach with orbital extension

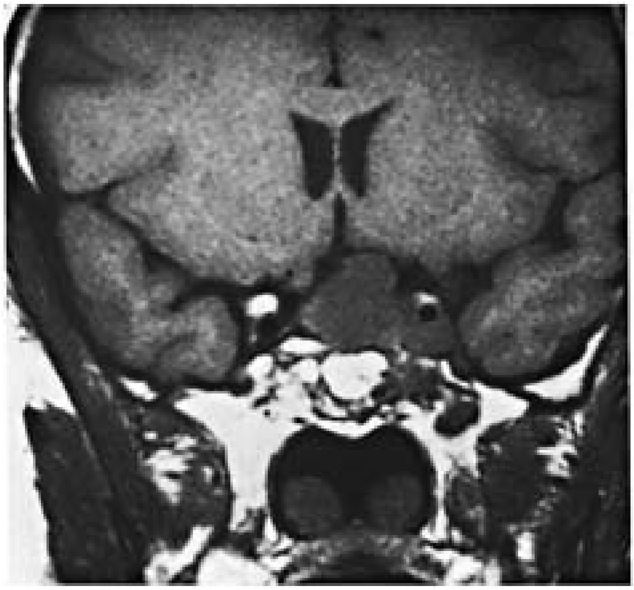


Figure 4

Coronal MRI showing suprasellar pituitary tumor. Note the relationship of the tumor under the optic nerves (subchiasmatic position) and the flow voids from the carotid arteries

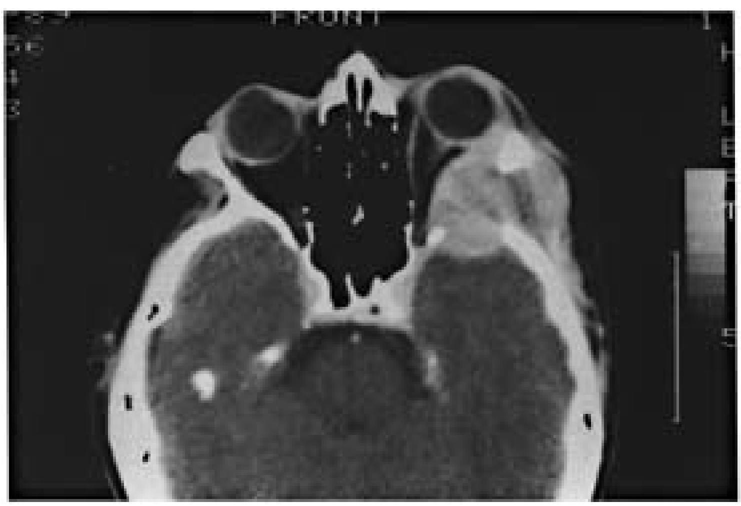


Figure 5

Axial CT scan showing metastatic tumor; initially thought to represent a meningioma involving the greater wing of the sphenoid bone and lateral orbit. Such a tumor may be approached by the pterional approach with an orbital extension

ANATOMICAL CONSIDERATIONS

Knowledge of the surgical anatomy within the region of the extracranial temporal and infratemporal regions and intracranial anterior and middle skull base is essential in order to carry forth the dissection successfully. From the outset of the operation prior to the craniotomy, the frontozygomatic branch of the facial nerve must be preserved when the scalp flaps are raised. The facial nerve lies lateral to the deep temporal fascia. The nerve is protected as long as dissection is maintained deep to the deep temporal fascia. Alternatively, the main trunk of the facial nerve may be identified within the parotid gland if the inferior limb of the incision extends to the preauricular area. The frontozygomatic branch is traced distally to identify and protect the facial nerve. Preservation of the superficial temporal artery in the preauricular area is important for reconstructive purposes, and injury to the main artery must be avoided when the incision is carried into this area. Maintenance of temporalis muscle viability is important to prevent cosmetic deformity and to restore function. Therefore, the deep temporal arteries on the medial aspect of the temporalis muscle, traversing through the mandibular notch, should be protected when turning down to muscle over the zygomatic arch.

Once the soft tissue and periosteum are cleared from the temporal fossa, the greater wing of sphenoid, frontal bone, zygoma and superolateral orbital rim, preparations are made for the bone work. The pterional approach requires removal of a bony plate (known as the ‘keyhole’) posterior to the lateral orbital rim (posterior to the zygomatic process of the frontal bone and frontal process of the zygomatic bone) at the level of the floor of the anterior cranial fossa (Figure 6). Additional bone removal from the supraorbital region and zygoma is required for the orbital extension. If an orbital extension is planned, the pterional bone flap incorporates a segment of frontal bone above the orbit, superior and lateral orbital walls, and zygoma (Figure 7).

Intradurally after removal of the cranium and facial bones, several landmarks should be sought. Identification of the frontal and temporal lobes is usually evident. The sylvian fissure lies between the frontal and temporal lobes. Dissection through this portal is a key feature of the pterional approach (Figures 8 and 9). Once the frontal and temporal lobes are identified and retracted away from each other, access to the suprasellar region is permitted. Bony landmarks, such as the sphenoid ridge, anterior clinoid process, and the remainder of the floor of the anterior cranial fossa, are identified. Extradurally and within the petrous apex bone, the petrous carotid artery may be identified after bone removal in Glasscock’s triangle; bordered by the middle meningeal artery, greater superficial petrosal nerve, and the trigeminal ganglion/V3 complex in Meckel’s cave.

Once dural entry is made and the frontal and temporal lobes are retracted away bone removal of the sphenoid ridge, anterior clinoid process, and superior lateral orbital walls is performed. This allows for access into the lateral suprasellar space. Additional bone removal of the orbital roof through the orbital extension will permit access under the frontal lobe.

PROCEDURE

The patient is placed in the supine position with the head turned 45–60° toward the opposite side. Alternatively, the patient can lie supine and secured on the operating table; rotated away from the surgeon until the zygoma is parallel to the floor. The choice of patient positioning, however, is really the surgeon’s choice because the surgeon’s approach angle into the anterior-middle skull base will dictate the patient positioning.

The skin incision follows the hairline from the frontal region down into the temporal area and resembles an elongated question mark (Figure 6). For the standard exposure, the inferior limb of the incision stops just above the zygoma anterior to the ear. The closer the incision is to the ear, the greater the subtemporal exposure. It is cosmetically best to keep the incision hidden within the hairline.

In the elevation of the scalp flaps, division of the superficial temporal artery should be avoided if possible, particularly if there is any thought that an arterial anastomosis would be needed to reconstitute the carotid artery Partial transection of the superficial temporal artery in its anterior frontal division may be performed if necessary.

The skin flap is dissected forward in a plane just above the temporalis fascia. At the anterior margin of the temporalis muscle, the surgeon encounters a plane of fat between the galea and temporal fascia. By staying close to the temporalis muscle, the surgeon is enabled to lift this plane in its entirety. This fascial plane contains the zygomaticofrontal branch of the VIIth nerve and avoids transection injury during the dissection, as the nerve is lifted up with the temporalis fascia.

The temporalis muscle is exposed in its entirety. There are several ways to deal with the temporalis muscle, depending upon what is planned. In a true osteoplastic flap, the temporalis muscle is left attached to the bone along the broad origin of the muscle. An incision is made through

(a)

(b)

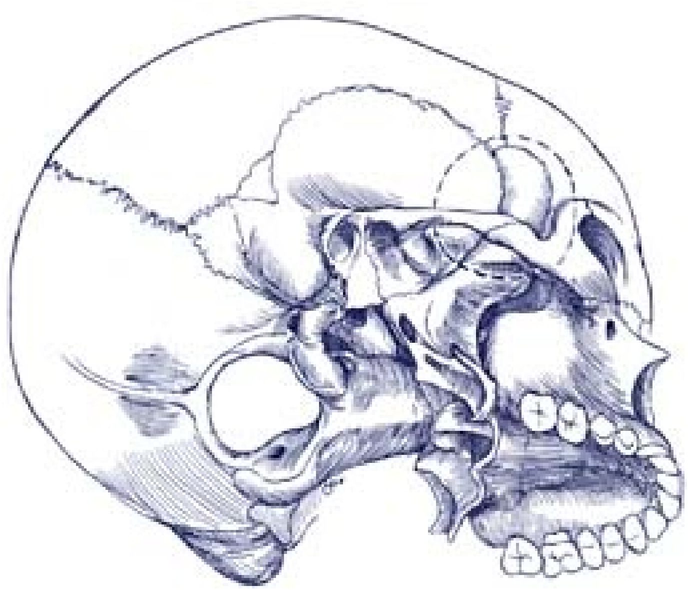


Figure 6

The basic pterional approach. (a) Dotted lines demarcate skin incisions with the more posterior skin incision allowing greater subtemporal exposure. The bony craniotomy is through the 'keyhole' region; (b) pterional craniotomy from inferior vantage point

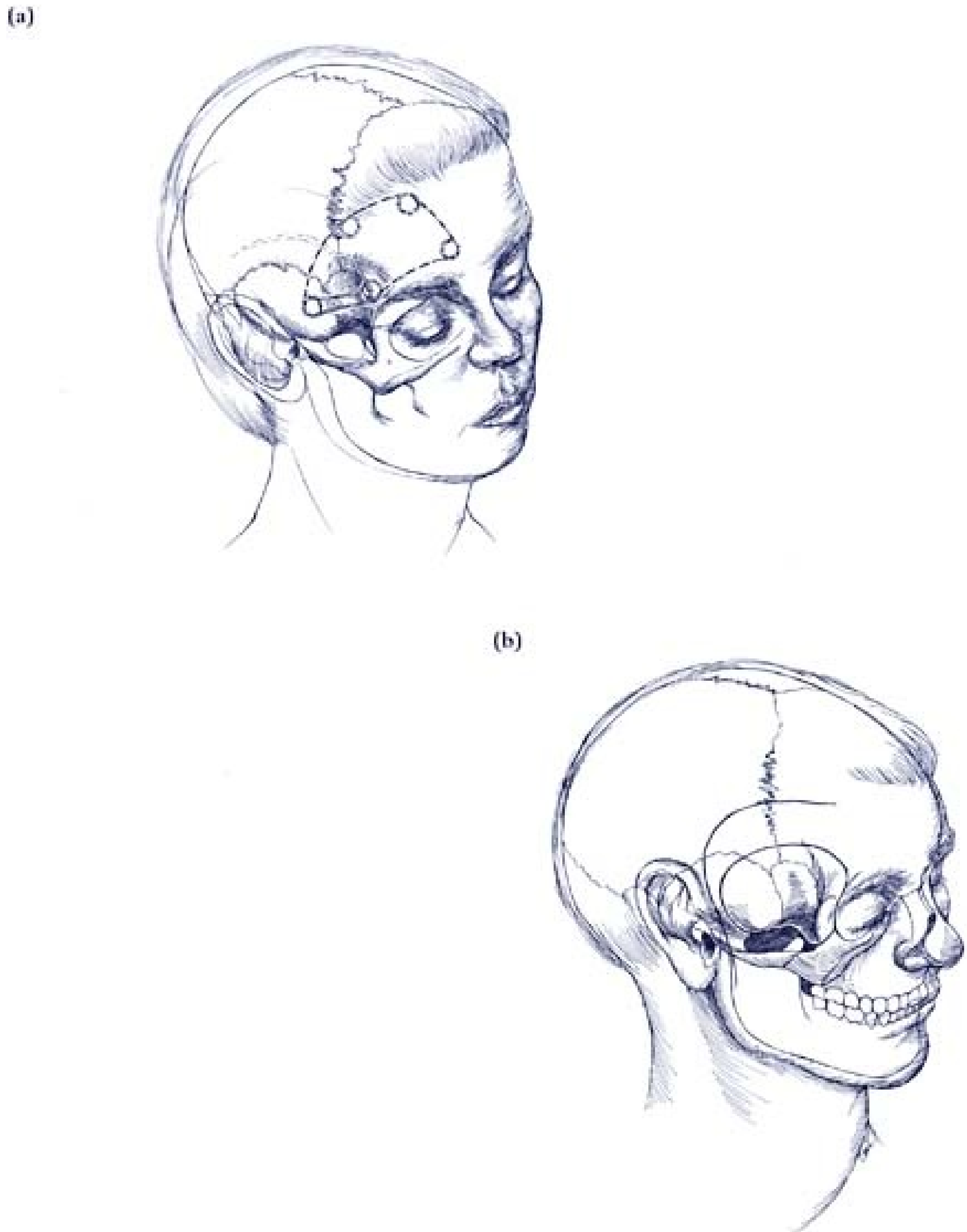


Figure 7

The orbital extension to the pterional approach involves additional bone removal from the (a) frontal bone or (b) lateral orbit

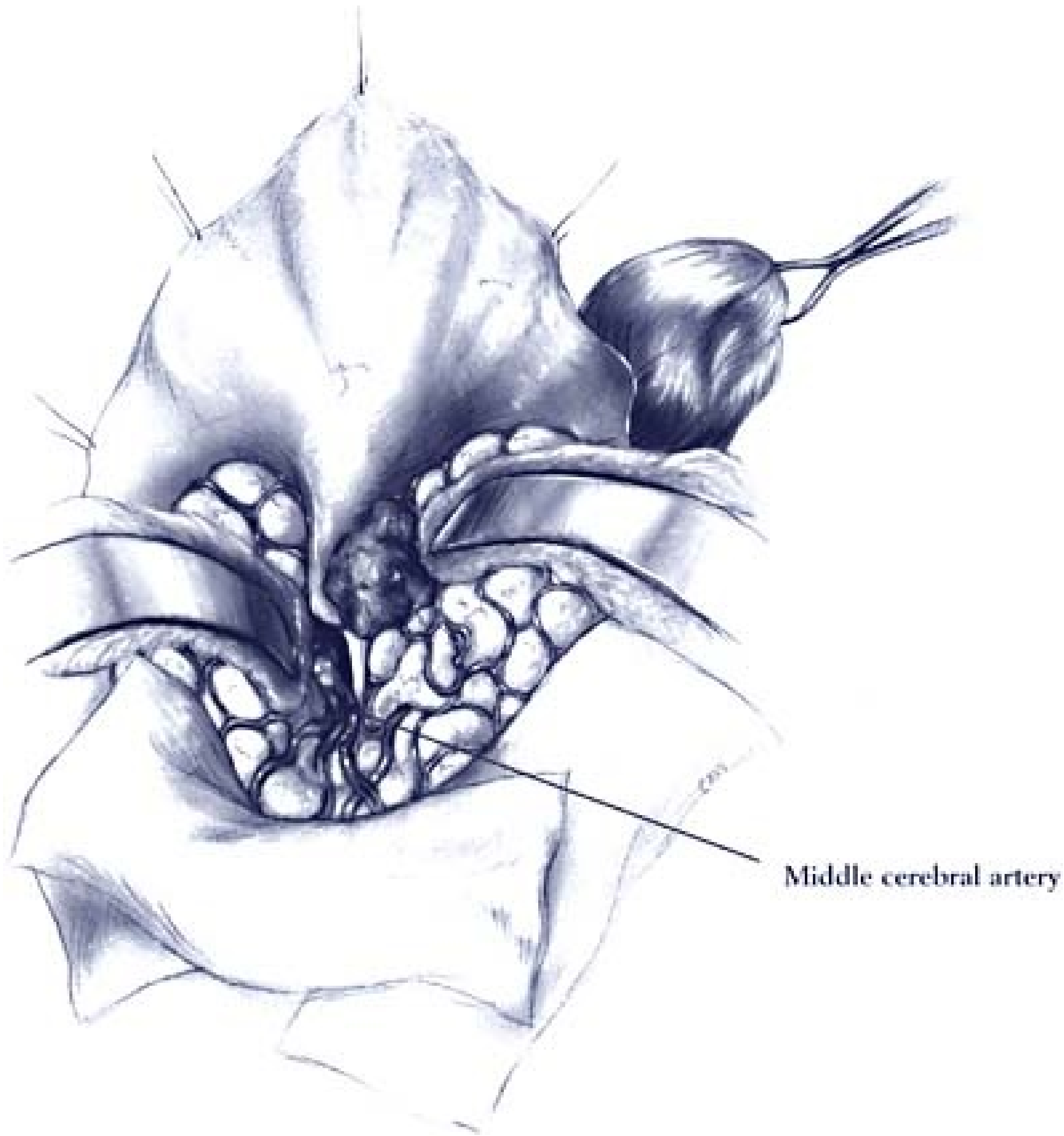


Figure 8

Right frontal and temporal lobes are retracted to create a portal through the sylvian fissure. Pictured is a sphenoid wing meningioma

temporalis muscle from superior to inferior along the line of the posterior margin of the skin incision and then anteriorly from the keyhole down to the zygomatic arch. The muscle is divided sharply and the bone exposed to allow saw cuts to be made.

An alternative technique is to cut the temporalis muscle along its broad attachment on the squamous portion of the temporal bone and frontal bone at the superior temporal line. A 2-cm cuff of fascial insertion of the temporalis muscle is left for suturing the temporalis muscle to return it to its original position during wound closure. The entire belly of the temporalis muscle is dissected free from the underlying bone and retracted inferiorly over the zygomatic arch.

Some have suggested simply dividing the temporalis muscle parallel to the zygomatic arch, but this leads to substantial temporalis muscle atrophy and loss of tissue support and volume. This occurs as the result of denervation of the muscle; as well as interruption of the blood supply to the muscle from the deep temporal artery.

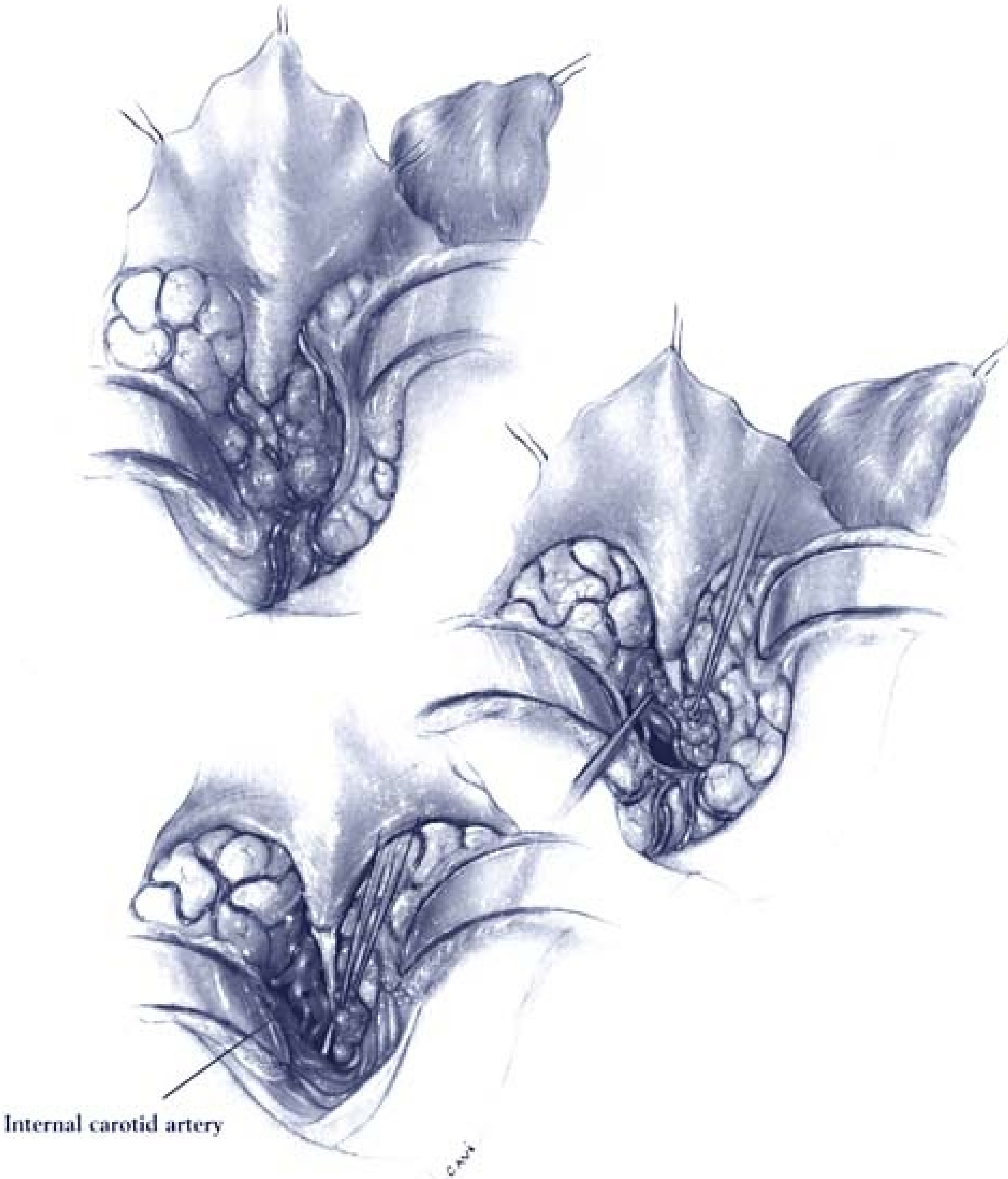


Figure 9

Sequential tumor dissection per pterional approach of a right medial sphenoid wing tumor

A third variation of skull exposure is to dissect deep to the temporalis muscle, leaving it attached to the skin flap. With this approach, the muscle is transected parallel to the posterior limb of the incision and from the entire attachment to frontal and temporal bones. This has the disadvantage of leaving a sizeable muscle mass with the reflected scalp flap, which sometimes obstructs the surgical view, particularly for lesions that extend anteriorly along the orbital wall.

Whichever technique is used to deal with the temporalis muscle, the placement of the bony incision is the same. The bone flap can be turned with one or more access burr holes, depending upon the age of the patient. In older patients, it is better to use more; in younger patients without adherent dura, one burr hole may be entirely adequate.

This final exposure is focused on what is termed the ‘keyhole’ in neurosurgery slang. This is the bony opening just posterior to the zygomatic process of the frontal bone, and above the upper border of the zygomatic arch. The keyhole is placed at the root of the zygomatic process of the frontal bone overlapping temporal and frontal bones. This essentially approximates the floor of the anterior cranial fossa at the orbital-frontal junction.

The dura should be exposed after removal of the bone plate. If other holes are made, they are made along the line of the bone flap. A power saw is used to cut the flap between burr holes and in the mid-line of the muscular incisions through the temporal squamosa as low as possible. It is usually feasible to simply break the thin temporal bone across the base.

Once the bone flap is removed, a high-speed drill is used to remove the greater wing of the sphenoid bone as low as possible, to provide access to the floor of the middle fossa and the anterior clinoid process.

Variations in the technique of exposure

Transzygomatic exposure

When access to the infratemporal fossa is required, some minor changes are required in the exposure. The skin incision is extended down in front of the ear towards the angle of the jaw. If the incision is kept just behind the posterior border of the mandible, it can be hidden in a manner similar to a rhytidectomy or parotidectomy incision.

The extension will allow the zygoma and the masseter muscle below to be identified. The zygoma arch can then be cut at either extremity. Bevel the bony cuts and use a fine-bladed saw in order to allow perfect apposition. When ready for closure, the zygomatic arch is replaced and held in place with pre-fashioned titanium microplates and screws. Once the zygomatic arch is divided, the temporalis can be cut along its insertion on the temporal bone squamosa and elevated from the temporal bone. Muscle can be lifted from the mandible so the entire side of the skull from the angle of the mandible to the frontal region is exposed. This provides access to the upper infratemporal fossa (Figure 10).

Transmandibular approach

Occasionally, it is necessary to obtain greater access to the infratemporal fossa and region of the pterygoid plate. To do this, the incision is extended along the anterior border of the sternocleidomastoid muscle and the carotid sheath is exposed. The dissection should identify the carotid artery, vagus and hypoglossal nerves, and the internal jugular vein. The muscular dissection through the pterygoid muscles exposes the mandible and lateral aspect of the skull.

A key concern with infratemporal exposure is the required dissection of the VIIth nerve in the parotid gland. The main trunk of the facial nerve is located, based on landmarks of the tympanosquamous suture line, the tragal pointer and the digastric muscle. The main nerve trunk is followed into the parotid gland to the pes anserinus, and each division is mobilized.

Once the VIIth nerve is mobilized, access to the pterygoid region and lower infratemporal fossa can be obtained by one of three techniques:

(1) The temporomandibular joint can be dislocated and inferiorly retracted to provide the access;

(2) The mandible can be transected at the base of the condylar process;

(3) The mandible can be transected across the body of the mandible.

An angled cut with a fine-bladed saw allows apposition with pre-fashioned microplates and screws during closure. Using either technique, the mandible is displaced anteriorly and

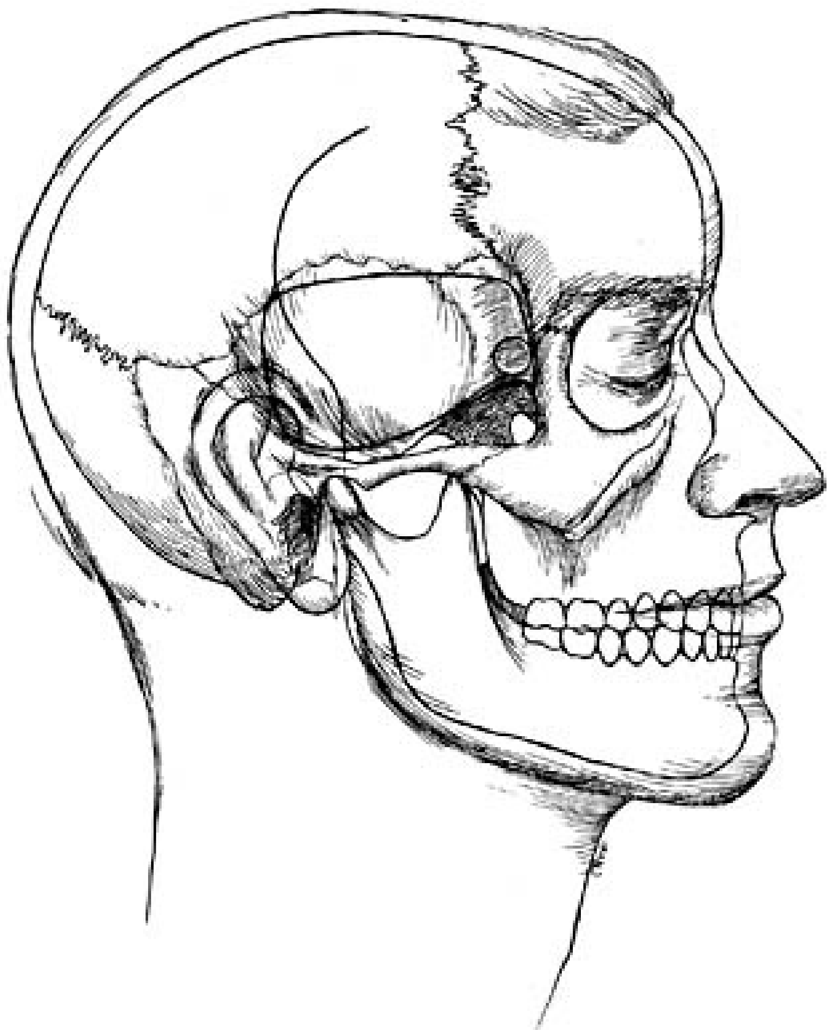


Figure 10

Transzygomatic extension of the pterional approach to gain access to the infratemporal fossa. Cuts are made on the zygomatic arch to mobilize and displace it inferiorly to expose the infratemporal fossa

thus provides access to pterygoid musculature and pterygoid plates. The plates can be removed with drill or rongeur and the pterygoid muscles sacrificed, if necessary. This provides access to the infratemporal and retropharyngeal spaces from the lateral approach and has the advantage of providing control of the vertical segment of the carotid artery, if the vessel is injured during the deep dissection.

Orbital extension

The orbital extension to the pterional approach will help to gain further access to the anterior cranial fossa floor and under the frontal lobe of the brain. Anterior extensions of the ‘keyhole’ bone flap are created to incorporate the superior and lateral orbit and zygoma (Figure 11). Once the

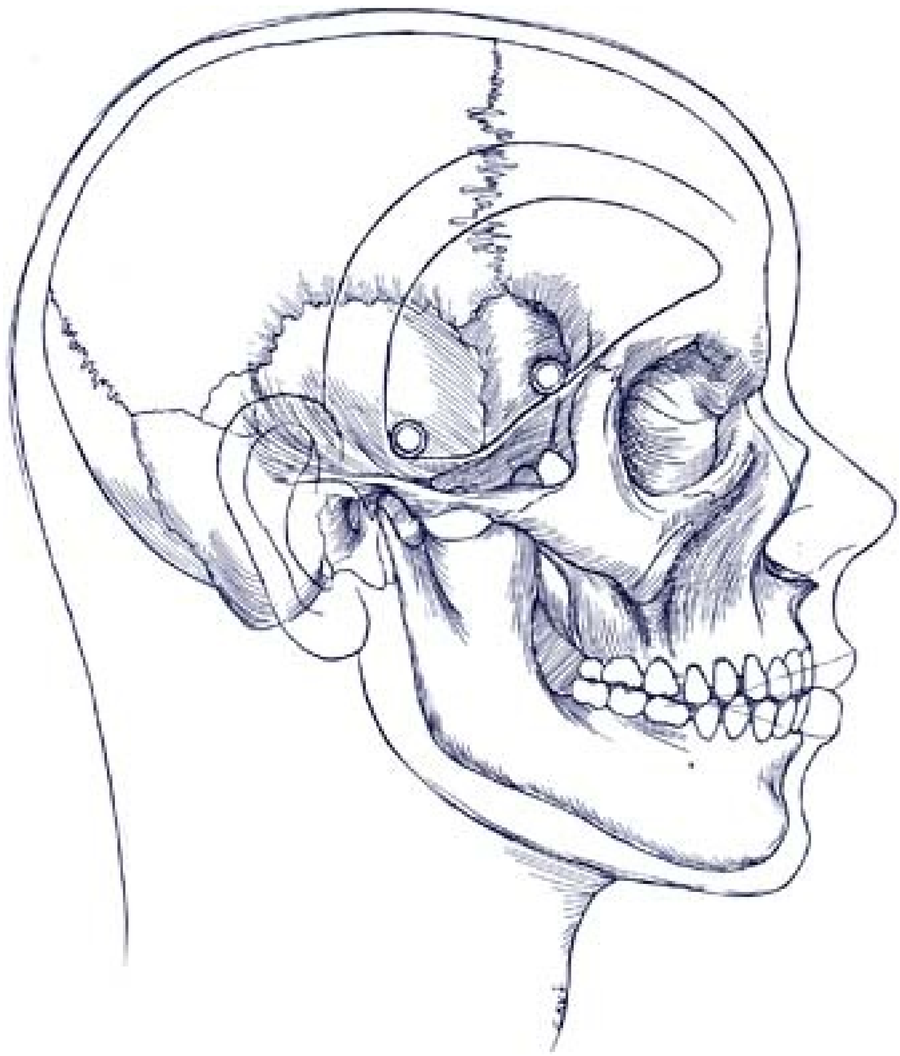


Figure 11

Orbital extension of the pterional approach. Further exposure toward the anterior cranial fossa is achieved. The orbital roof may be removed to minimize frontal lobe retraction

craniofacial bone segment is removed, the bony orbital confines within the anterior cranial fossa are drilled away including the sphenoid wing and anterior clinoid process, as needed for exposure. In this way, the maximal bone removal is made to minimize frontal lobe retraction. Similar exposures of this type have been described in the 'cranio-orbito-zygomatic approaches', differing by only the amount of frontal and zygomatic bone removed. The bony segments are either replaced or reconstruction with titanium mesh is performed during closure.

A host of tumors may be accessed with this approach, including optic nerve sheath tumors/meningiomas (Figure 12) (Appendix I), pituitary tumors with suprasellar

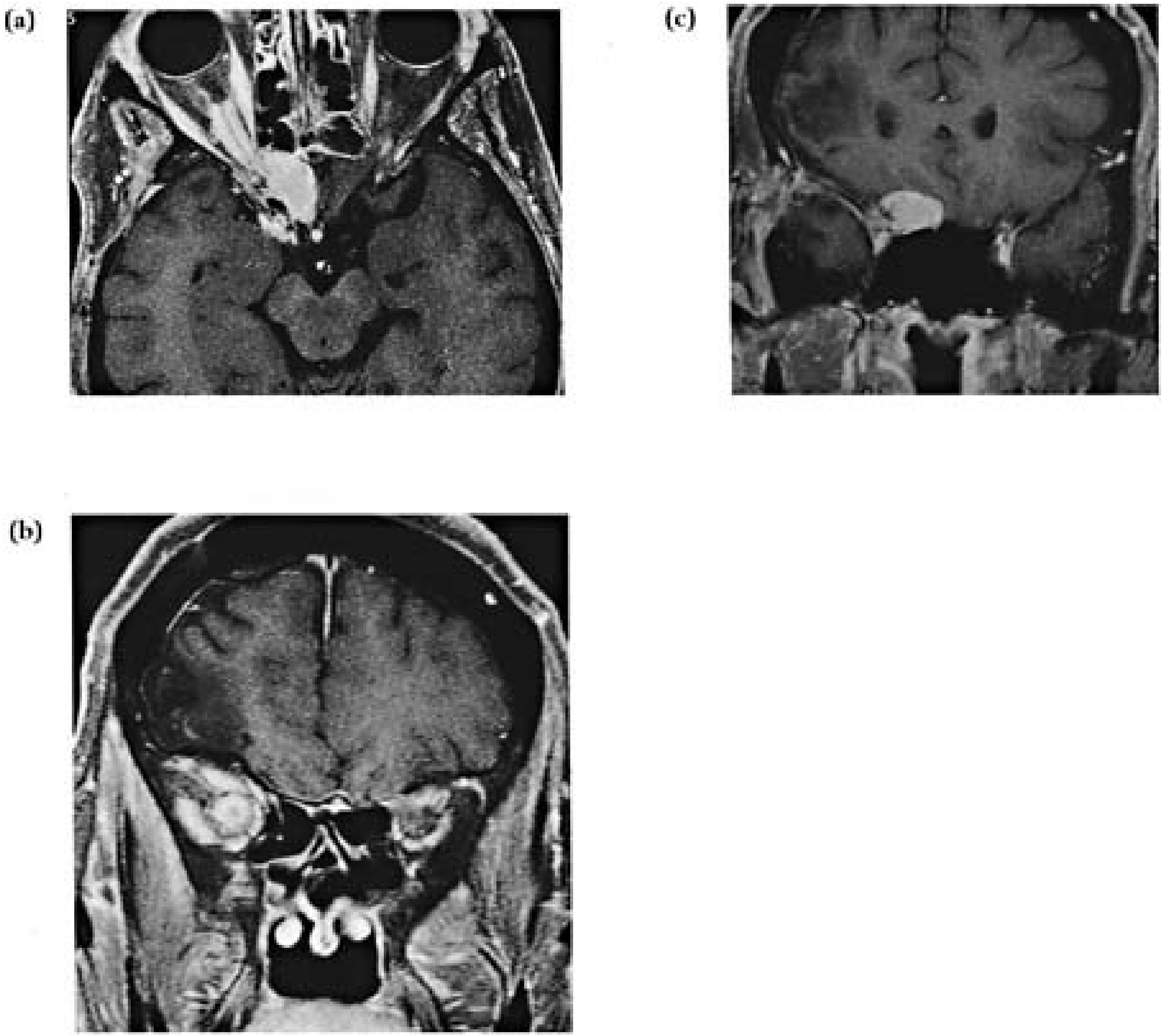


Figure 12

Optic nerve sheath tumor. (a) T1-weighted axial MRI of right optic nerve sheath tumor. Note the posterior medial extension towards the optic chiasm; (b) T1-weighted coronal MRI of same tumor in the anterior orbit; (c) T1-weighted coronal MRI of the same tumor under the frontal lobe in the posterior orbital

extension to the subchiasmatic area (Figure 4) (Appendix II), meningiomas in proximity to the planum sphenoidale (Appendix III), and tumors in proximity to the cavernous sinus (Appendix IV).

Wound closure

Closure of these various incisions is straightforward, but several steps can reduce postoperative morbidity. The temporalis muscle should be replaced as near to the anatomical position as possible and the temporalis fascia closed, if possible. In virtually all cases, we now replace the lateral aspect of the sphenoid wing and the temporal squama with molded titanium mesh, which is shaped to replicate the removed bone. The zygoma and mandible, if divided, must be reapproximated with anatomical accuracy, paying attention to restoration of proper dental occlusion and cosmesis. It is important that the masseter muscle is not injured and that it is replaced in its normal anatomic relationship with the bone. Plate and screw systems which anchor the bone flap solidly are particularly important for the pterional flap because of the pull of the temporalis muscle, which is both painful and retards bone healing. A mobile bone flap is often so painful that it requires repair. Moreover, attention given to the cosmetic result (sculpting the bony defect and repositioning of viable temporalis muscle) during closure will reduce the likelihood that any subsequent plastic procedures will be required.

COMPLICATIONS

Complications arising from the pterional-supraorbital approach include potential injury to the extracavernous portions of cranial nerves III and IV, leading to diplopia. Due to bony decompression of the orbit in the superior and lateral walls, enophthalmos may occur. Cosmetic deformities may result if the bone flaps and soft tissue are not returned to their appropriate anatomic position. Injury with resultant brisk hemorrhage of the carotid artery anterior cerebral circulation, or cavernous sinus are possible. Control of the petrous portion of the carotid artery, by passing a balloon catheter in the carotid bony canal adjacent to the artery, may precede any tumor removal to prevent this complication.

ADDITIONAL READING

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Haines SJ, Marentette LF, Wirtschafter JD. Extended fron-to-orbital approaches to the anterior cranial base: variations on a theme. *Skull Base Surg* 1992;2:134–41

Jane JA, Park TS, Pobereskin LH, Winn HR, Butler AB. The supraorbital approach: technical note. *Neurosurgery* 1982;11:537–42

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Appendix I Pterional approach with orbital extension

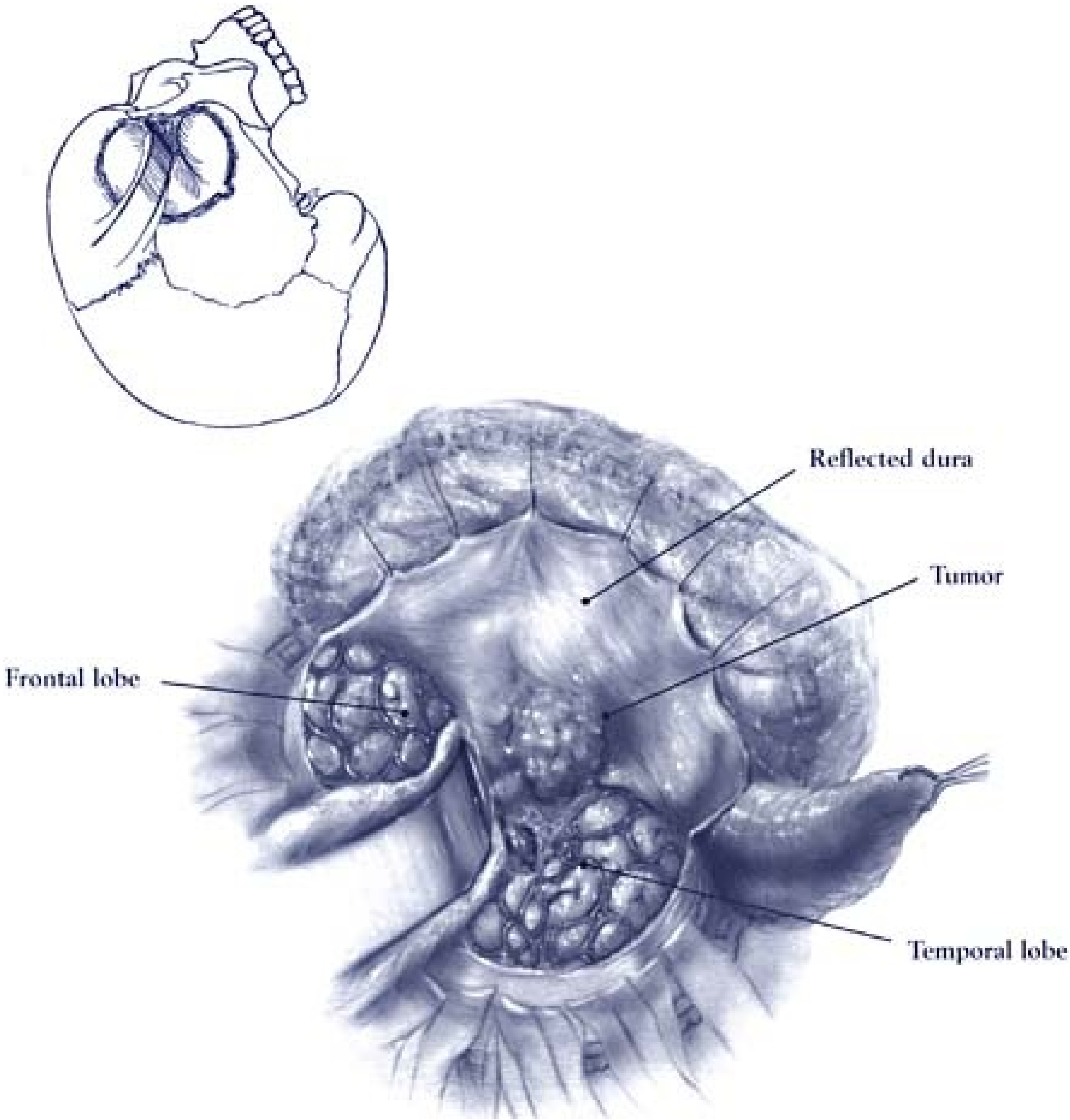

Plate 1

Intradural dissection is carried through the sylvian fissure via orbital extension of the pterional approach. The frontal lobe is retracted superiorly to expose the optic nerve sheath tumor

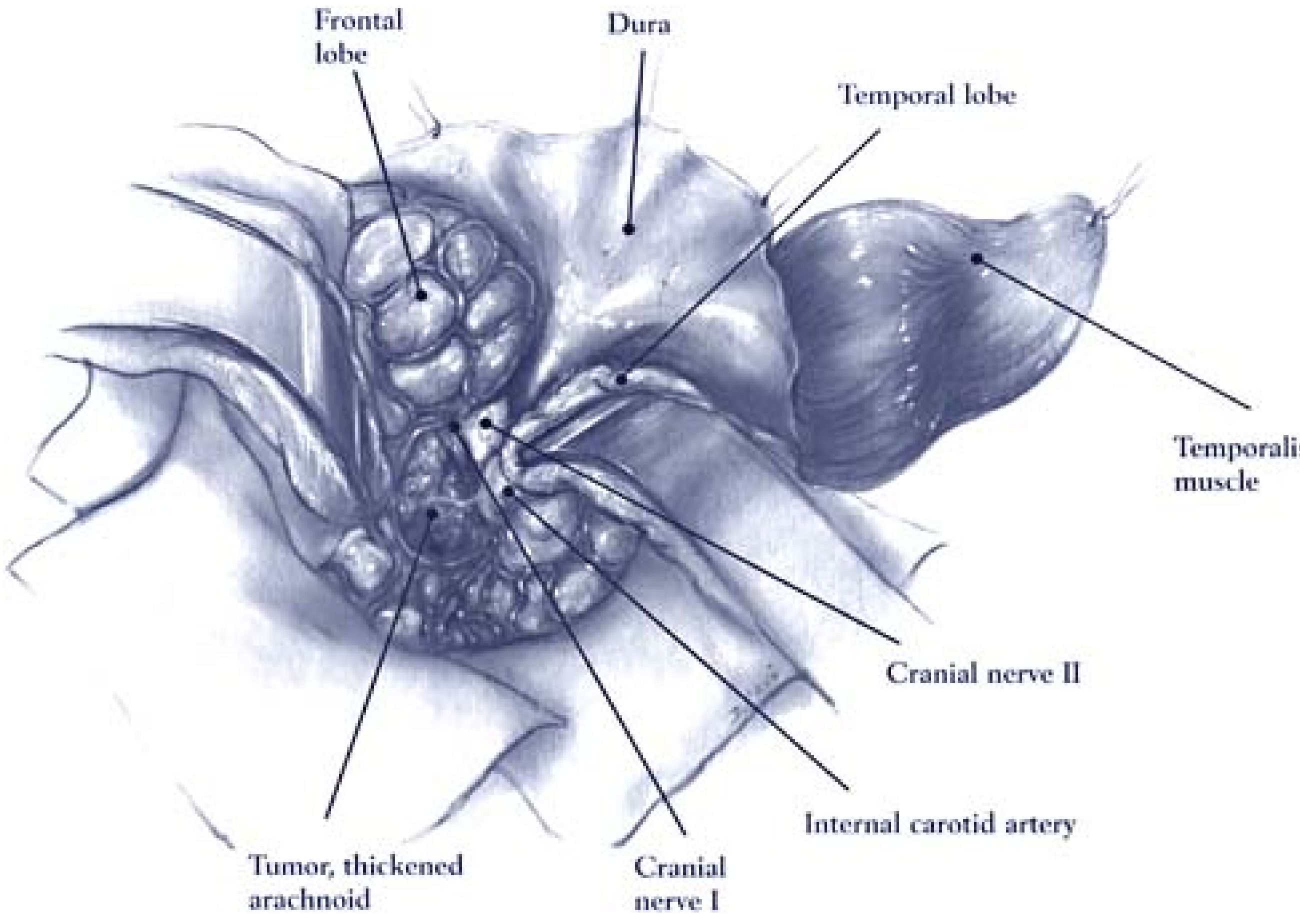

Plate 2 Initial intradural operative view. The tumor is shown with thickened arachnoid. Note the additional exposure with the right temporal lobe retracted inferiorly

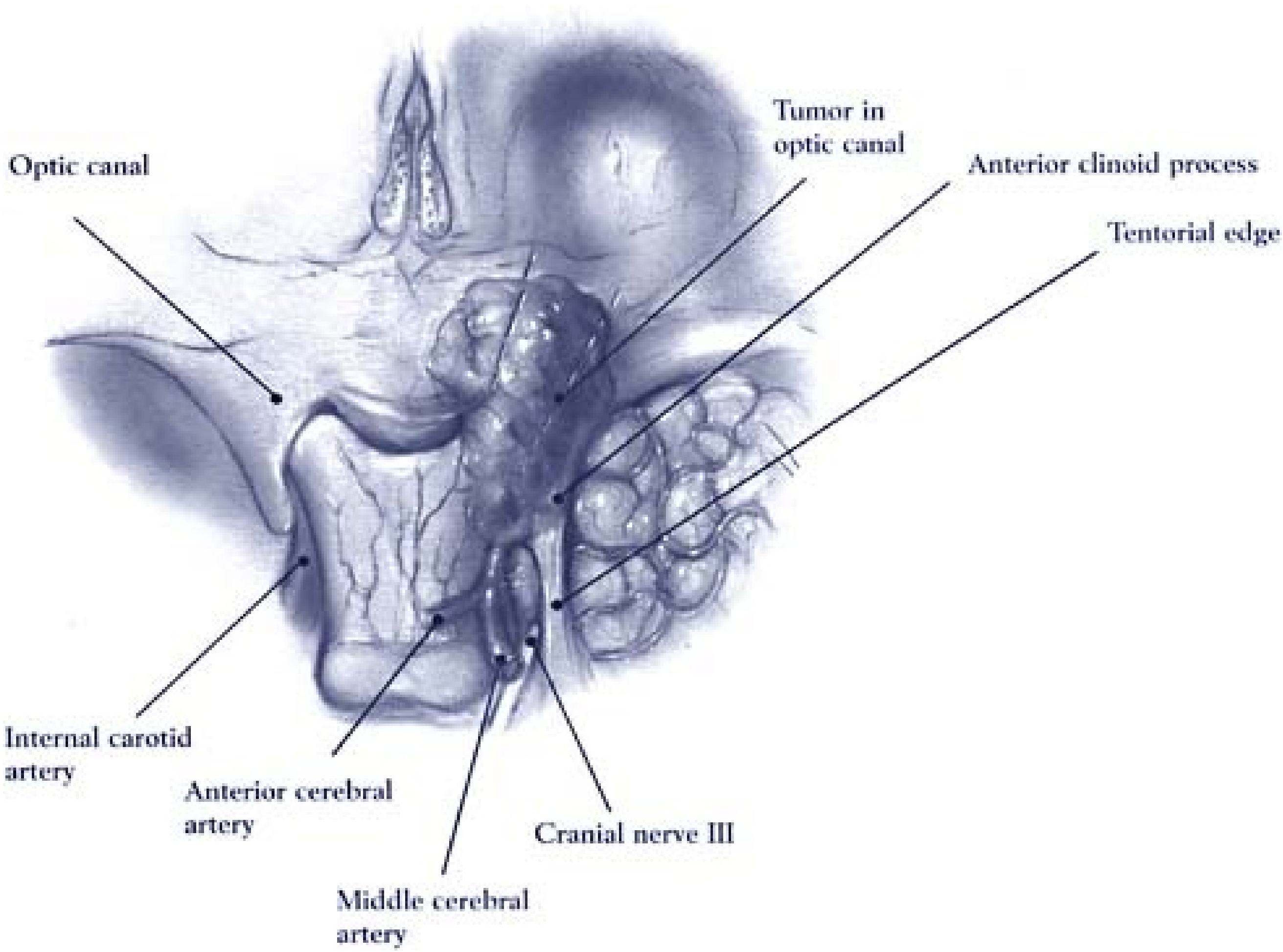

Plate 3

The tumor is shown within the optic canal. Dashed lines demarcate the outlines of the optic canal. There is extracanalicular extension of the tumor

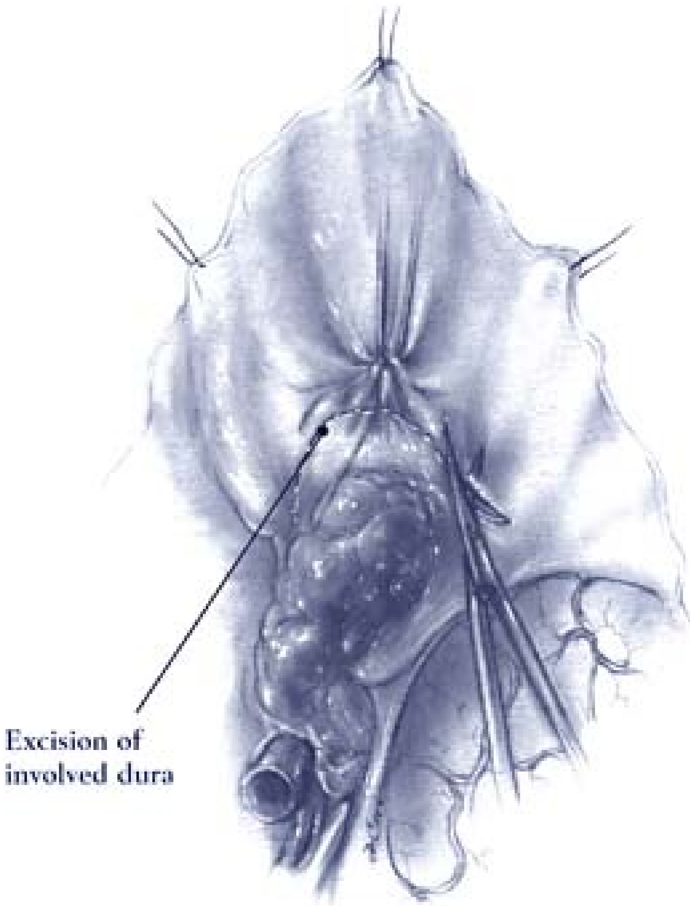

Plate 4

Involved dura is resected along with the tumor specimen

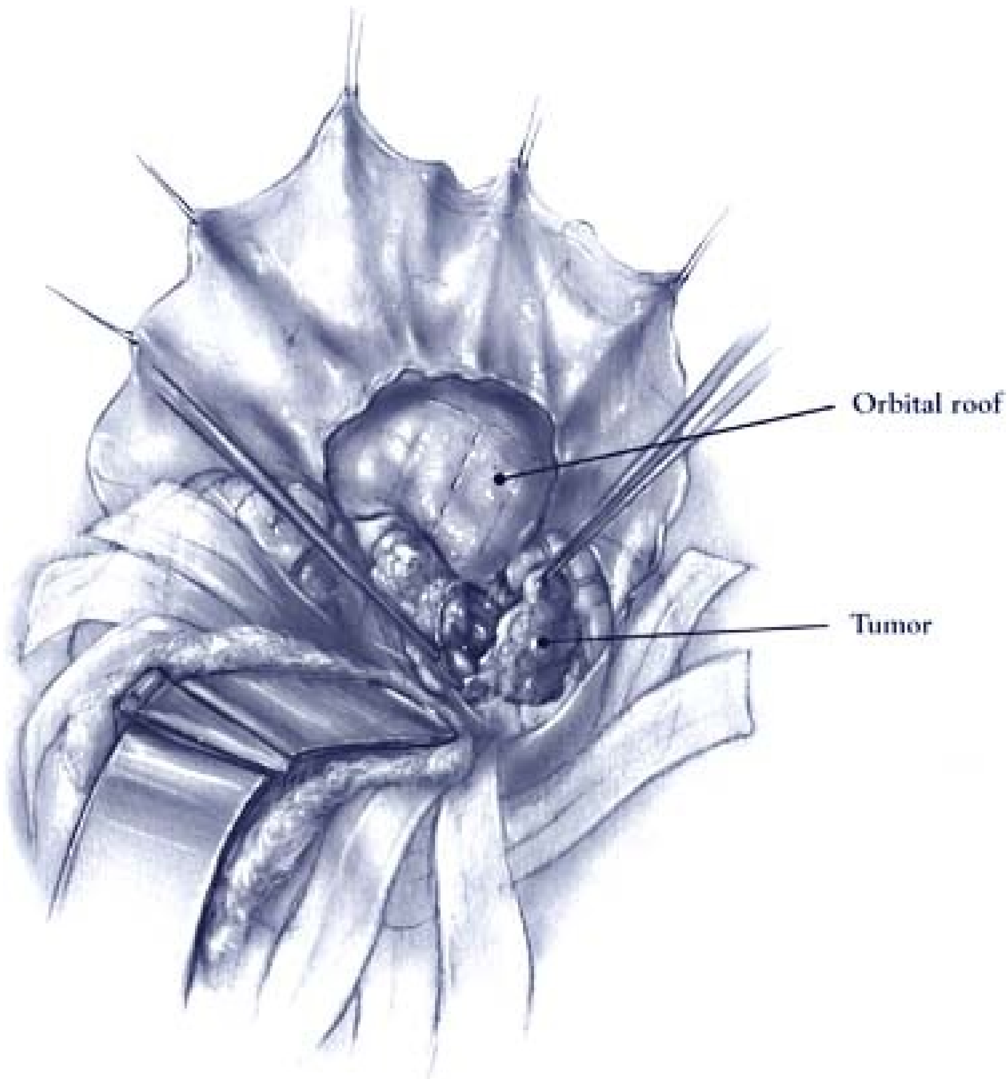

Plate 5

The dural incision is made over the optic canal

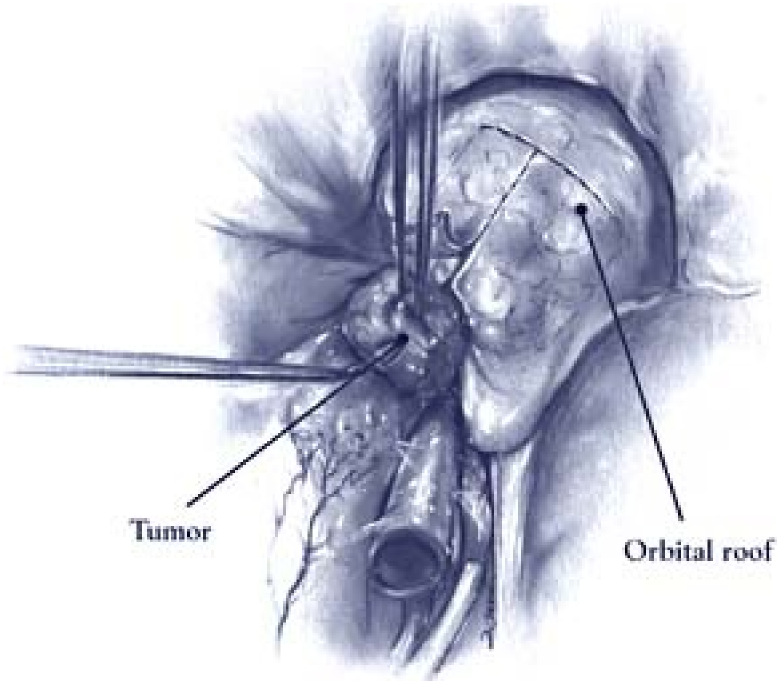

Plate 6

Removal of the tumor outside of the optic canal

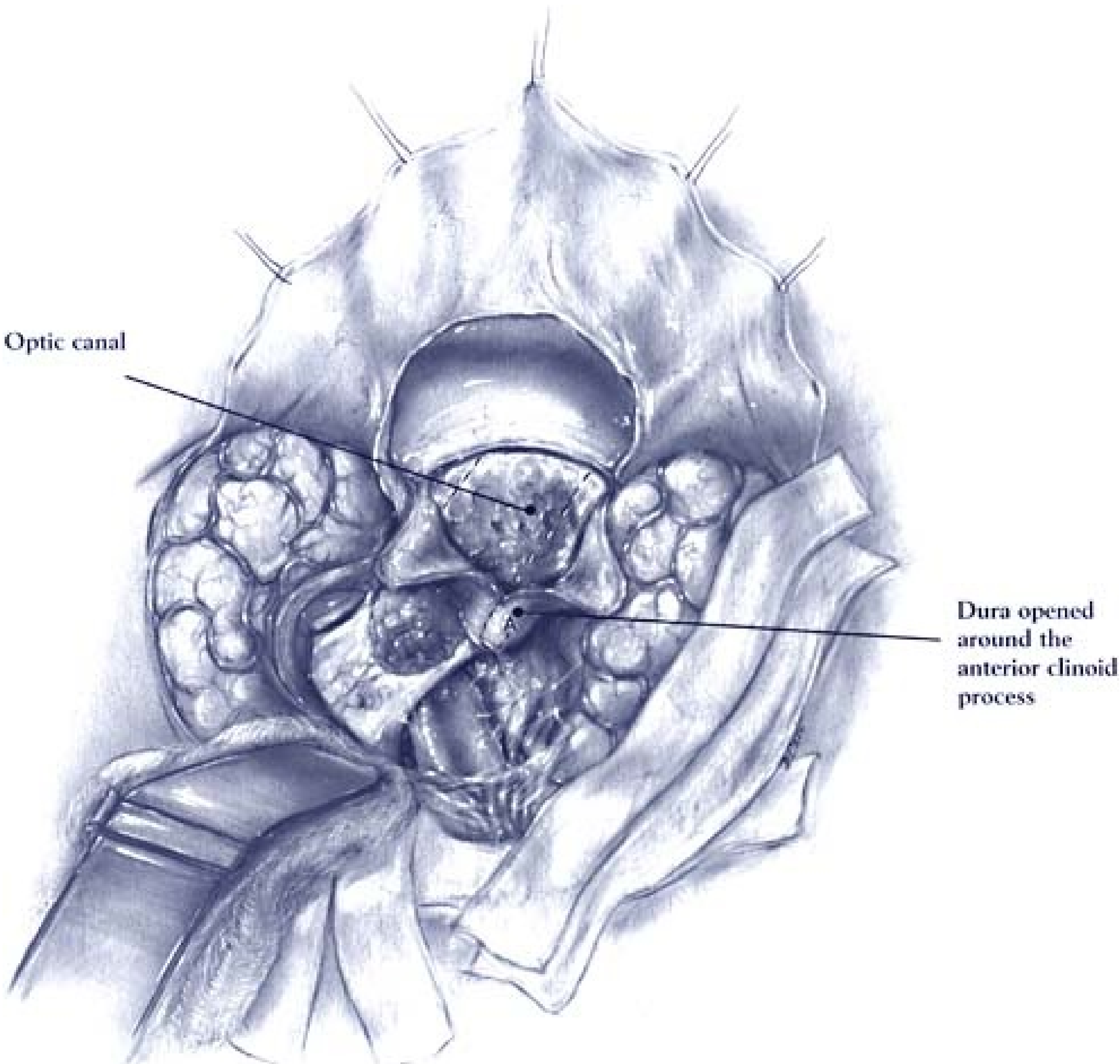

Plate 7

The dura over the optic canal is reflected. ‘A’ demarcates the right anterior clinoid process

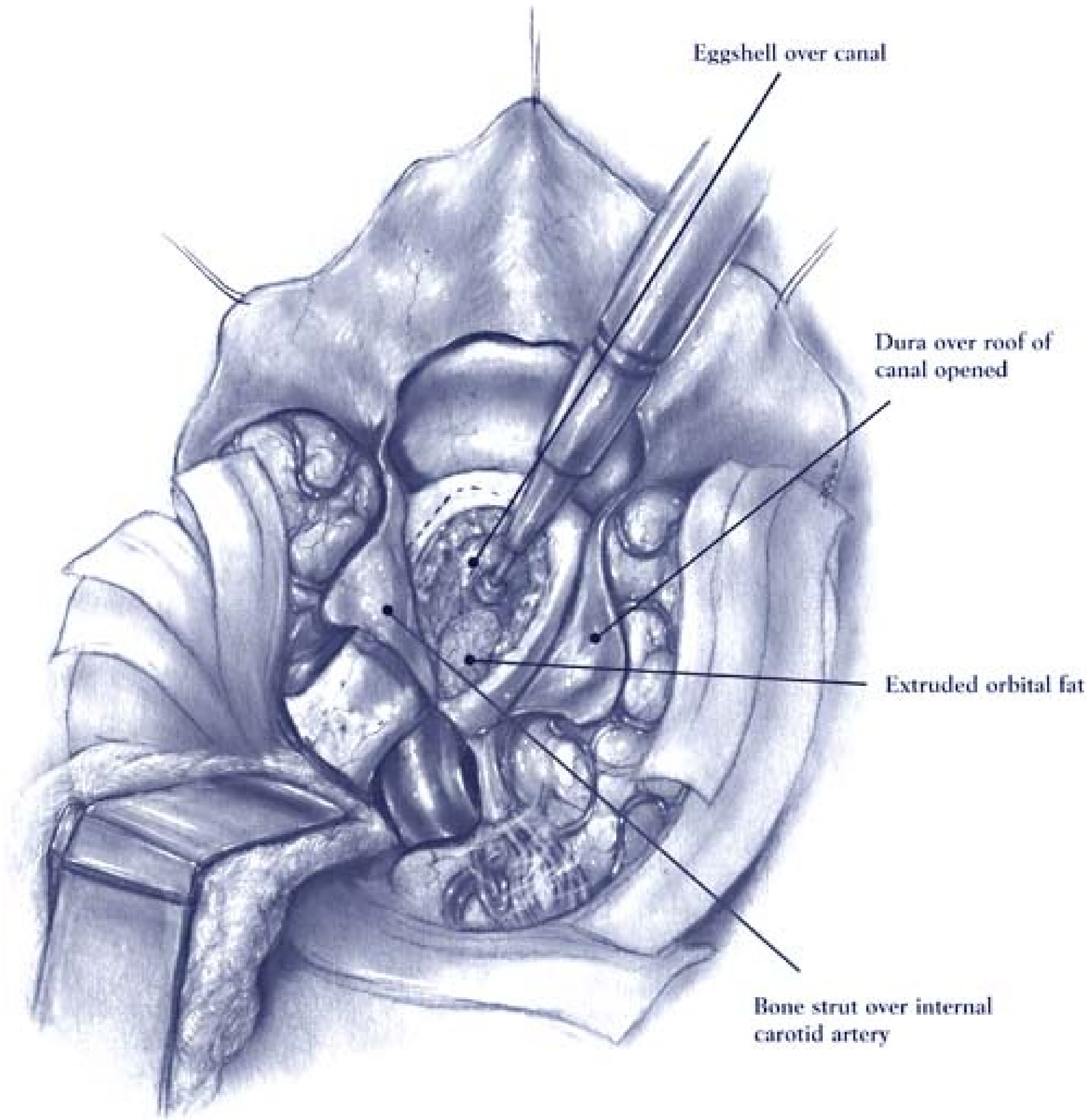

Plate 8

Removal of bone over the optic canal. A bone strut is left over the internal carotid artery. Orbital fat is seen through the areas of complete bone removal

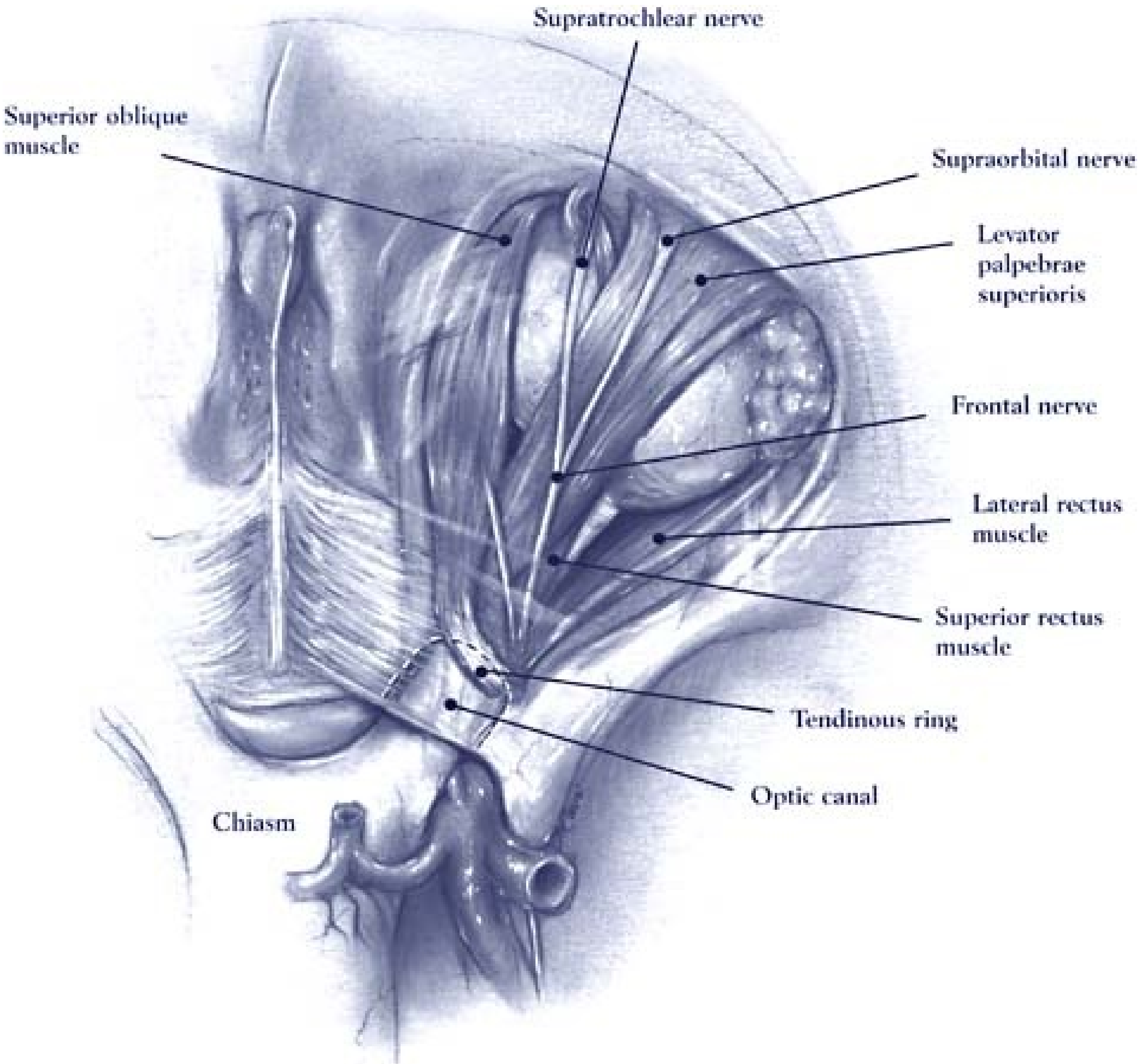

Plate 9

The optic nerve sheath and surrounding anatomy with the optic canal and tendinous ring for extraocular muscles

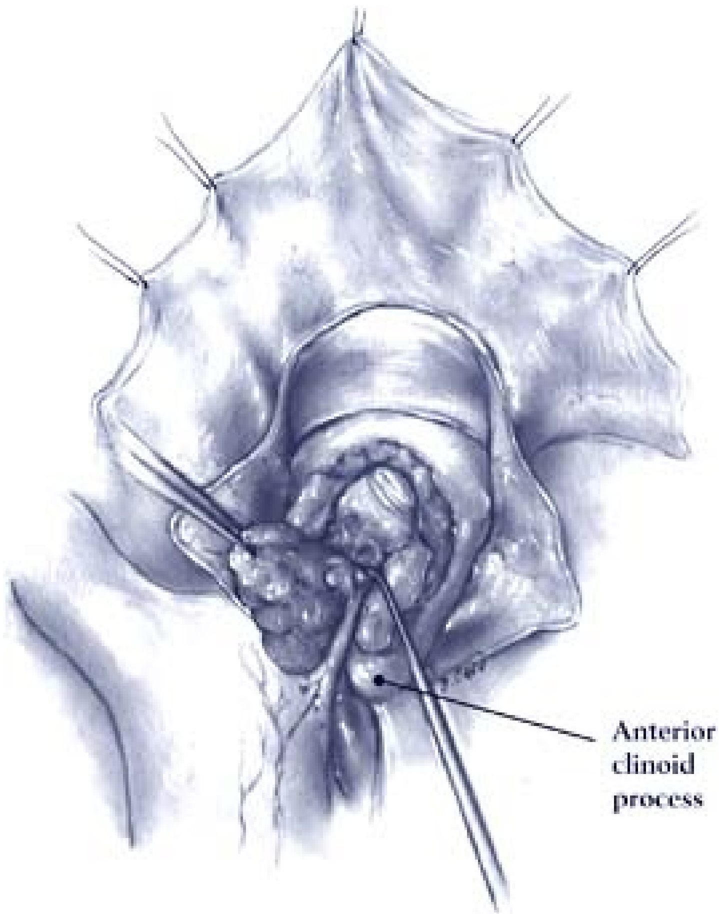

Plate 10

Removal of the intracanalicular optic nerve sheath tumor

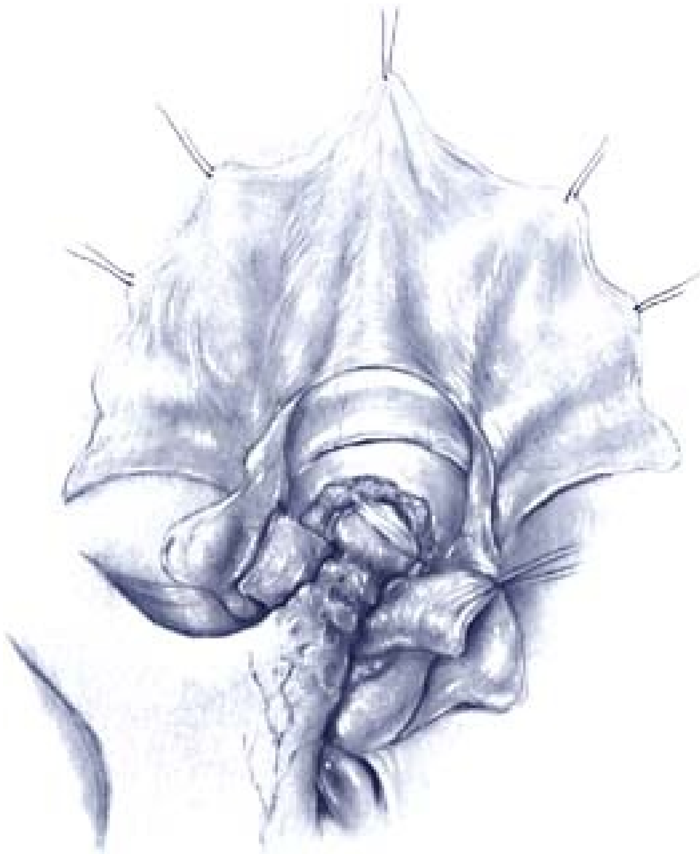

Plate 11

Preservation of the optic nerve

Appendix II Pterional approach for dissection of tumor with subchiasmatic extension

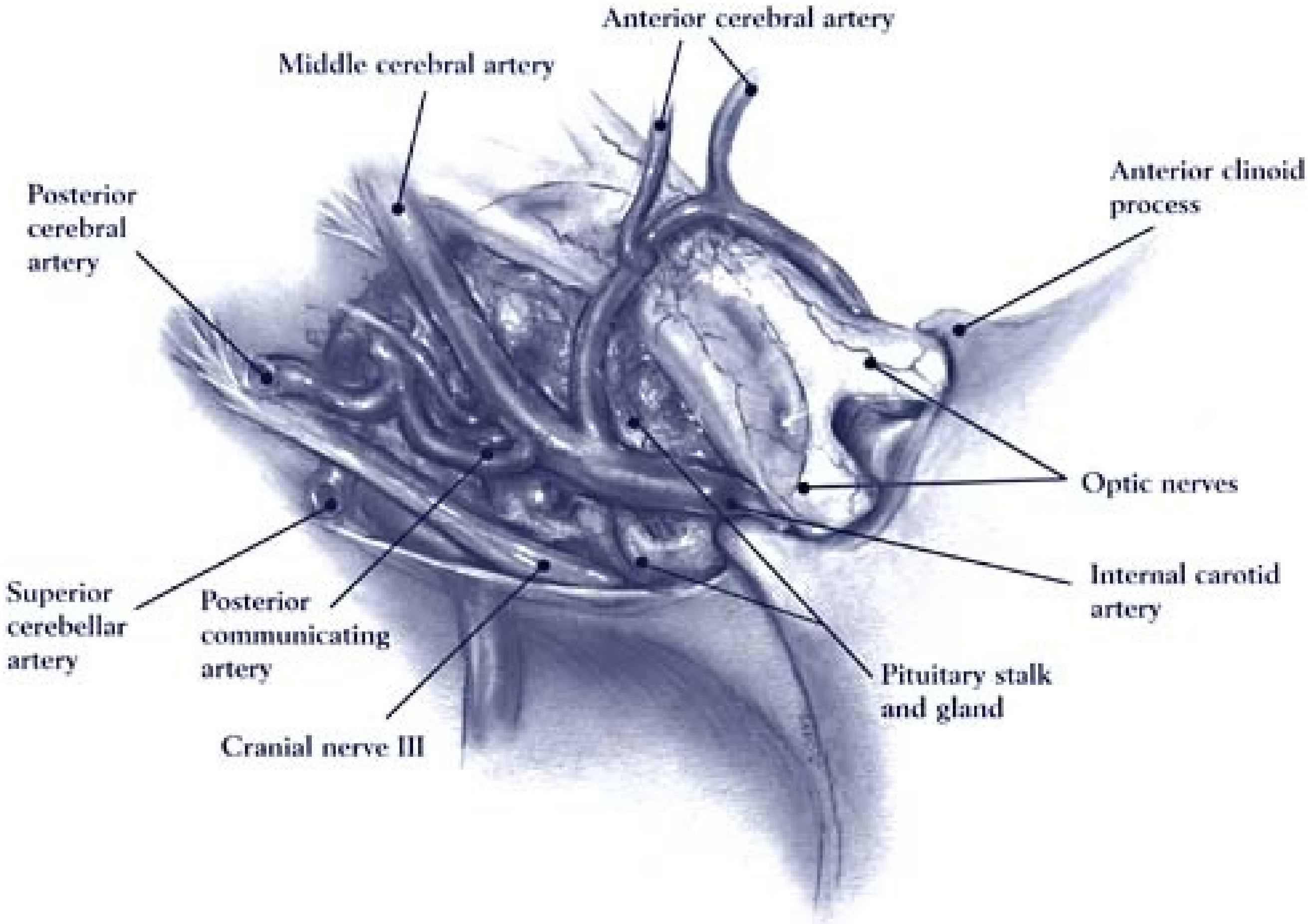

Plate 1

Subchiasmatic tumor with surrounding neurovascular anatomy

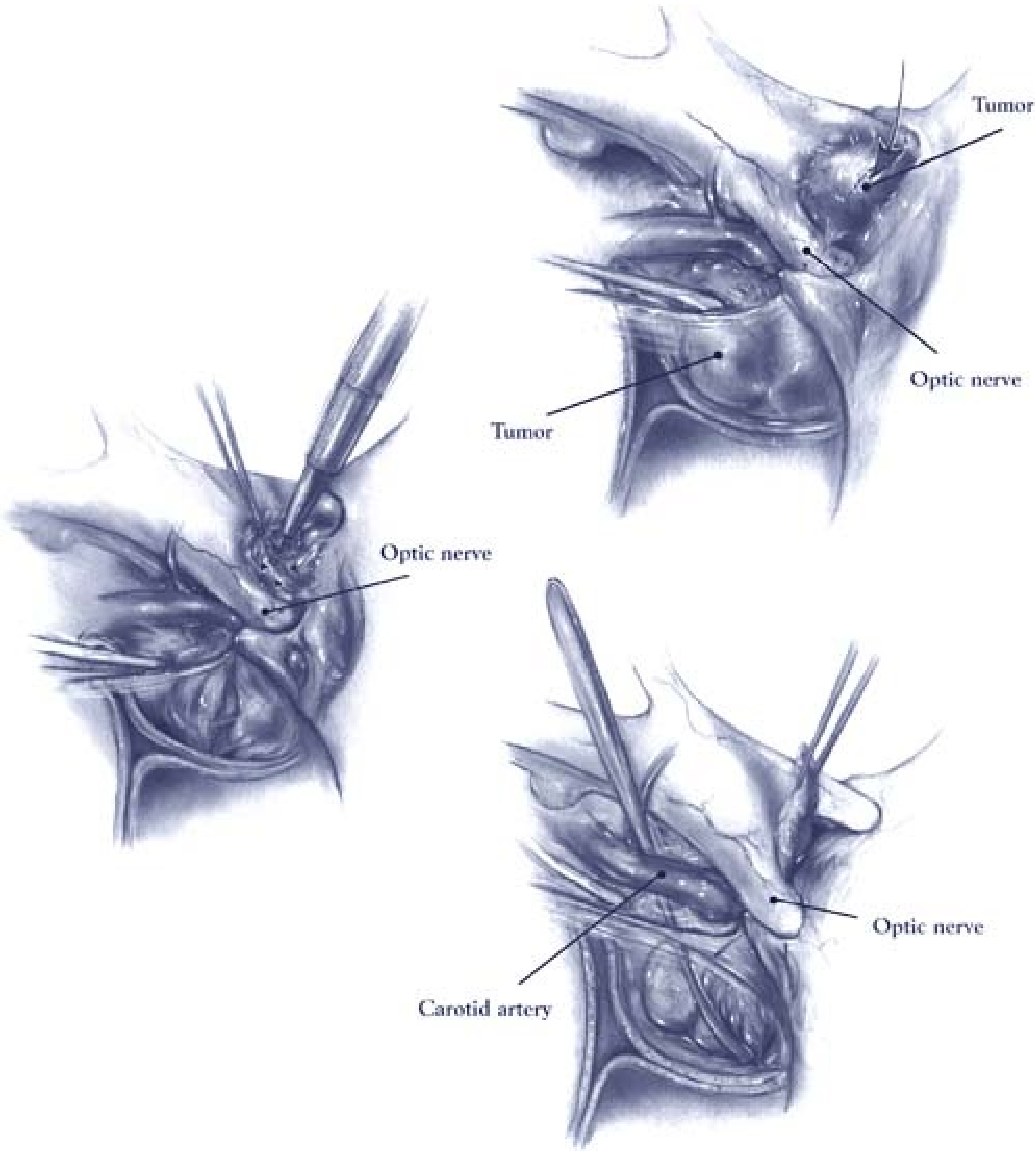

Plate 2

Subchiasmatic tumor with the internal carotid artery seen on the lateral aspect of the tumor, giving off anterior cerebral and middle cerebral arteries. The oculomotor nerve is seen alongside the dural edge

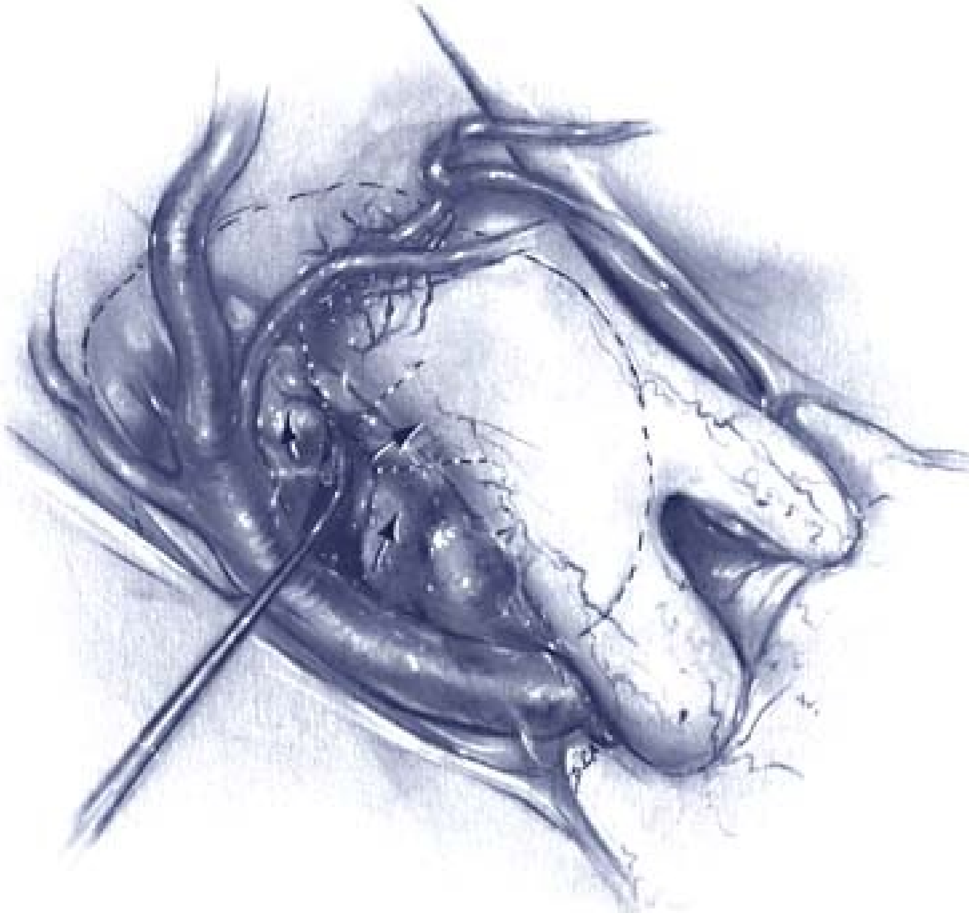

Plate 3

Tumor dissection within the opticocarotid triangle, separating the tumor from the internal carotid artery and undersurface of the chiasm

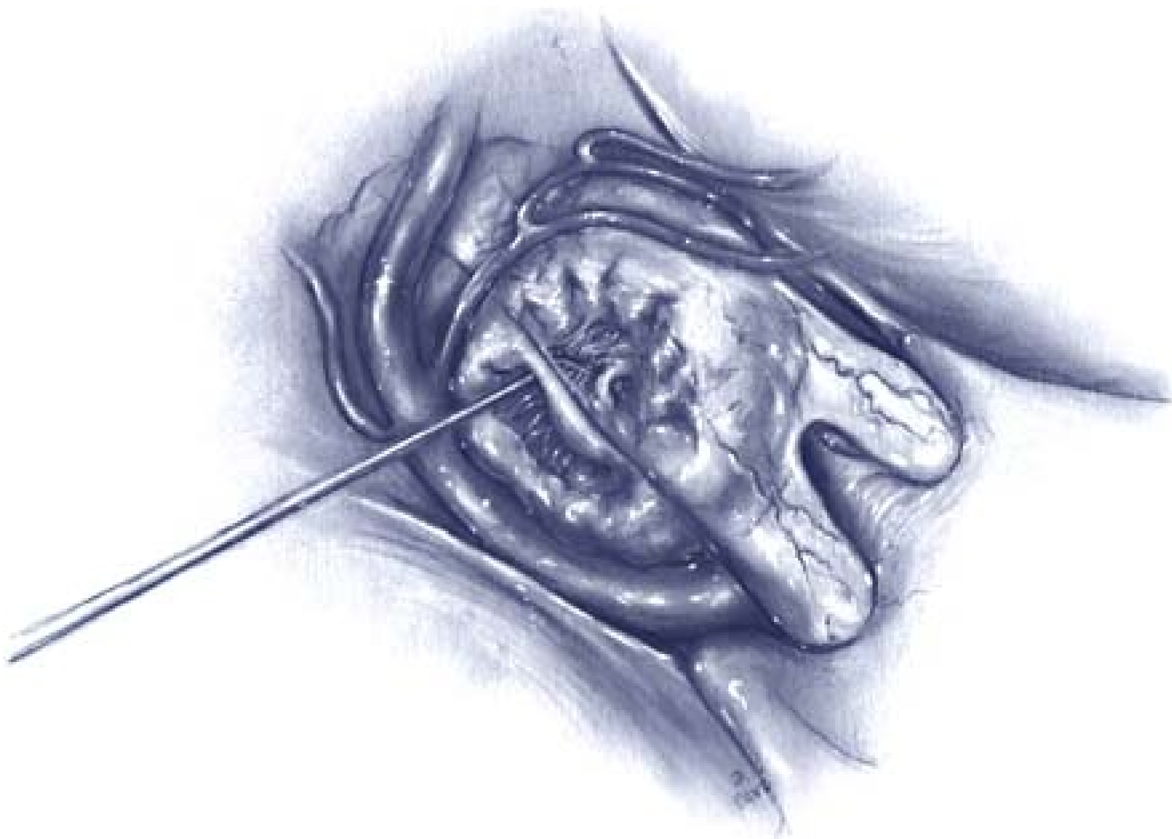

Plate 4

Tumor dissection in the subchiasmatic area. The first step in the dissection is intracapsular

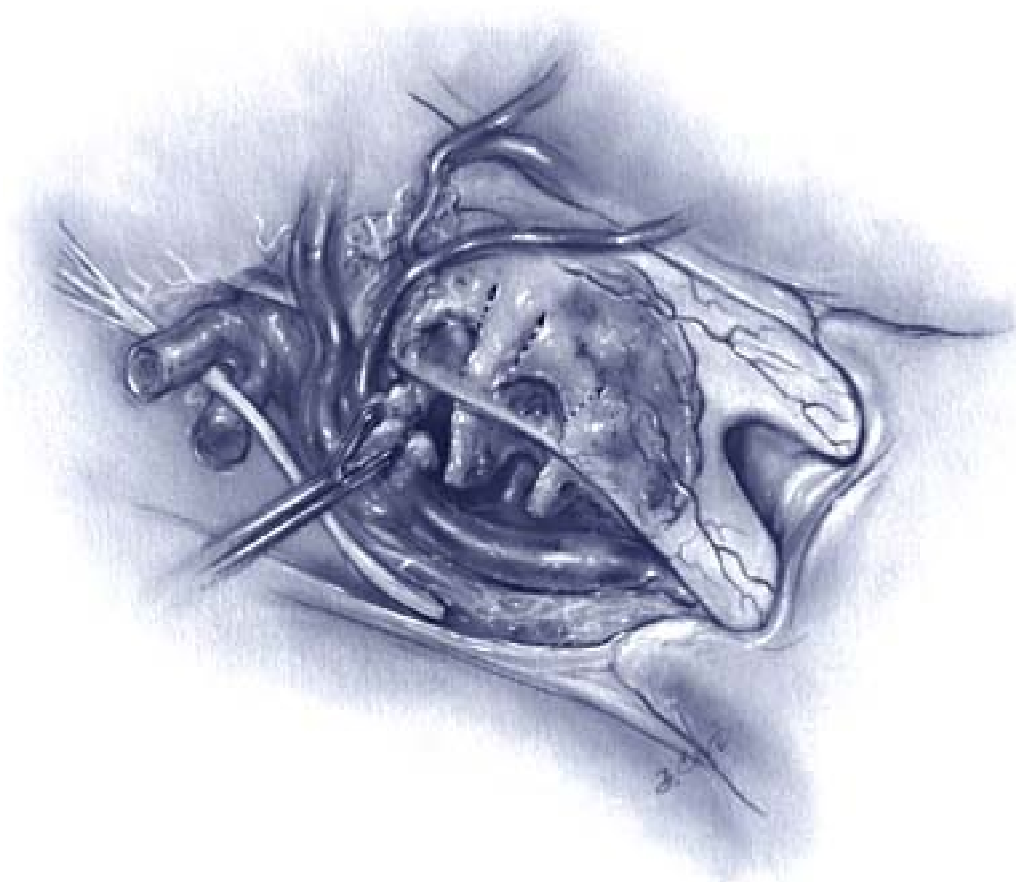

Plate 5

Tumor dissection within the opticocarotid triangle. After intracapsular dissection, the tumor is removed piecemeal to preserve circumneural vasculature of the underside of the chiasm

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Appendix III Pterional approach for dissection of chiasmatic tumor extending to planum sphenoidale

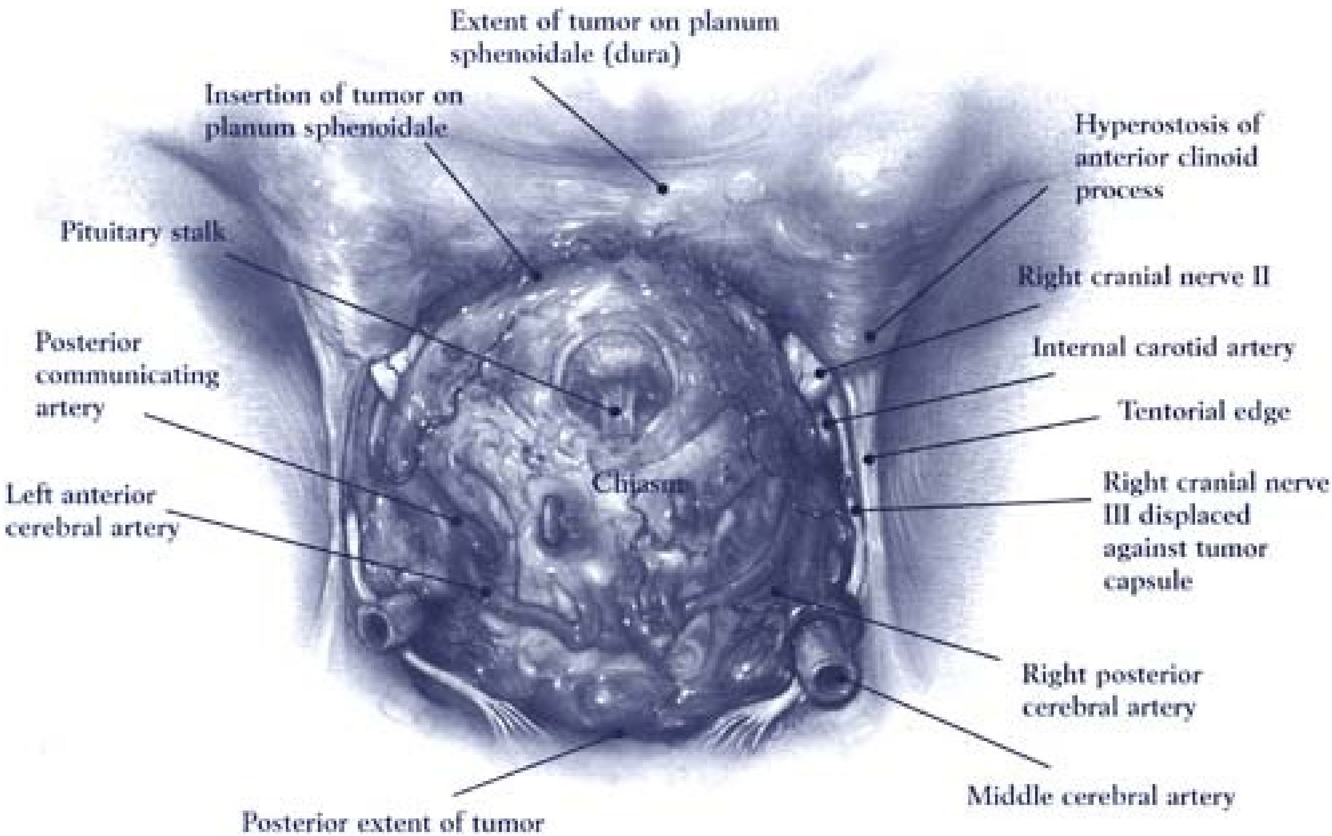

Plate 1

Overview of the planum sphenoidale region and tumoral relationships. The tumor extends to the planum sphenoidale dura. The tentorial edge is on either side of the tumor. The tumor overlies the optic nerves and chiasm. The pituitary stalk is seen anterior to the optic chiasm. The circulation of the anterior circle of Willis is in close association with the tumor

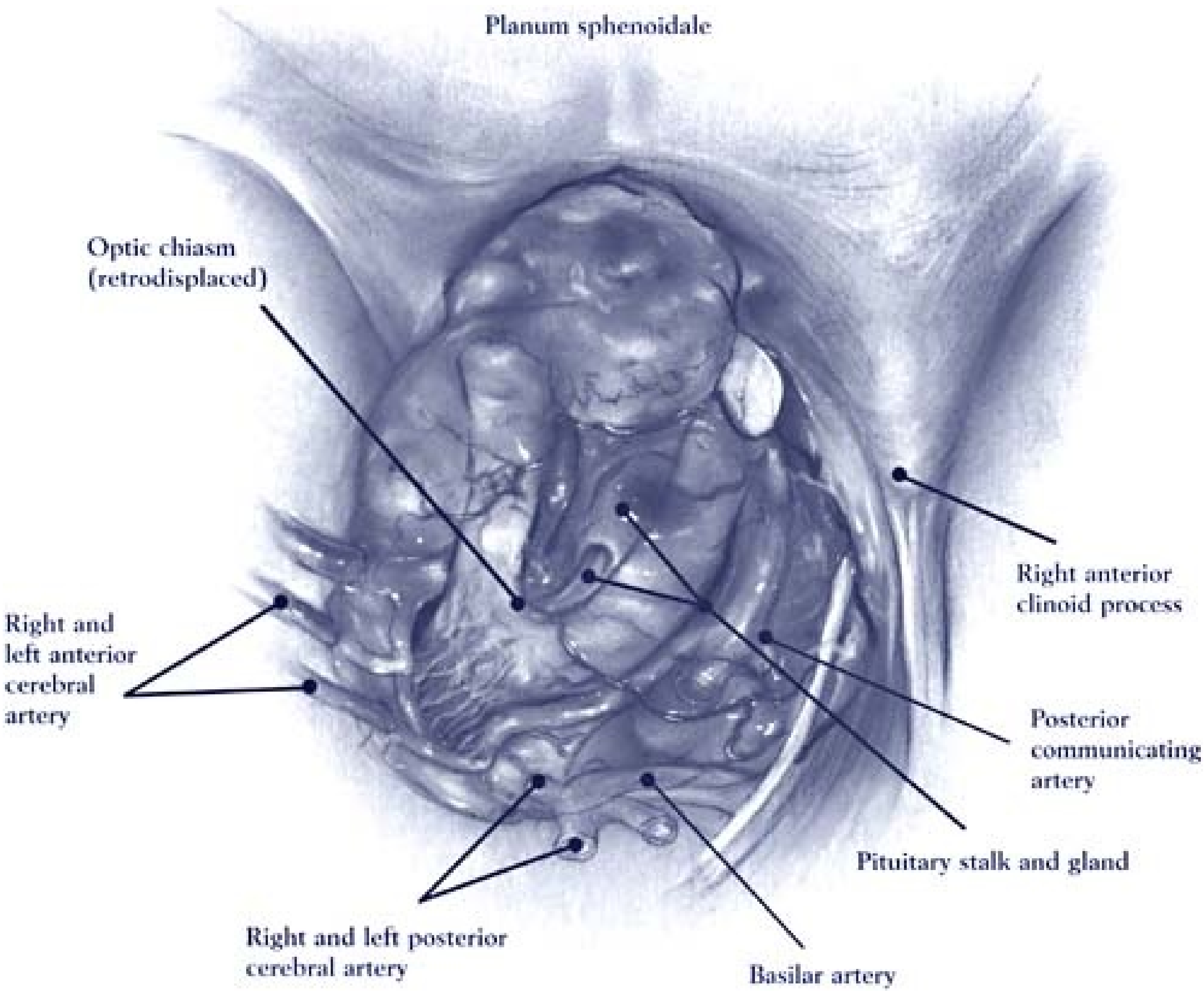

Plate 2

View of chiasmatic tumor with vessel and optic nerve encasement

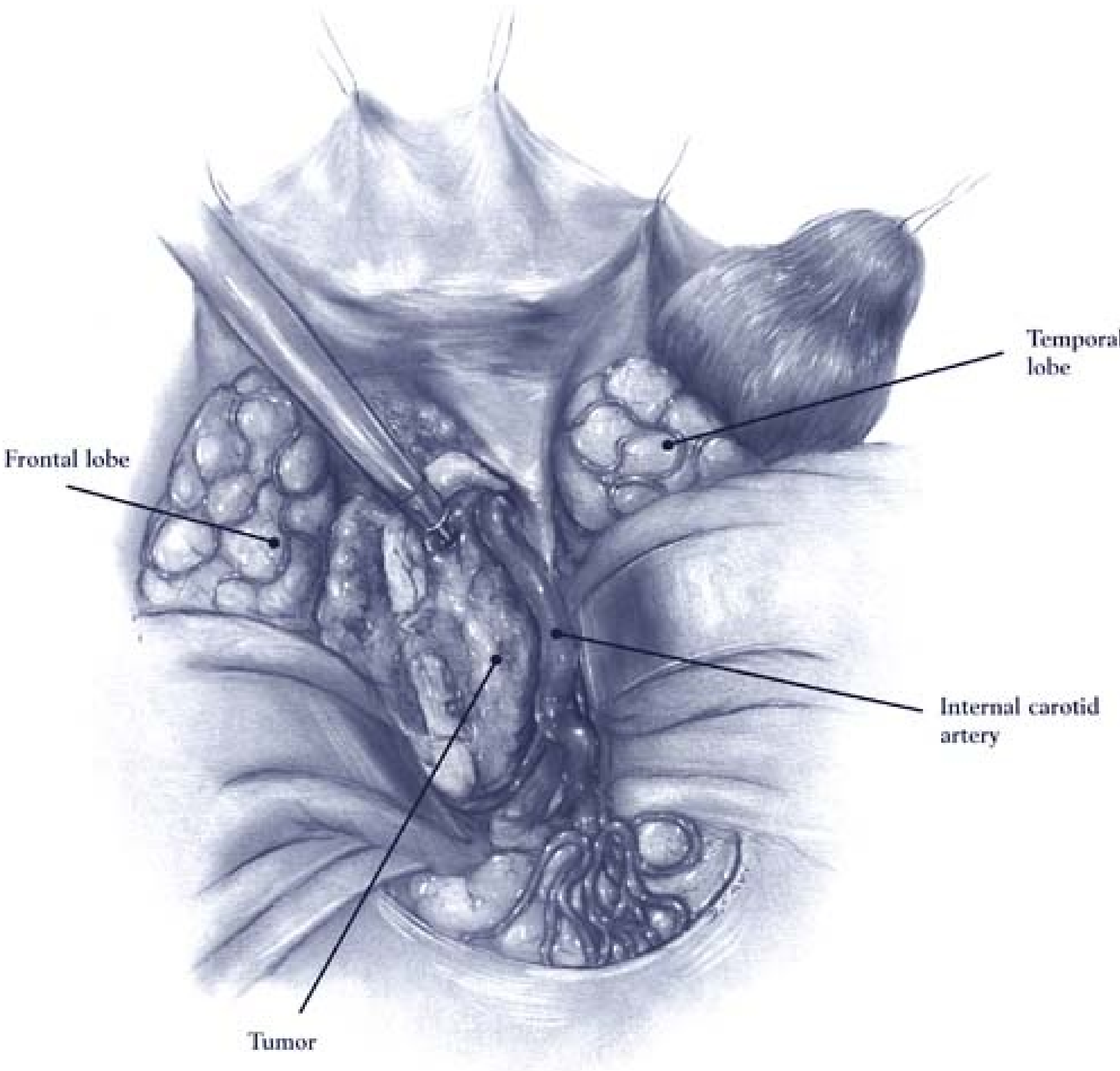

Plate 3

The suprachiasmal and subchiasmal components of the tumor are removed

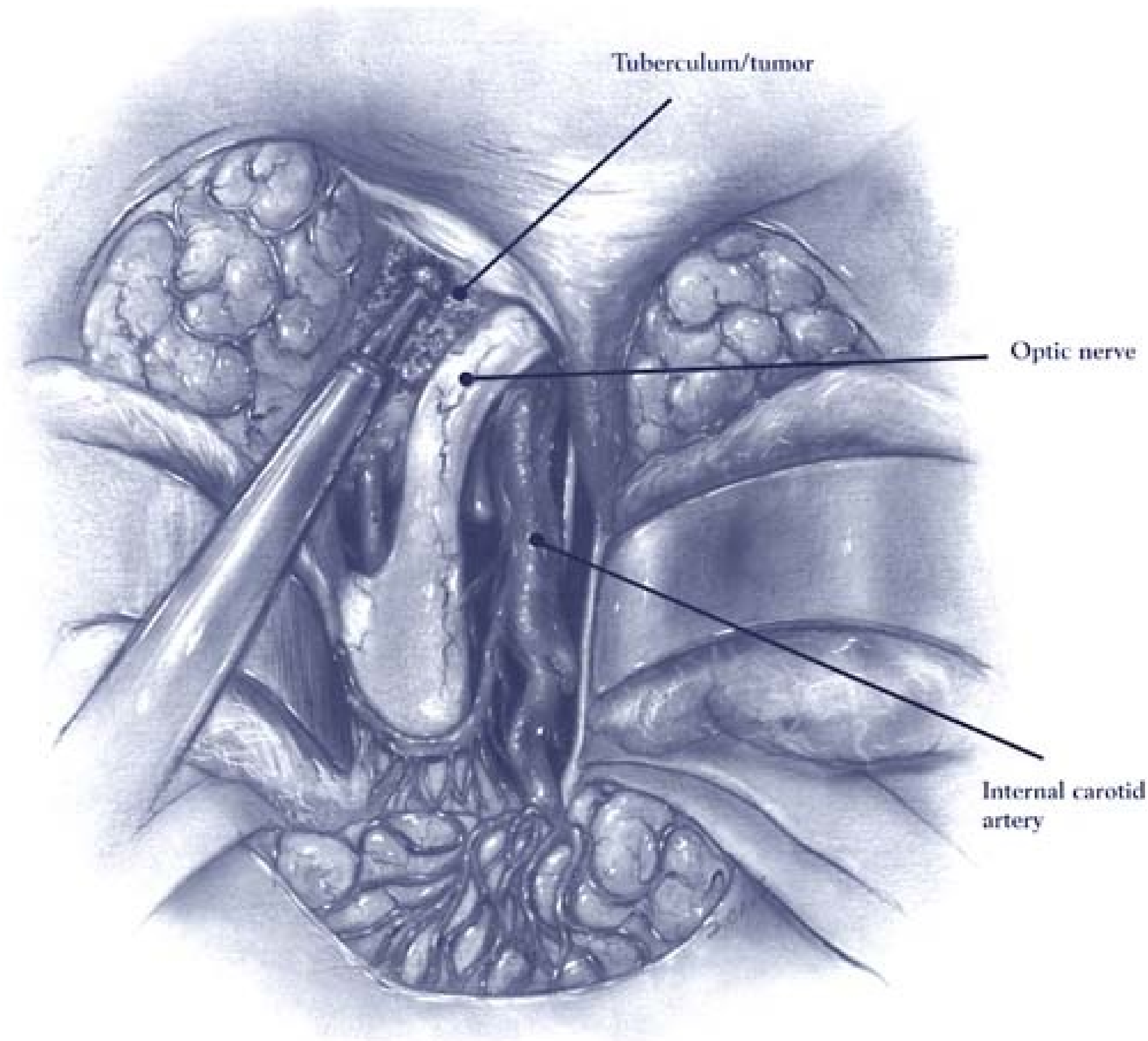

Plate 4

The hyperostotic bone at the tuberculum sellae is removed with the drill. The oculomotor nerve is seen alongside the carotid artery

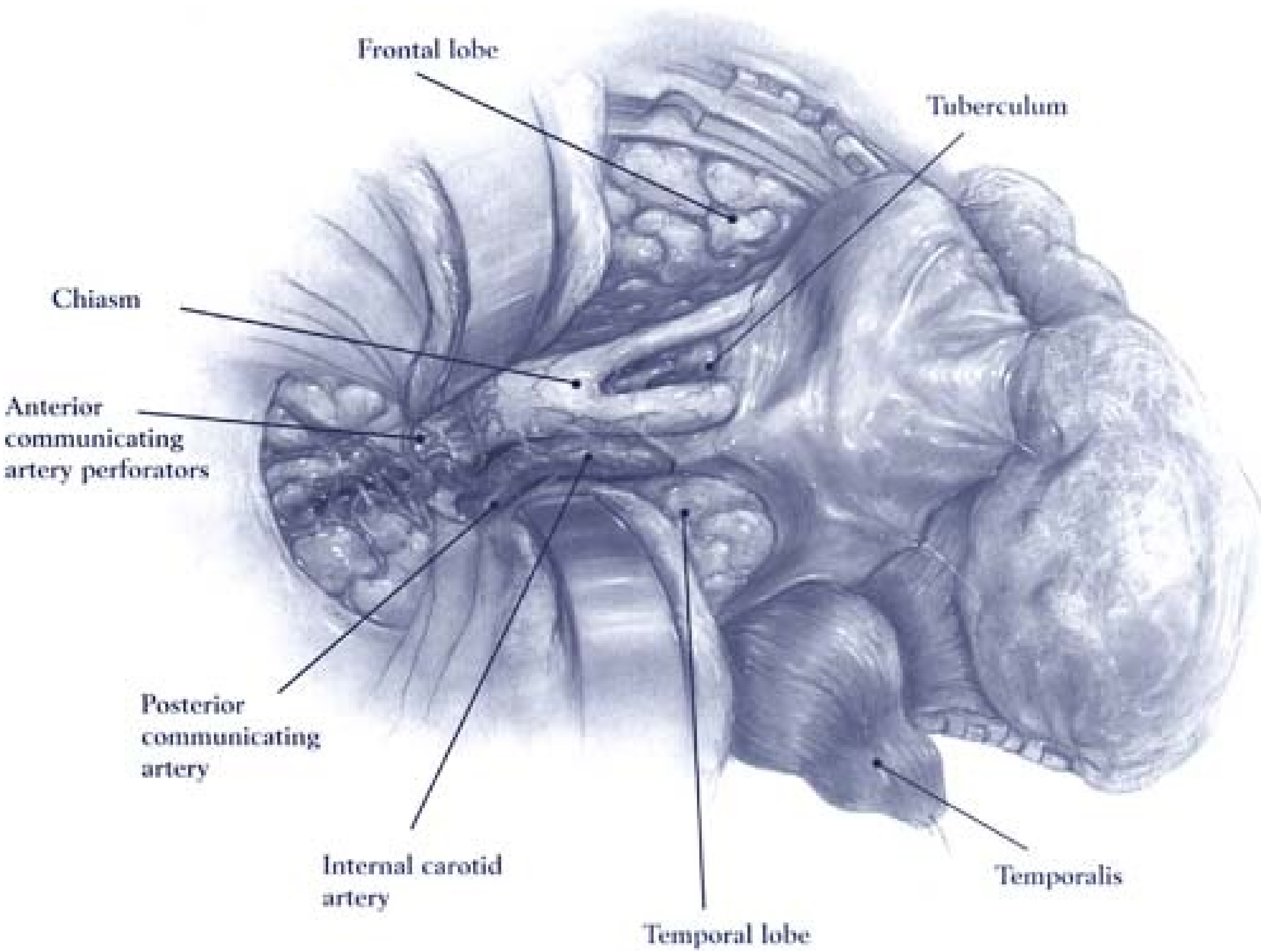

Plate 5

The tumor is removed providing a full view of the planum and tuberculum region with the optic nerve and chiasm and surrounding vasculature

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Appendix IV Pterional approach for dissection of cavernous sinus tumor

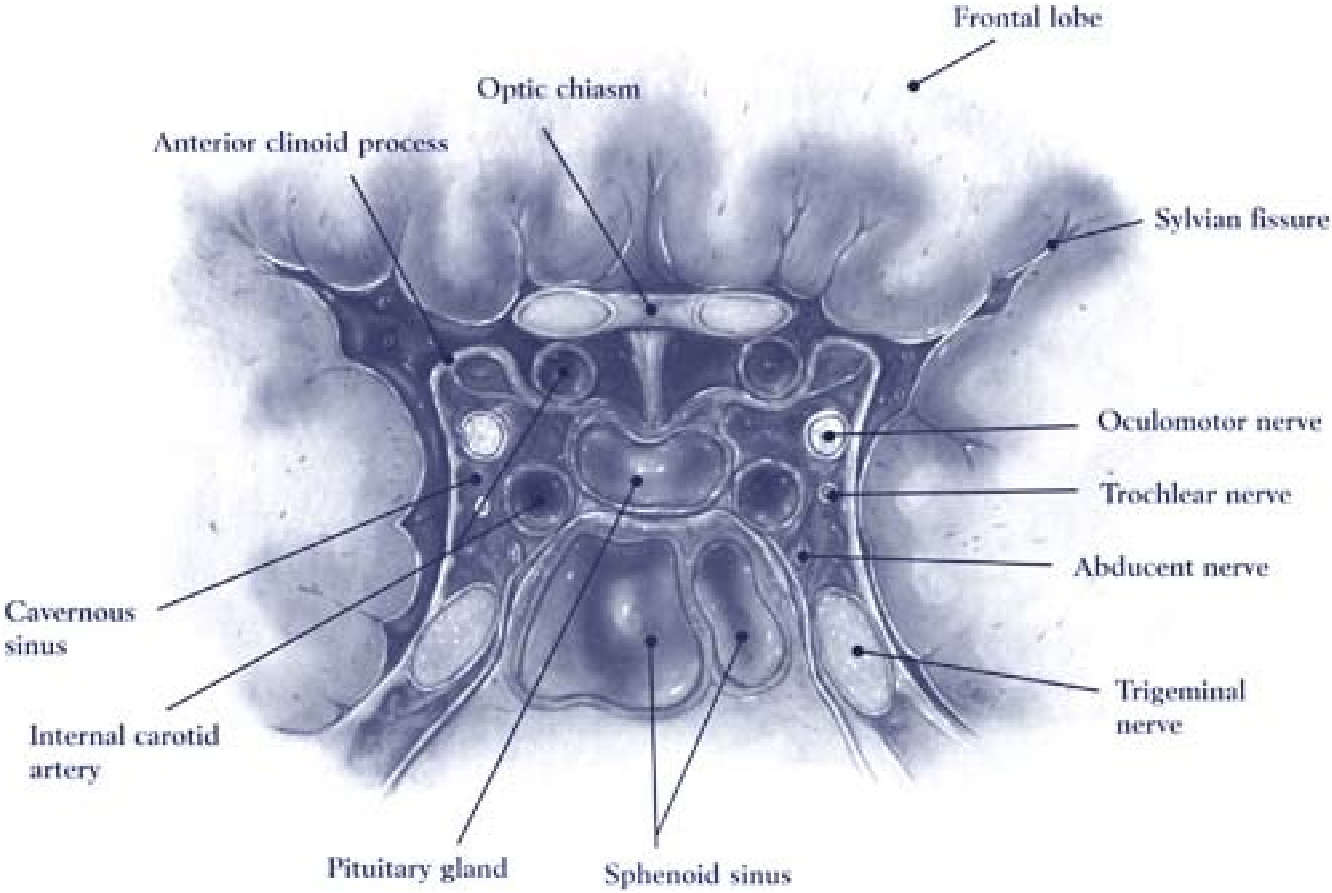

Plate 1

Cross-section of the cavernous sinuses with the internal carotid artery, cranial nerves III, IV, V, and VI coursing through

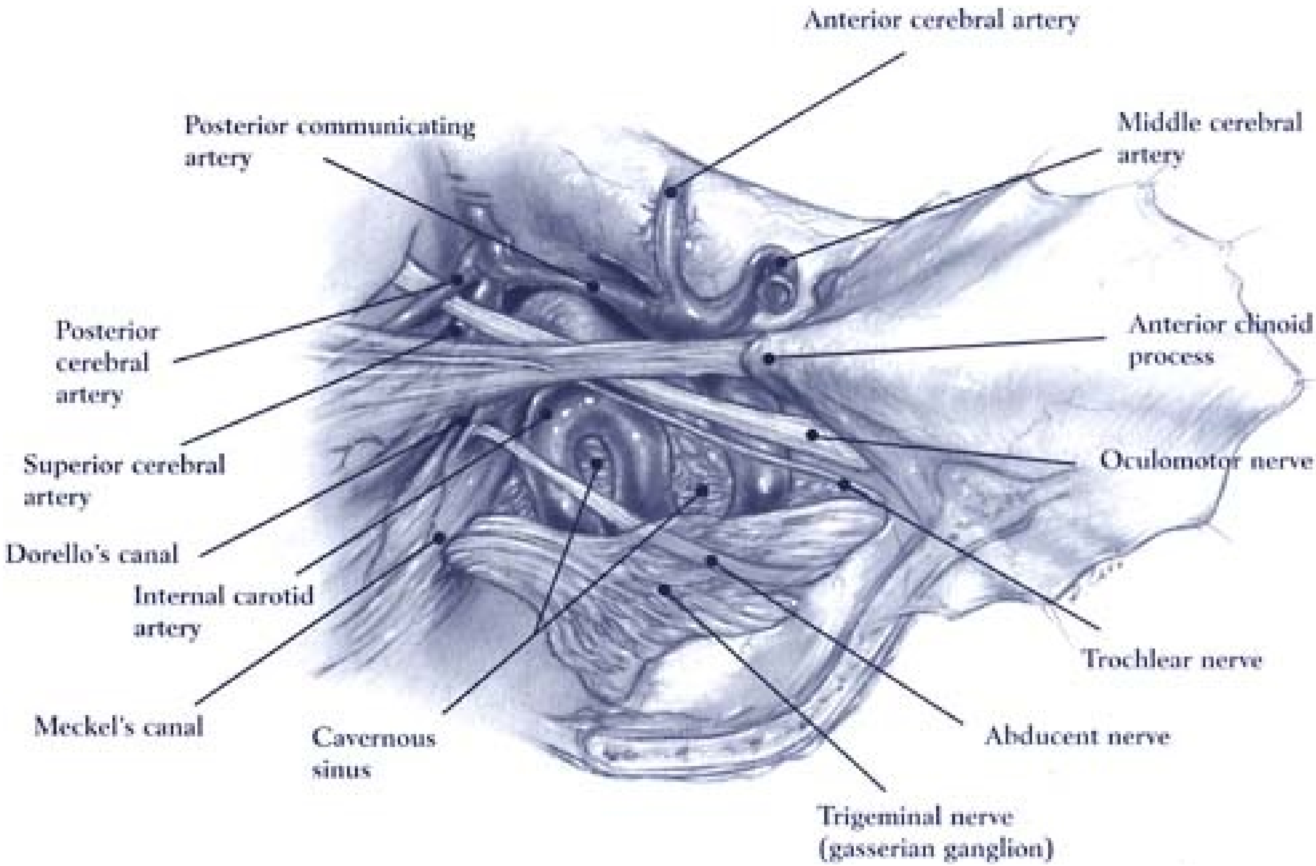

Plate 2

Lateral view of the cavernous sinus after exposure through the sylvian fissure on right

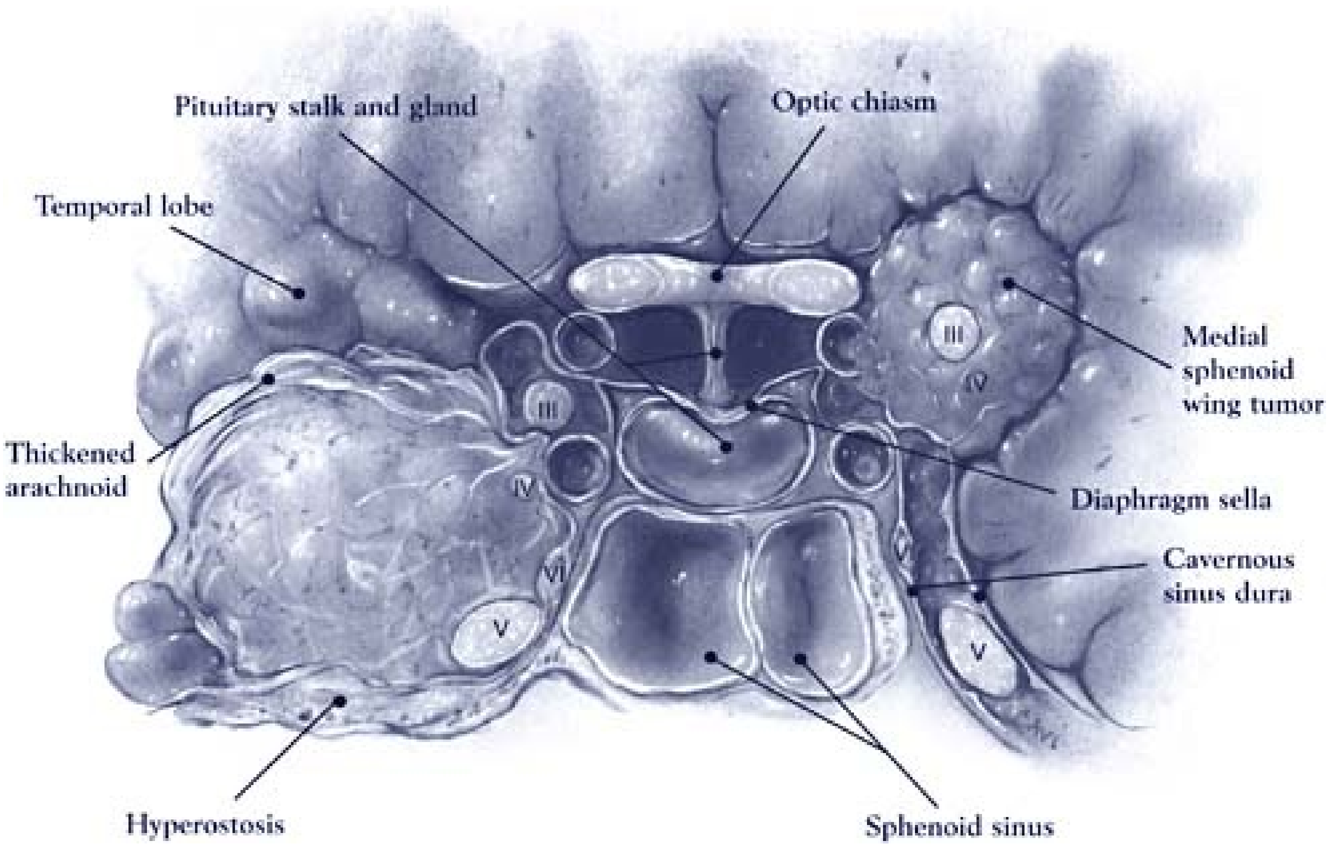

Plate 3

Bilateral cavernous sinus tumors as a typical presentation of a large sphenoid wing meningioma. A cavernous sinus tumor depicted near the right cavernous sinus. The medial sphenoid wing tumor is depicted adjacent to the left cavernous sinus.

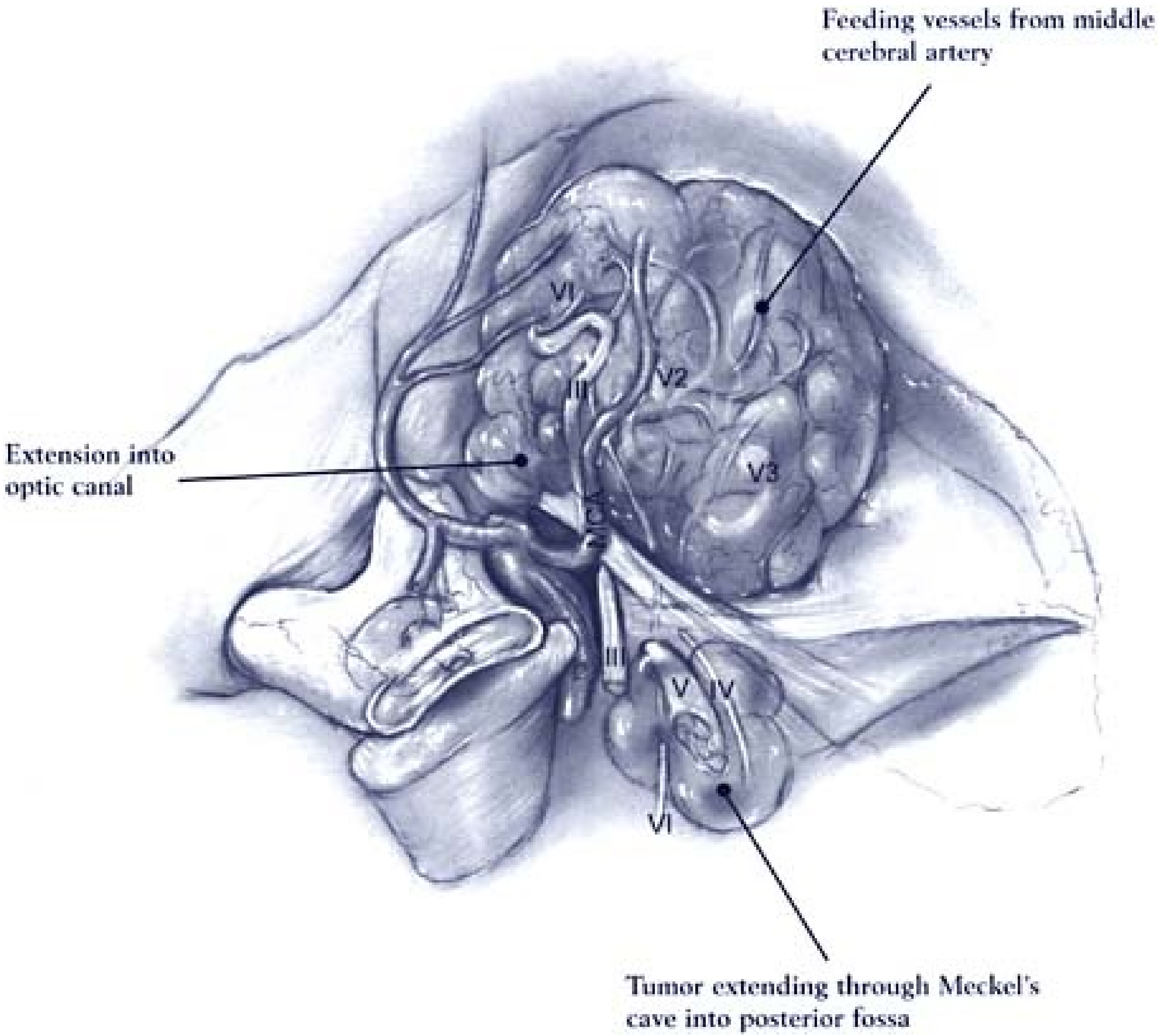

Plate 4

A cavernous sinus tumor with extension into the optic canal and posterior fossa toward the middle fossa floor

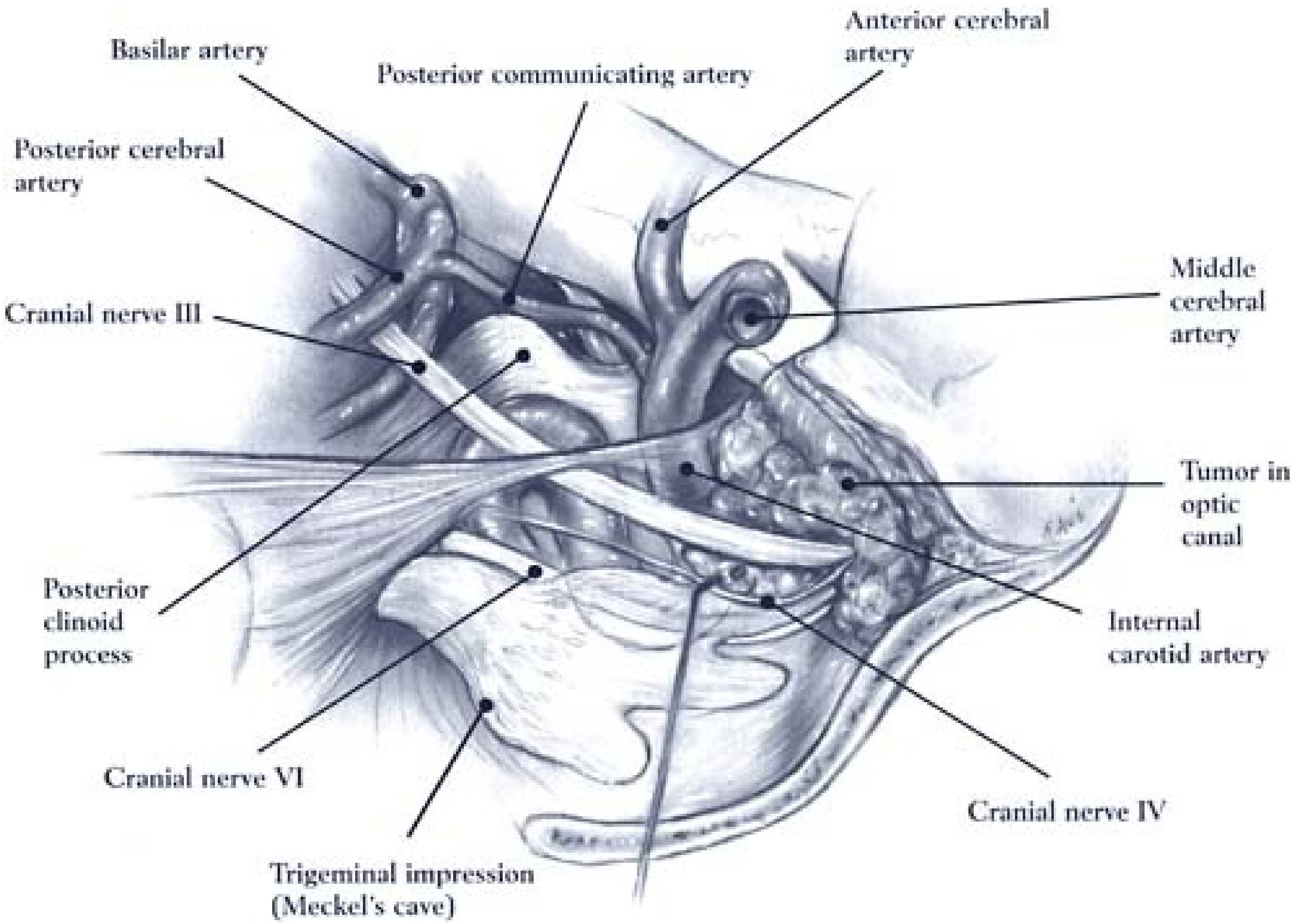

Plate 5

Removal of the optic canal portion of the tumor on right. The medial sphenoid wing and anterior clinoid process are removed for access to the optic canal

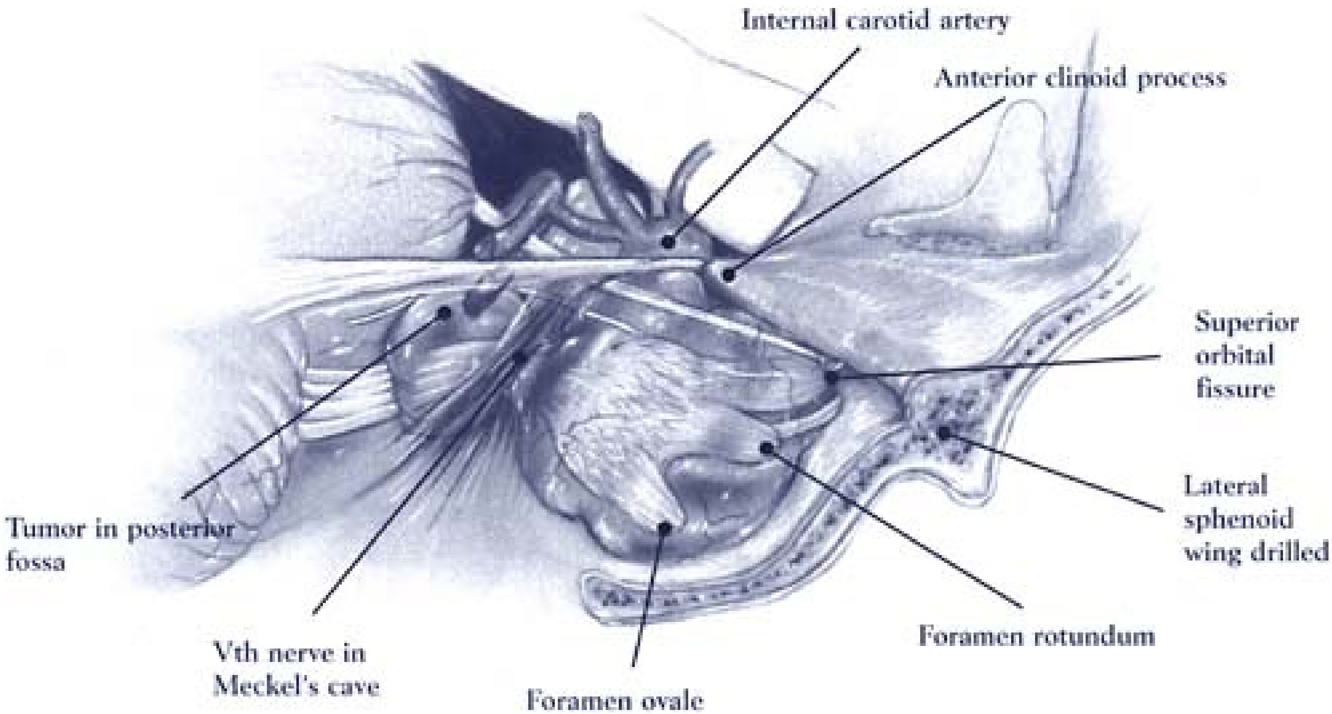

Plate 6

A tumor extending across the middle and posterior fossae and its relationship to cranial nerve V

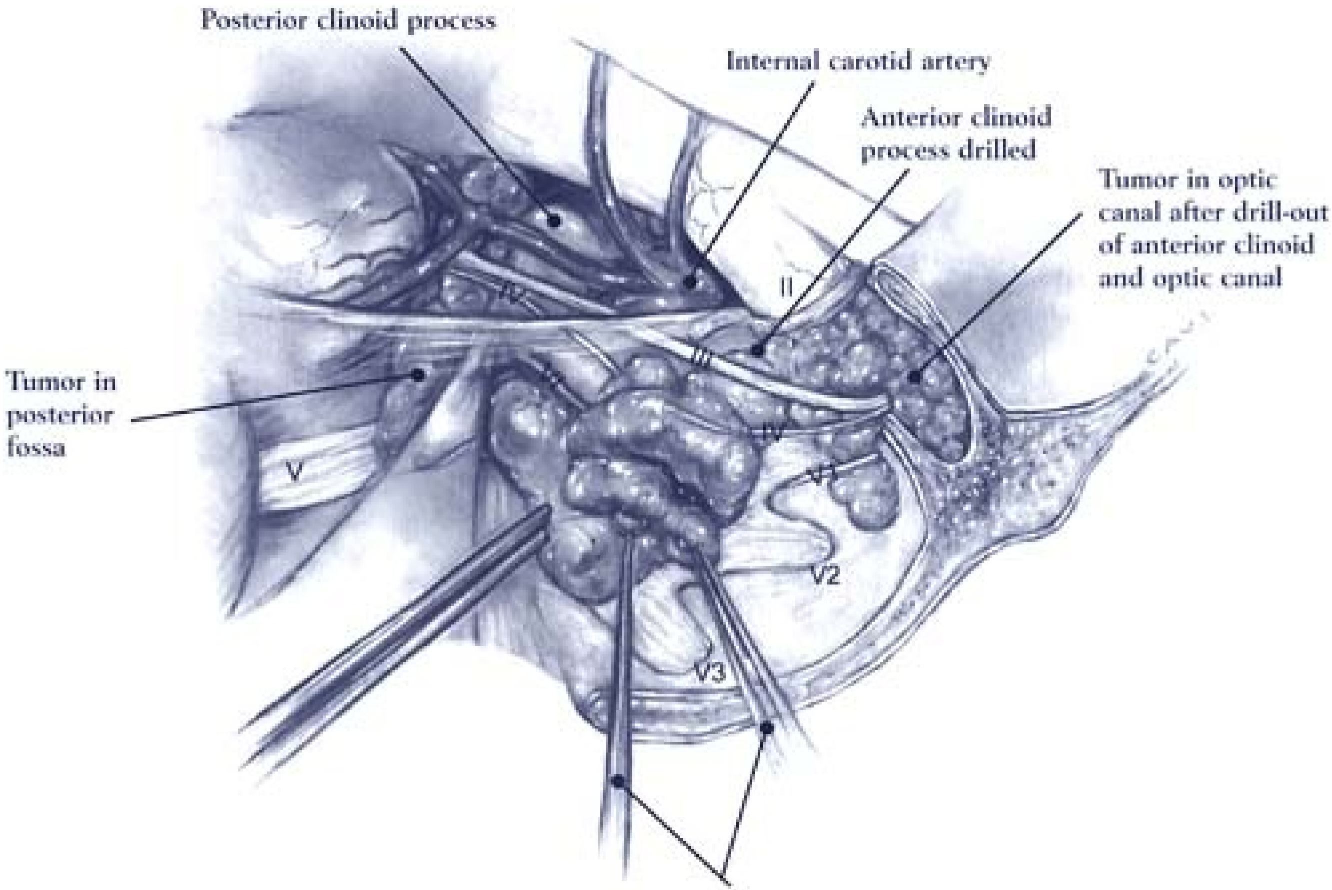

Plate 7

Removal of the middle fossa floor component of the tumor. The tumor lies above the trigeminal ganglion

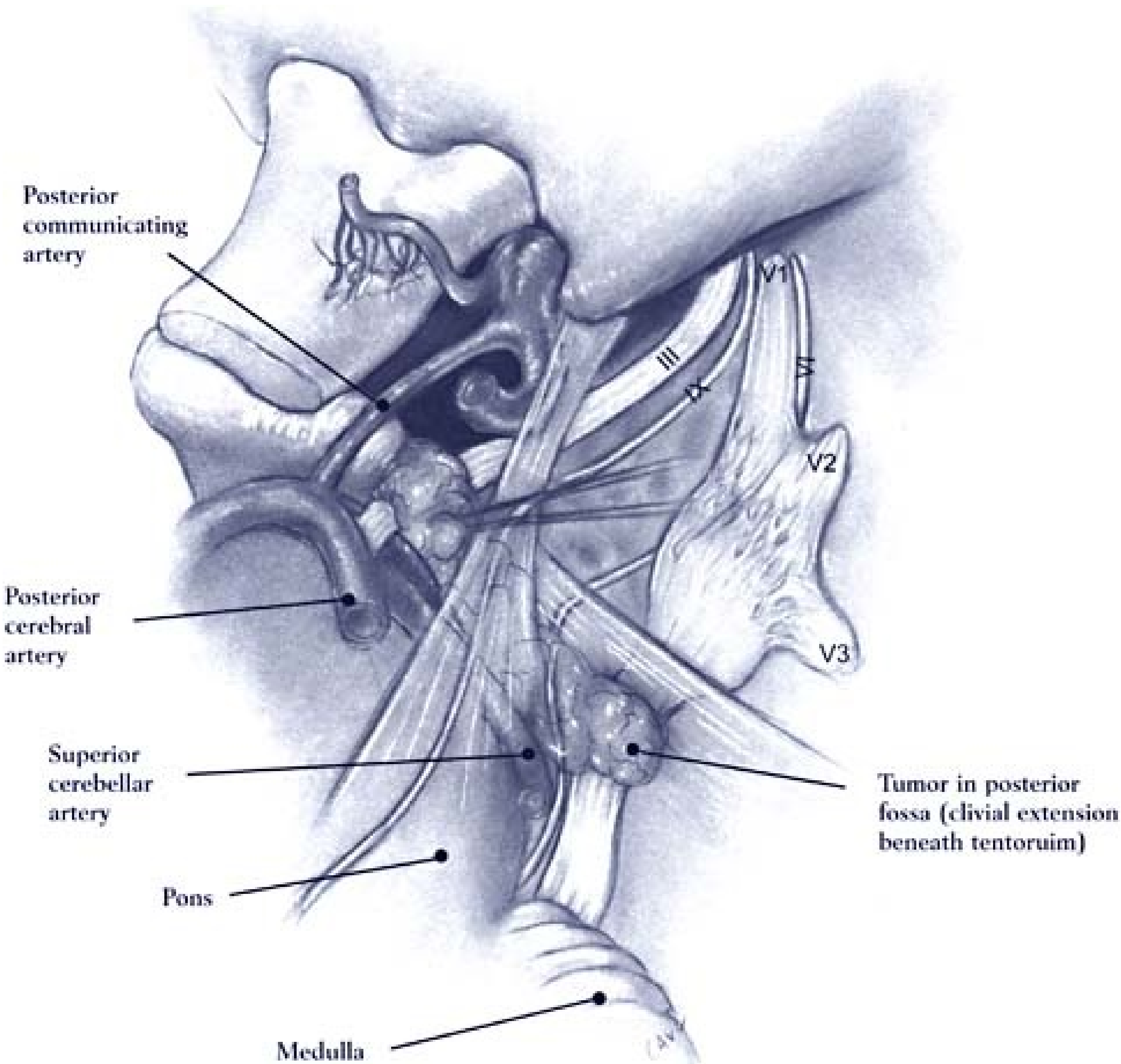

Plate 8

A tumor in the posterior fossa and its relationship to the cranial nerves viewed through the subtemporal extension of a right pterional approach

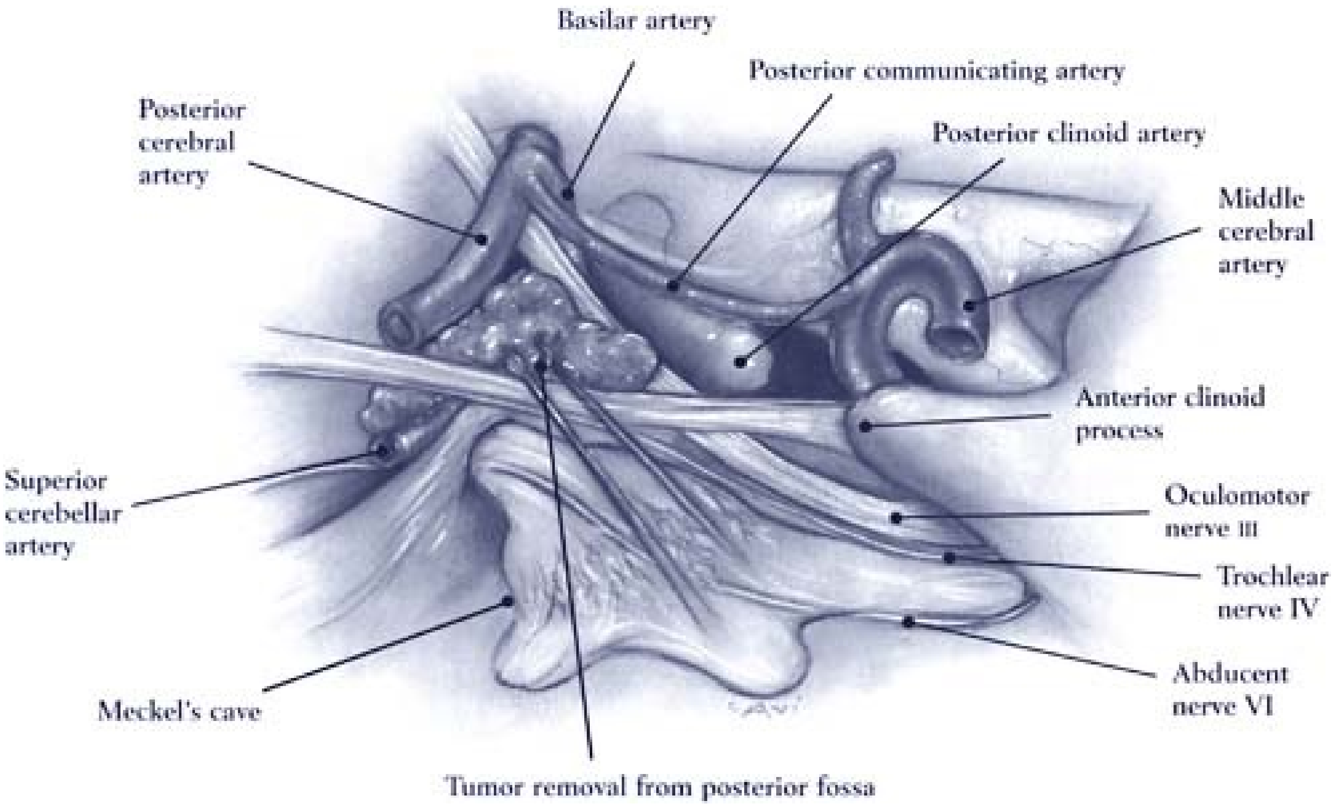

Plate 9

Removal of the posterior fossa component of the tumor, noting the course of the adjacent cranial nerves

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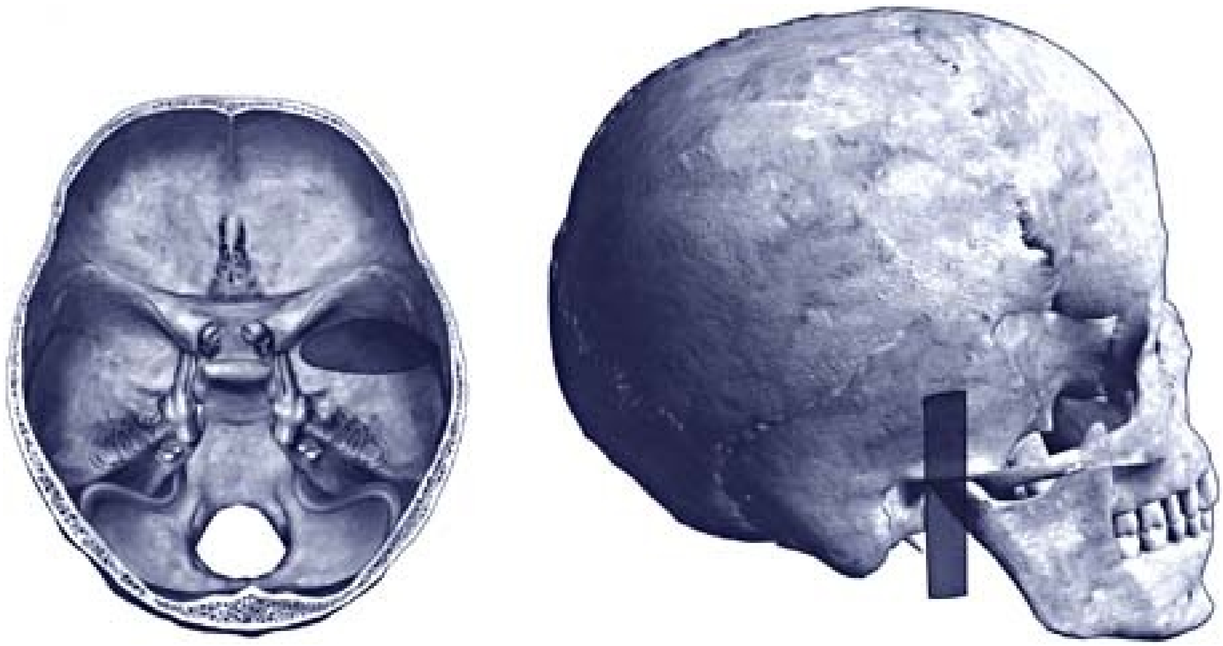
7
Lateral transtemporal-sphenoid approaches

Michael J.Holliday and Matthew Ng



INDICATIONS

Surgical removal of lesions of the parasellar, petrous apex, clival, pterygomaxillary fissure, and nasopharyngeal areas is particularly challenging for several reasons (Table 1). Difficulties with exposure are related to the complexity of neural structures and proximity to the adjacent brain and brain stem. Added to this is the need for careful control of the great vessels. Too often, inexperienced surgeons may inadequately remove disease with resultant morbidity and even mortality.

The lateral transtemporal-sphenoid approach to the skull base provides an exposure of one of the more challenging areas of the lateral skull base. This approach provides an alternative to the posterior, anterosuperior, or laterosuperior approaches commonly employed typically by neurosurgeons and the more anteroinferior approaches often utilized by head and neck and maxillofacial surgeons.

PATIENT EVALUATION

The common lesions addressed by the lateral transtemporal-sphenoid approach include tumors of the fifth nerve ganglion (Figure 1), tumors adjacent to the cavernous sinus (Figure 2), tumors of the temporal and infratemporal fossa (Figure 3), posterior and lateral orbital tumors, and sphenoid wing meningiomas (Figure 4). Preoperative evaluation of the patient should include both computed tomography (CT) and magnetic resonance imaging (MRI) studies. Computed tomography helps to delineate the pathology relative to the surrounding bone and neurovascular foramina. The floor of the middle fossa should be evaluated with particular attention paid to all the structures which will be sequentially encountered from a lateral to medial direction: greater wing of sphenoid, inferior orbital fissure, pterygoid plates, foramen spinosum, foramen ovale, carotid canal, and sphenoid sinus. MRI/magnetic resonance angiography studies help further to define the relationship of the tumor

Table 1 Regions accessible by the lateral transtemporal-sphenoid approach

Parasella
Upper clivus
Nasopharynx
Posterior lateral orbit
Pterygopalatine fissure
Pterygomaxillary space
Petrous apex
Sphenoid ridge
Temporal/infratemporal fossa
Posterior superior maxillary sinus
Trigeminal nerve

Anteromedial temporal lobe

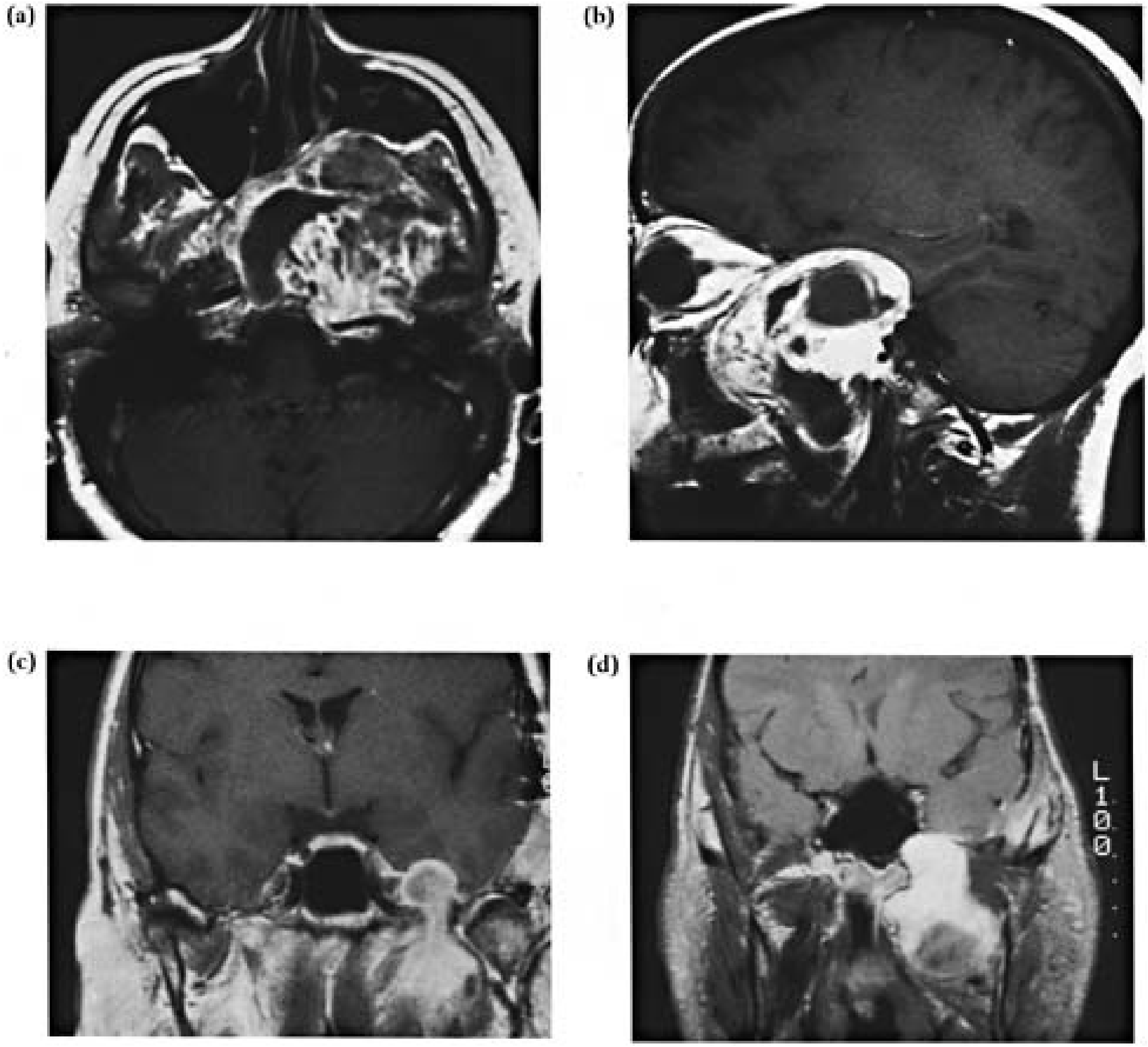


Figure 1

Fifth nerve schwannomas. Case 1: (a) T1-weighted axial MRI of left fifth nerve schwannoma. Heterogenous mass with cystic component extending to masticator space; (b) T1-weighted sagittal MRI of fifth nerve schwannoma with notable cystic component within the tumor. Case 2: (c) T1-weighted coronal MRI with gadolinium of smaller fifth nerve schwannoma with extension through fora-men ovale into pterygopalatine fossa; (d) T1-weighted coronal MRI scan of same lesion in more posterior section

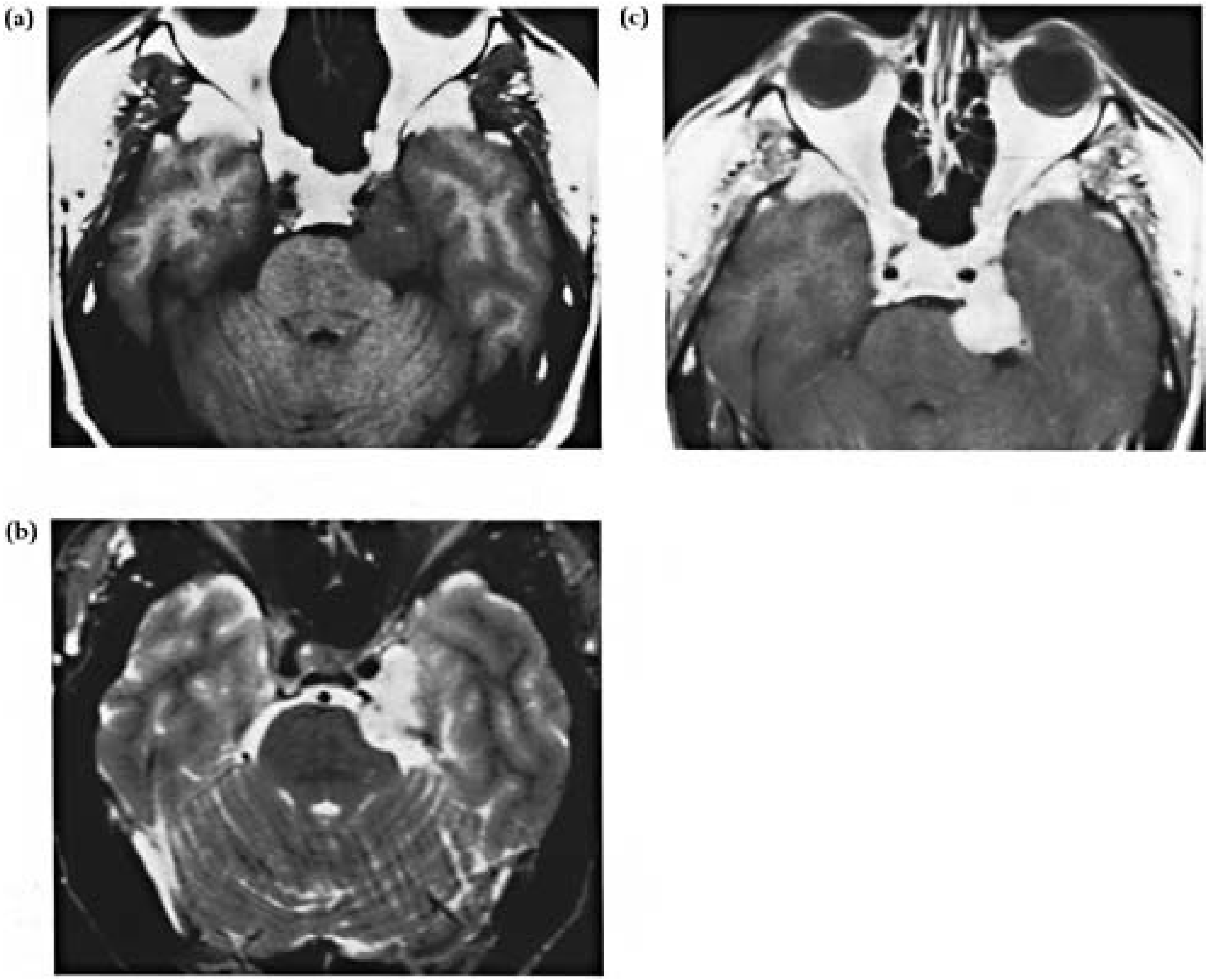


Figure 2

(a) T1-weighted axial MRI of schwannoma emanating in close proximity to cavernous sinus near petroclival region; (b) T1-weighted axial MRI scan with gadolinium showing enhancing mass. Note carotid flow void in cavernous sinus; (c) T1-weighted axial MRI of same tumor. Note proximity to petroclival area

to the brain, cavernous sinus, and carotid artery. They will indicate whether there is extension of the tumor into the pterygomaxillary space or temporal and infratemporal fossae.

ANATOMICAL CONSIDERATIONS

The lateral transtemporal-sphenoid approach allows direct lateral access to the skull base with adequate exposure for gross and microsurgical dissection of pathology present. In certain cases, the approach is used as part of a planned multi-stage procedure and can be combined with another technique. Problems of sensorineural hearing losses that occur with translabyrinthine and transcochlear approaches and the disability of permanent conductive hearing losses that result from the infratemporal fossa approach can be avoided. Time is saved in mastoid, middle ear, facial nerve, and otic capsule dissection with these techniques. The transient pan-facial paralysis and resultant synkinesis

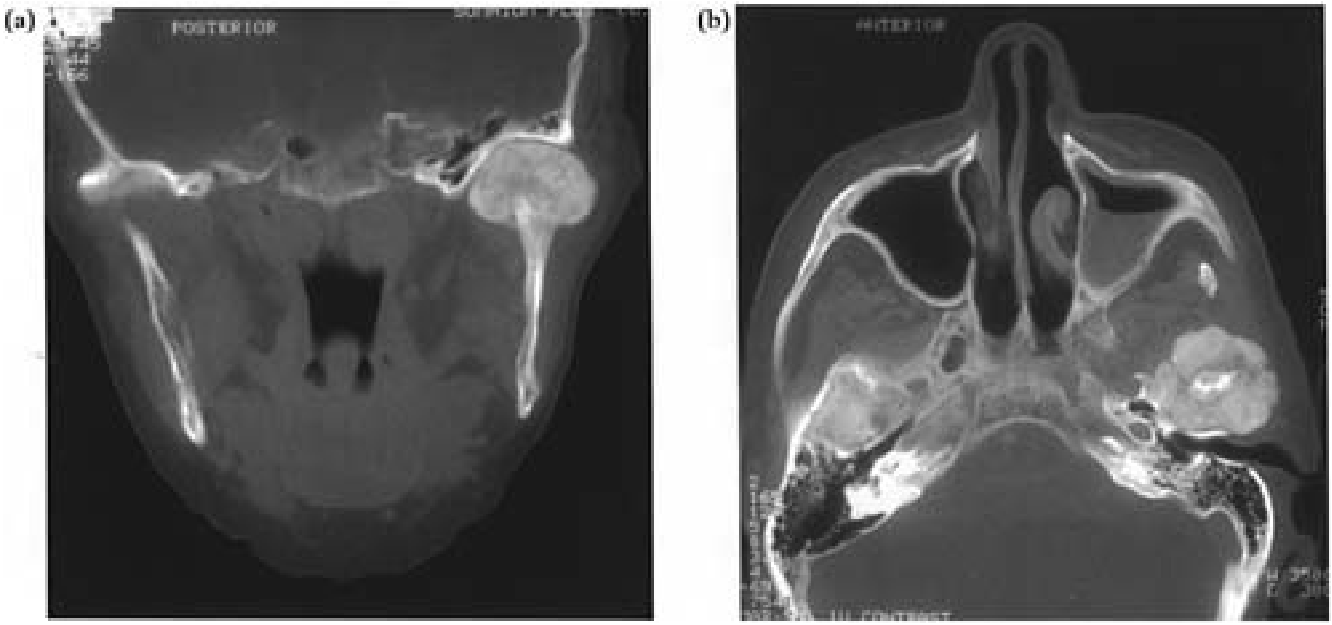


Figure 3

Tumoral calcinosis of left temporomandibular joint. (a) Coronal CT demonstrating mass within infratemporal fossa; (b) axial CT (bone window) demonstrating mass emanating from the glenoid fossa

associated with nerve degeneration occurring with the last two approaches are also avoided.

Another advantage of this surgical method is that it can remain an extradural approach, or, because it is a sterile technique, can be used intradurally if necessary. For lesions of the parasellar region, anteromedial temporal lobe, and trigeminal nerve, the main advantage is minimal temporal-lobe retraction, which diminishes the risk of aphasia and temporal-lobe seizures.

We have changed from an acute to an obtuse angle to shorten the working distance and to minimize angulation of the line of viewing. The net result is less retraction of intervening structures to achieve the same microscopic views. The anterior approaches to the skull base, such as the mandibular splitting technique of Biller and Wood’s combined approach with glossotomy, transpalatal, or transmaxillary techniques, all have the disadvantages of potential cosmetic or functional deglutitional deficits, malocclusion, necessity for tracheotomy, and, most importantly, upper aerodigestive contamination with potential leakage of cerebrospinal fluid and meningitis. These anterior approaches may also have limited lateral exposure in the area of the carotid arteries and parasellar regions.

The lateral transtemporal-sphenoid approach is a sterile approach unless nasopharyngeal mucosa or the sphenoid sinus, or both, must be resected. It is not an ideal approach as a single operation for lesions that are posterior to the carotid foramen, that are intrasellar (involving the lower

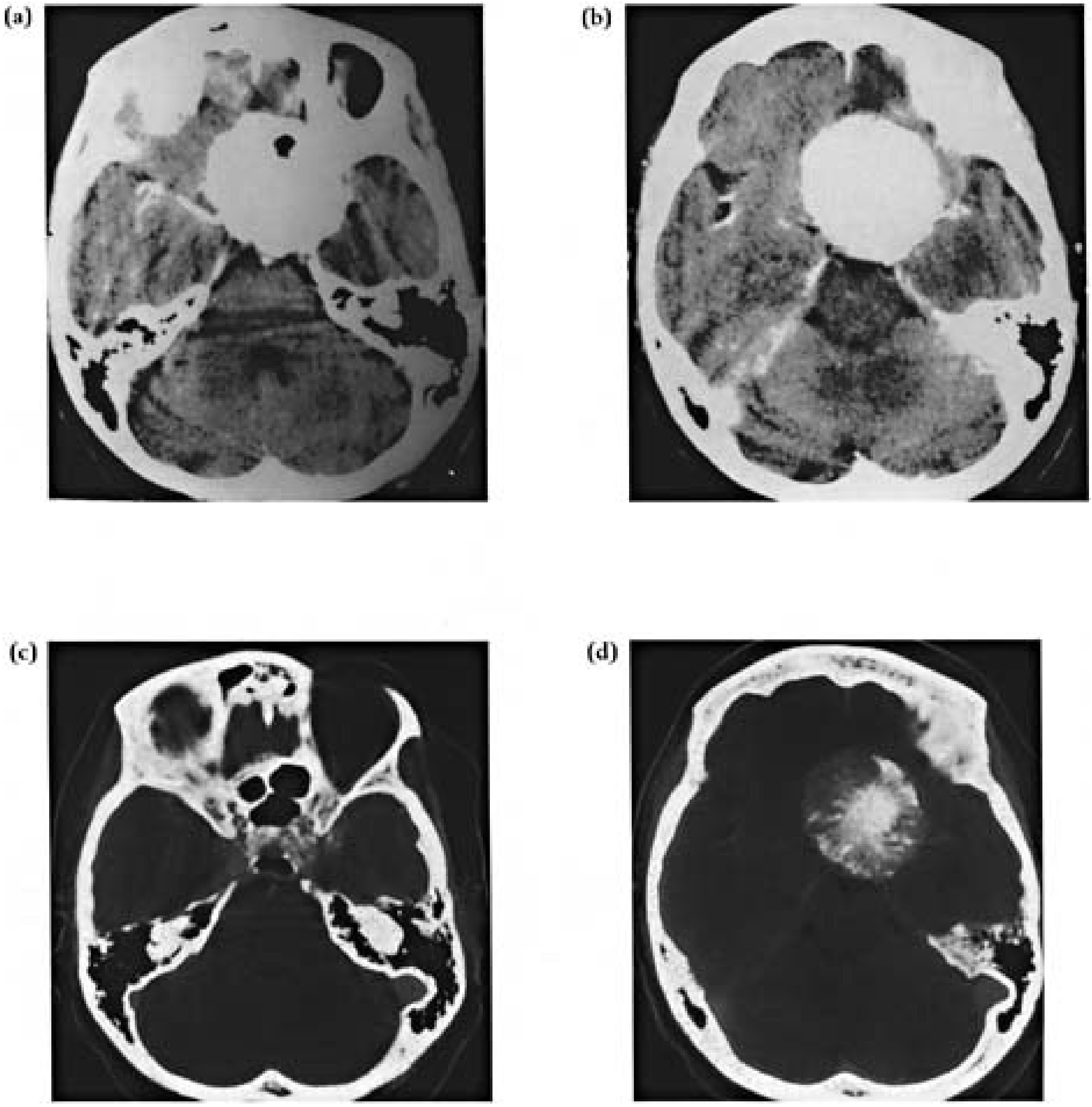


Figure 4

Sphenoid wing meningioma. (a) and (b) axial CT scan demonstrating sphenoid wing meningioma; (c) axial CT demonstrating bony erosive changes in the medial sphenoid wing; (d) axial CT of same tumor in more superior cross-section at level above the orbits clivus and upper cervical vertebrae), or those that extend into the cerebellopontine angle or parapharyngeal spaces.

PROCEDURE

The patient is placed on the operating table in a supine position, with the face turned slightly opposite the operative side. Hair is shaved in the lateral frontotemporal region. General endotracheal anesthesia is administered. A curvilinear incision is begun superiorly in the temporal hairline posterior to the lateral aspect of the superior orbital rim, and is curved posteriorly parallel with and one finger-width above the zygomatic arch. At the preauricular crease, the incision is curved inferiorly as far as the attachment of the lobule (Figure 5).

Superiorly and inferiorly based flaps are developed deep to the subcutaneous tissue to expose the superficial areolar tissue and fascia of the temporalis muscle, as well as the upper parotid-investing fascia. Self-retaining cerebellar retractors and retention sutures are used for exposure. A curved incision, through temporalis fascia parallel to the superior aspect of the zygomatic arch and 3 cm above it, is continued anteriorly until the incision extends to a point 1 cm posterior to the posterior aspect of the lateral orbital rim (Figure 6a). Transection injury to the frontozygomatic branch of the facial nerve is thus avoided. A smaller self-retaining retractor may be used for exposure of the temporalis muscle (Figure 6b). Traction on the frontalis branch of the facial nerve at this point may result in transient paresis.

The fascial reflection around the zygomatic arch is incised with cutting electrocurrent on the superior aspect of the arch, deep to the lateral fascial reflection. The periosteum is elevated to expose the arch. The temporalis muscle can be retracted inferiorly (Figure 7a) after elevation with a periosteal elevator, or a portion of the muscle may be retracted after it is split vertically. If the area of interest does not involve the nasopharynx or sphenoid sinus or a muscular flap will not be necessary, the temporalis muscle can be transected and reflected upward for greater exposure.

The zygomatic arch may then be transected on its anterior and posterior attachments with a drill or saw, and may be reflected inferiorly with the attached masseter muscle. The zygomatic arch can also be removed completely and replaced later as a free graft with wiring or plate fixation to restore proper anatomy The arch is reflected from the field if exposure of the pterygomaxillary fissure, clivus, nasopharynx; or petrous apex is required. The bone of the greater wing of the sphenoid is then thinned to an egg-shell thickness with the use of suction irrigation, a high-speed drill, and the operating microscope. Dural entry may be made after complete bone removal at the greater wing of sphenoid (Figure 7b).

Partially thinned bone over the anterior aspect of the temporal lobe may be left as an island for use in temporal lobe retraction, reminiscent of ‘Bill’s island’ in the temporal bone over the sigmoid sinus. If desired, bone is thinned over the periorbita and lesser sphenoid wing to expose the dural reflection of the superior orbital fissure and orbital areas. This dissection of the greater wing of the sphenoid may not be necessary if the areas of interest are posterior or inferior, such as the nasopharynx, petrous apex, and lower infratemporal fossa. The bone island is of greatest help when dissection is all extradural and involves the posterior orbit, optic foramen, parasellar region, main divisions of the trigeminal nerve, or pterygopalatine fissure areas.

The temporomandibular joint (TMJ) and its capsule may be elevated and retracted inferiorly with the joint intact to expose the carotid artery, eustachian tube, or petrous apex when necessary. With dislocation of the entire TMJ, the squamotympanic fissure is exposed and its entering fibrous bands resected with the cutting current. The squamotympanic fissure is an important landmark to the middle meningeal artery and eustachian tube (Figure 8). It runs in an anterior and medial direction and points toward the foramen ovale and pterygoid plates. The spine of the sphenoid is a small bony spur that projects just medial to its most medial extent. If this spine is drilled away, the middle meningeal artery can be identified on its anterior aspect, and the junction of the bony and cartilaginous eustachian tube can be found on its medial aspect. If more bone is removed by drilling of the tympanic bone just posterior to this junction, the internal carotid artery is exposed in its intratemporal course.

Continued microsurgical drilling dissection of the artery exposes the pericarotid air cell group as well as the superior compartment of the petrous apex. Further drilling of the

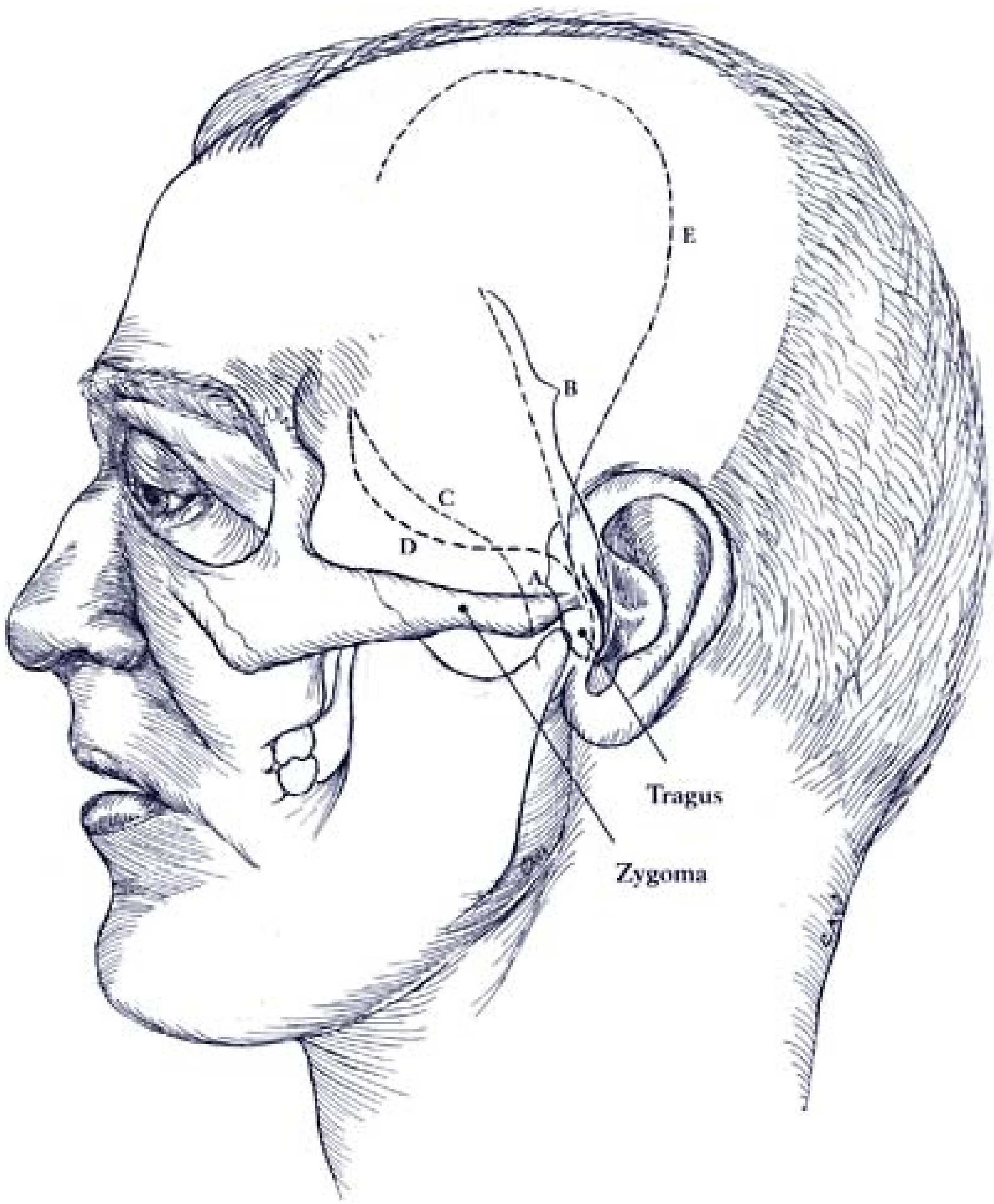


Figure 5

Variations of the skin incisions used for the lateral transtemporal-sphenoid approach. The incision described in the text is shown as D in the figure. B, C, and E are alternative incisions used depending on areas of needed further exposure

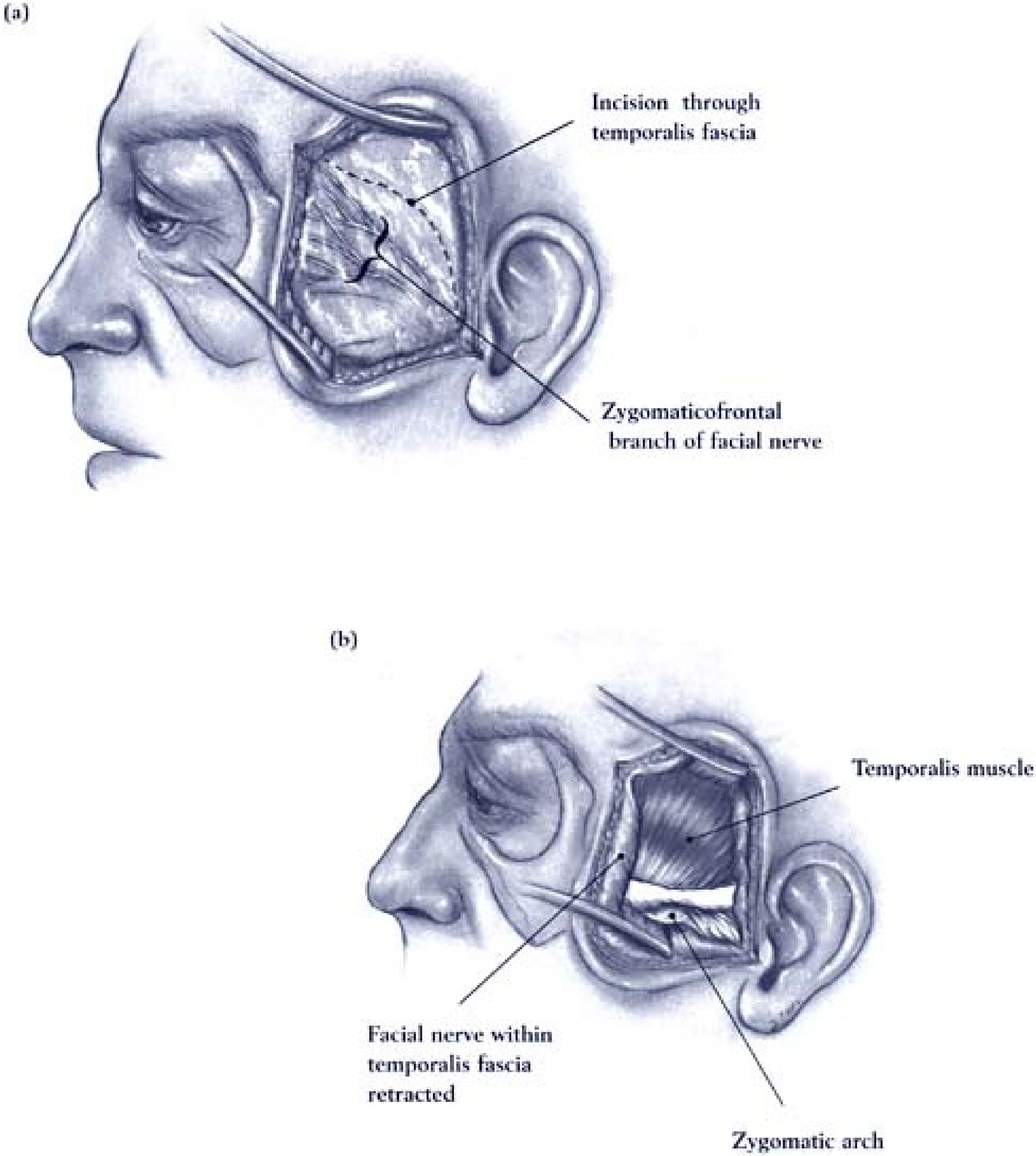


Figure 6

(a) Incisions made in the fascia to avoid transection injury of the frontal branch of the facial nerve; (b) exposure of the temporalis muscle and zygomatic arch

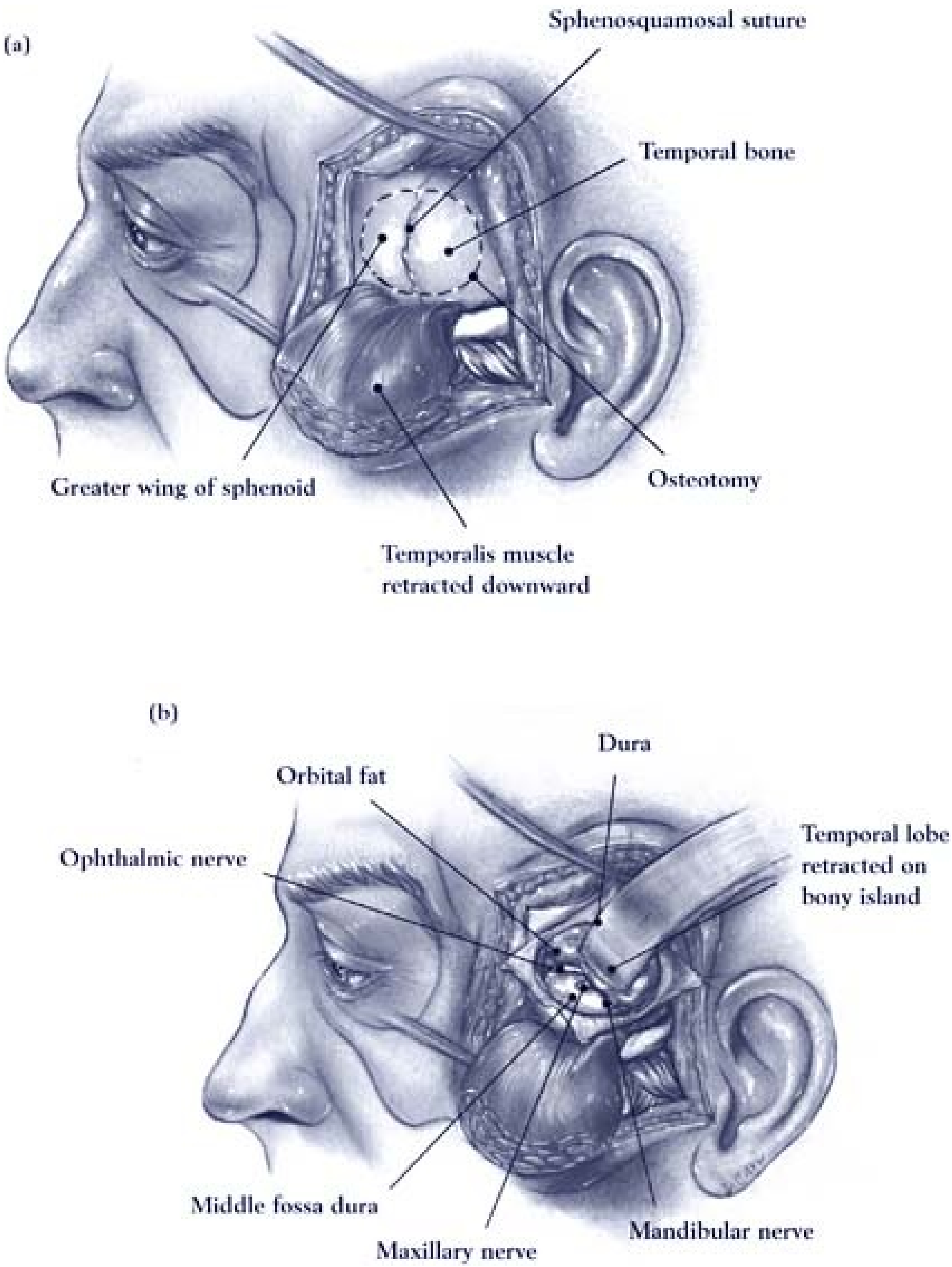


Figure 7

(a) Temporalis muscle reflected inferiorly to gain access to greater wing of sphenoid; (b) bone removal at greater wing of sphenoid completed with dural entry. The temporal lobe is gently retracted medially to expose branches from the trigeminal ganglion

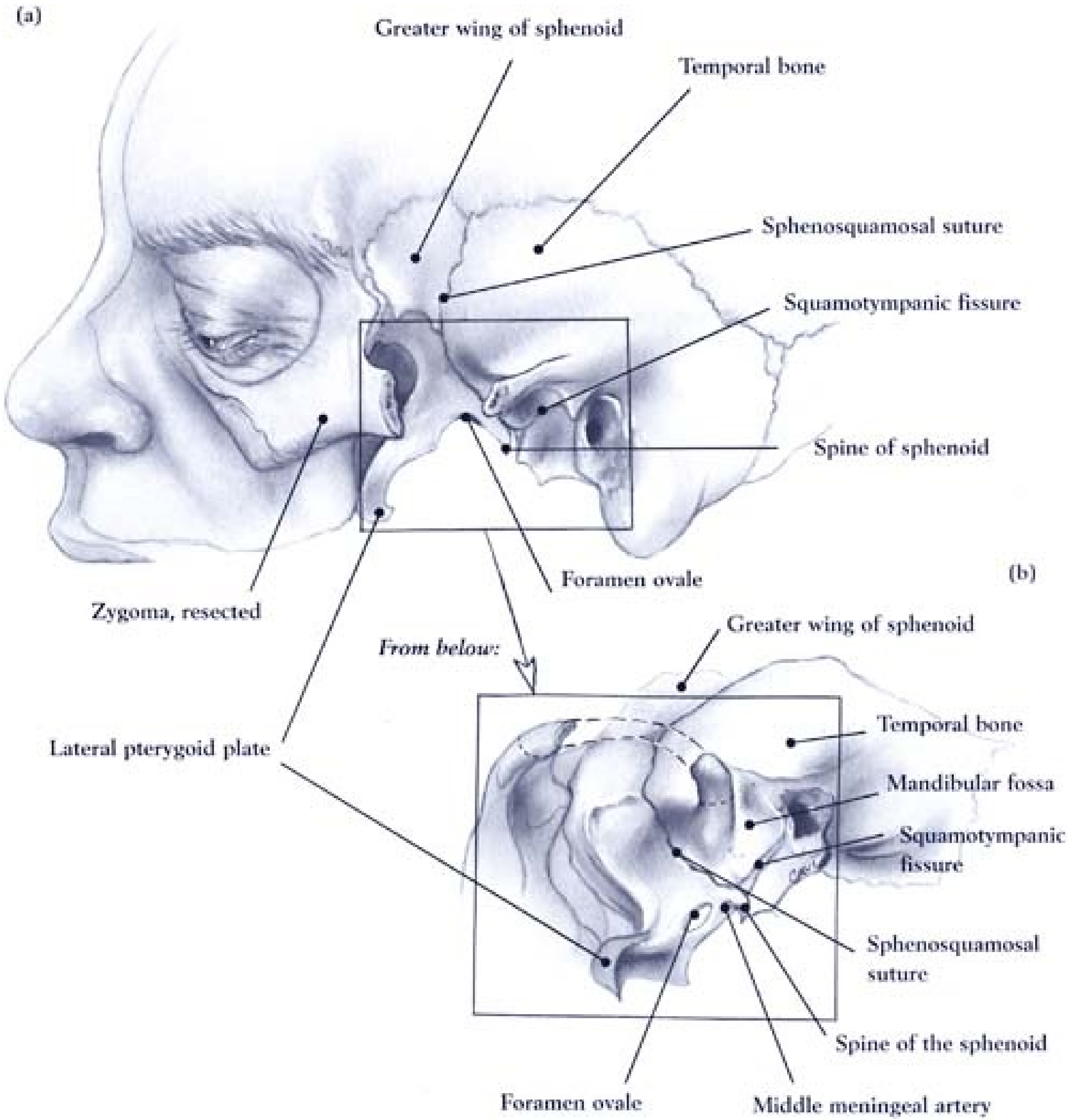


Figure 8

Inferior view of infratemporal fossa, pterygopalatine fossa, and pterygomaxillary space after the zygomatic arch is removed bone between the foramina ovale and rotundum and the superior orbital fissure will expose the dural reflection of the cavernous sinus. If the middle meningeal artery and the mandibular nerve are divided and more bone is removed medially, the eustachian tube, internal carotid artery and foramen lacerum can be exposed (Figure 9).

TIPS AND MODIFICATIONS

Flap coverage

When a musculofascial flap is anticipated, the incision can be modified slightly on its superior aspect. Coverage by the temporalis musculofascial flap of the nasopharynx is necessary only if resection of the clivus and nasopharyngeal mucosa is performed and condylar resection needed. If the surgeon performs an enucleation of the orbit and frontal lobe dura is exposed, the temporalis myocutaneous flap can be used for coverage and dural support. The temporalis muscle can be harvested with an attached underlying piece of rectangular calvarial bone from the frontal; parietal or temporal squamous regions to give additional bony support to the brain if desired. Generally, packing is required for support during the initial healing process.

Intracranial dissection

If pathology is intracranial; it may be necessary to remove more bone to achieve additional medial temporal lobe retraction. The anterior portion of the temporal lobe can also be removed with no gross disability for exposure of intracranial parasellar lesions. If a leak of cerebrospinal fluid is encountered during part of the case, this area should be sealed later with a free musculofascial graft or pedicled temporalis flap to isolate the middle ear and the eustachian tube. Whenever the eustachian tube is opened and secondarily sealed, a myringotomy tube for middle ear ventilation must be placed at the time of the resection if no leak of cerebrospinal fluid is encountered. However, it should be performed several weeks later in delayed fashion to ensure middle ear aeration if spinal fluid drainage occurs.

When entry of the sphenoid sinus is required and cerebrospinal fluid flow has occurred during the procedure, the sinus is eventually packed with a free fat graft after the interior mucosa is stripped from the sinus and the cavity burred clear of any residual mucosal lining. This is only practical without the use of pedicled flap when the anterior rostral mucosa is preserved.

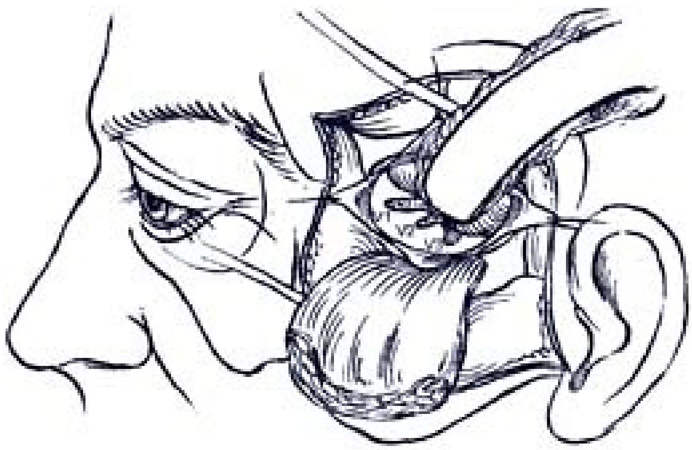
If the area of intracranial disease is in the region of the posterior clinoid process, a limited view can be obtained by dislocating the TMJ inferiorly and by removing the glenoid fossa bone. The temporalis muscle and zygomatic arch are reflected laterally and the middle meningeal artery and mandibular nerve are divided. Bone is then removed from the middle fossa floor medially as far as the eustachian tube, and the temporal lobe dura is elevated medially to the superior petrosal and cavernous sinuses. The dural incision is then made parallel to the superior petrosal sinus and approximately 5 mm lateral to it. With the use of the Janetta or Yasergil retractor, the medial temporal lobe is gently elevated. This allows an intradural exposure of the posterior clinoid region just over the attachment of the tentorium cerebelli.

A gentle suction drain with a sterile waterseal or vacutainer may be used if leak of cerebrospinal fluid, capillary drainage, or dead space appears imminent. In most cases, this has been necessary

Infratemporal fossa dissection

When significant infratemporal fossa dissection is required, it is advisable to free the zygomatic arch (Figure 8). Most of the dissection can be performed with unipolar electrocautery and cutting current, reserving bipolar cautery dissection for the areas adjacent to mucosa, periosteum, and neural and vascular structures.

If the entire mandibular condyle and intact TMJ has been mobilized and retracted (as in dissection of the petrous apex, parasellar and medial temporal-lobe lesions), the bone of the glenoid fossa and middle-fossa floor has usually been removed for adequate exposure. In these cases, we prefer to use a free bone graft of temporal squama to give support and prevent the TMJ from effecting temporal lobe compression. In our experience, the joint functions normally when healed. Because the temporalis muscle has been freed during the procedure and the joint is normally retracted directly, inferiorly rather than anteriorly, quite generous mobilization can be achieved with little pressure. We have not found it



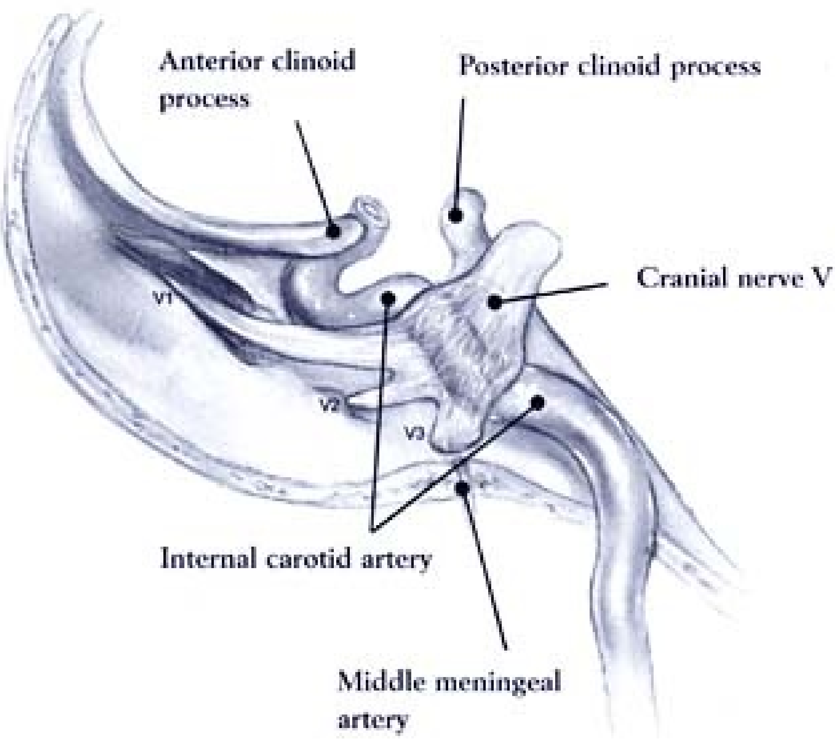


Figure 9

Relationship of the petrous internal carotid artery to the middle fossa floor. Access to the petrous carotid artery is obtained after traversing through the foramen spinosum (middle meningeal artery), foramen ovale (trigeminal nerve), and foramen rotundum (maxillary nerve) necessary, therefore, to employ a modified thoracotomy retractor, as used in the infratemporal fossa approach. Extension of dissection into the pterygoid plate region to include complete pterygoid process removal can also be accomplished.

COMPLICATIONS

The distinct advantage of the lateral transtemporal-sphenoid approach is accessibility without excessive temporal lobe retraction. Subtemporal bone of the middle fossa floor is removed in place of superior temporal lobe retraction. Therefore, the complications which follow from temporal lobe retraction are reduced. These include direct trauma to the temporal lobe, leading to aphasia or seizures.

Particular attention is paid after the skin incision is created to preserve the frontal branch of the facial nerve. It is lifted up and out of the way prior to translocation or dissection through the temporalis muscle. Even though the frontal branch is preserved over a fascial layer, the risk of stretch injury to the nerve still exists from vigorous retraction of the soft tissues lateral to the temporalis muscle. This may lead to transient upper facial weakness.

The risks of infections are reduced if the procedure does not involve entry into the sphenoid sinus, eustachian tube; or pneumatized spaces of the temporal bone. If such entry is made, appropriate peri-and postoperative antibiotic coverage should be instituted as for other clean-contaminated neurosurgical procedures; such as the anterior craniofacial resections with entry into the sinonasal cavity.

Cosmetic deformities are kept to a minimum as all the structures which are translocated are replaced. The bulky temporalis muscle, if split or detached, is returned to its anatomical position and sutured. The zygomatic arch, if cut and then displaced inferiorly to gain access to the infratemporal fossa, is replaced and plated by rigid fixation.

ADDITIONAL READING

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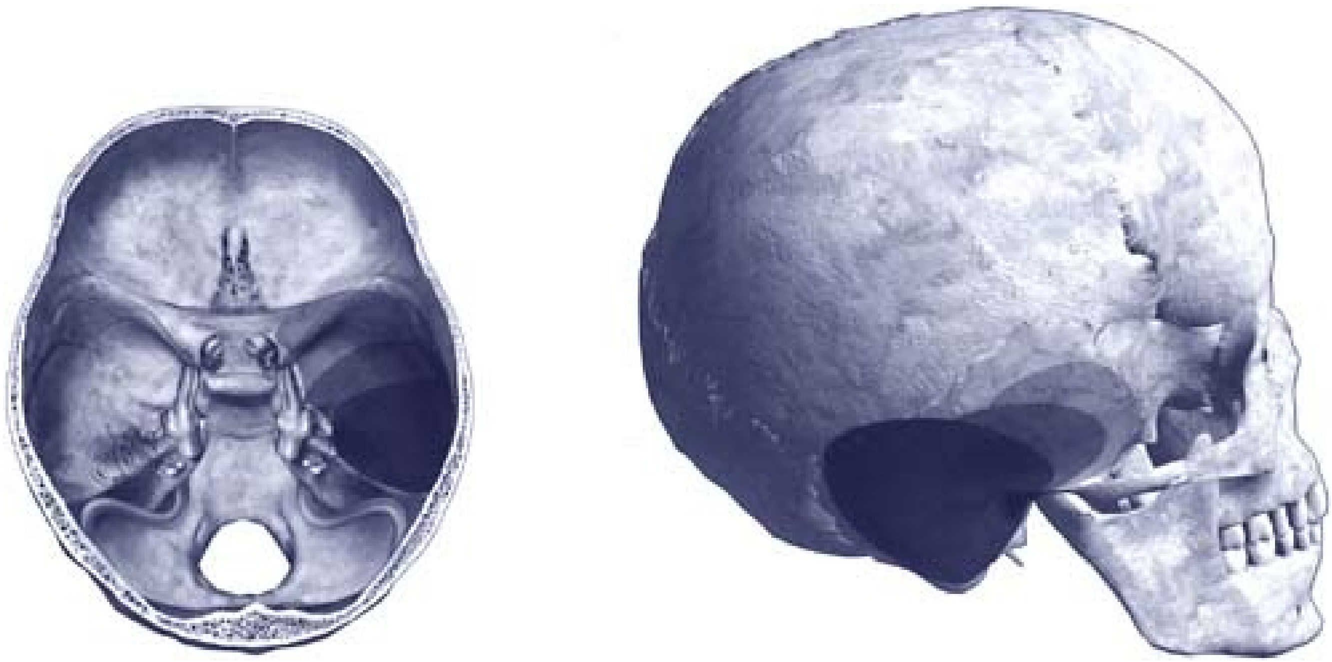
8
Infratemporal approaches

Douglas E.Mattox, John K.Niparko and Michal J.Holliday



INDICATIONS

The temporal bone presents unique surgical challenges to the complete removal of lesions that involve the major neurovascular structures. The neural and vascular elements within the temporal bone have tortuous courses and run at oblique angles to each other, often hampering deep exposure. Not uncommonly, lesions of the temporal bone lie adjacent to the internal carotid artery and the sigmoid-jugular venous system. The infratemporal approaches conceptualized and popularized by Professor Ugo Fisch offer direct and wide exposure of the common sites of temporal bone tumors while limiting risk to neural and vascular structures.

The infratemporal fossa type A approach effectively addresses tumors that involve the mastoid and hypotympanic regions of the temporal bone and that extend to the petrous apex (Figures 1 and 2). This approach is particularly useful for lesions of the infralabyrinthine space and jugular bulb, typically glomus jugulare tumors, vagal schwannomas and infralabyrinthine cholesteatomas.

The type B approach is used to address lesions that lie anteromedial to the genu of the internal carotid artery The facial nerve is left in its normal anatomic position and the dissection is carried anteriorly by removing the anterior

Table 1 Regions and structures accessible by the infratemporal fossa approaches

	• Hypotympanum
	• Mastoid
Type A	• Infralabyrinthine region
	• Posterior infratemporal fossa
	• Jugular foramen
	• Petrous apex
Type B	• Clivus
	• Superior infratemporal fossa
	• Petrous carotid artery
	• Parasellar region
	• Nasopharynx
Type C	• Peritubal space
	• Rostral clivus
	• Pterygopalatine fossa
	• Anterosuperior infratemporal fossa

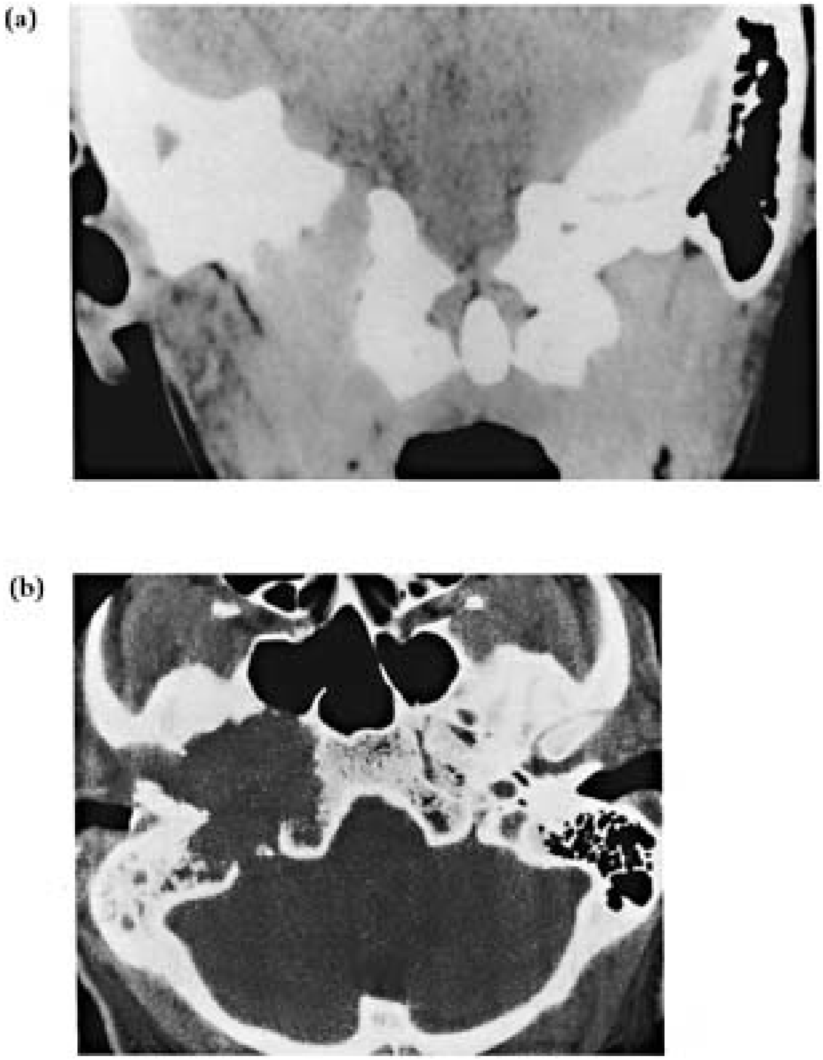


Figure 1

Right glomus jugulare tumor. Coronal (a) and axial (b) CT scan demonstrating typical location of glomus tumor emanating from jugular foramen and extending superiorly within the temporal bone. Note the bony destructive changes

tympanic ring and the bone of the skull base beneath the middle cranial fossa. The type B approach provides full access to the horizontal segment of the petrous internal carotid artery. Lesions of this extent commonly surround the internal carotid artery and involve the petrous apex and clivus. The type B approach provides exposure for the removal of petrous apex cholesteatomas, cholesterol cysts (Figure 3) and tumors of the clivus. The type B approach is employed most commonly to address chordomas of the clivus, extensive petrous apex cholesteatomas and meningiomas. Other lesions that can occur in this area include chondroma, squamous cell carcinoma, dermoid cyst, meningioma, craniopharyngioma, plasmacytoma, arachnoid cyst, and craniopharyngeal fistula.

The type C approach is an anteromedial extension of the type B approach to the pterygoid plates and the foramen rotundum. The mandibular condyle is released from the glenoid fossa and pushed inferiorly. Removal of the entire bony floor and lateral wall of the middle fossa with the drilling permits extradural retraction of the temporal lobe, allowing a wider exposure of the parasellar tumors. This

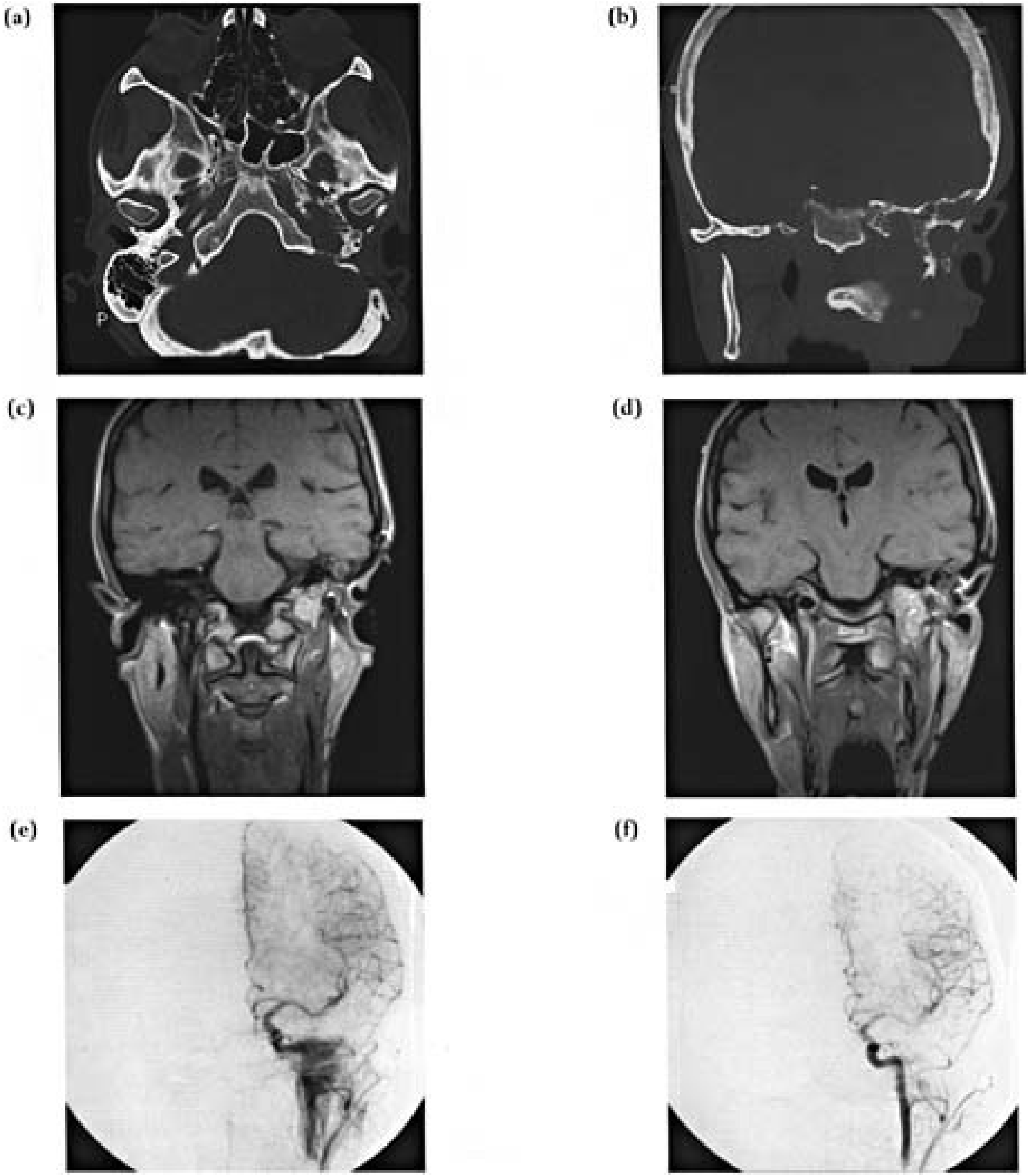


Figure 2

Recurrent left glomus jugulare tumor. Axial (a) and coronal (b) CT scans of temporal bones demonstrating expansion of entire jugular foramen with erosion of bone surrounding the carotid canal in the petrous apex. Coronal MRI (c and d) with gadolinium demonstrating tumor mass within jugular foramen. Left carotid arteriogram demonstrating arterial supply to left glomus jugulare tumor (e and f). Pre-embolization study is shown in (e). Vessels feeding the tumor occluded post-embolization (f)

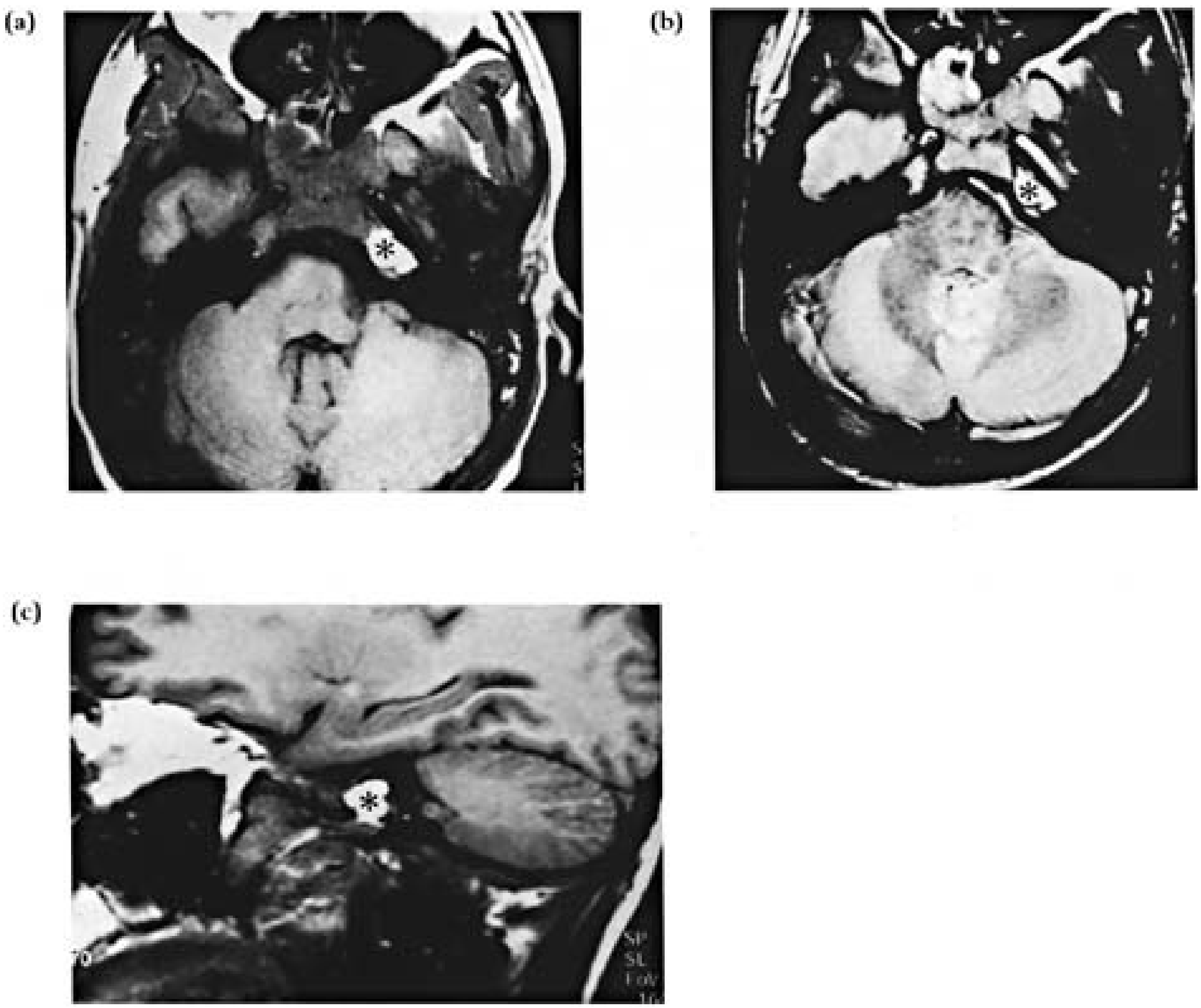


Figure 3

(a) T1-weighted axial MRI scan of cholesterol granuloma (*) in petrous apex; (b) T2-weighted axial MRI scan of same lesion. Note the characteristic enhancement on both T1-and T2-weighted images; (c) T1-weighted sagittal MRI of same lesion (*)

approach provides direct access to tumors situated as high as the level of the floor of the sella, and is restricted only in its exposure to tumors extending posterior to the posterior clinoid process. The type C approach is an effective approach to chordomas (Figure 4), meningiomas and extensive glomus tumors that involve the parasellar lesion and extend anteriorly into the nasopharynx.

PATIENT EVALUATION

The specific infratemporal approach used is dictated by the pattern of tumor extension in each individual case. Bony extension is evaluated with computed tomography (CT) scanning of the temporal bone and infratemporal fossa (Figures 1, 2 and 5) and magnetic resonance imaging (MRI) (Figures 2, 3 and 6) can help to distinguish tumor type, in addition to providing added information regarding soft tissue

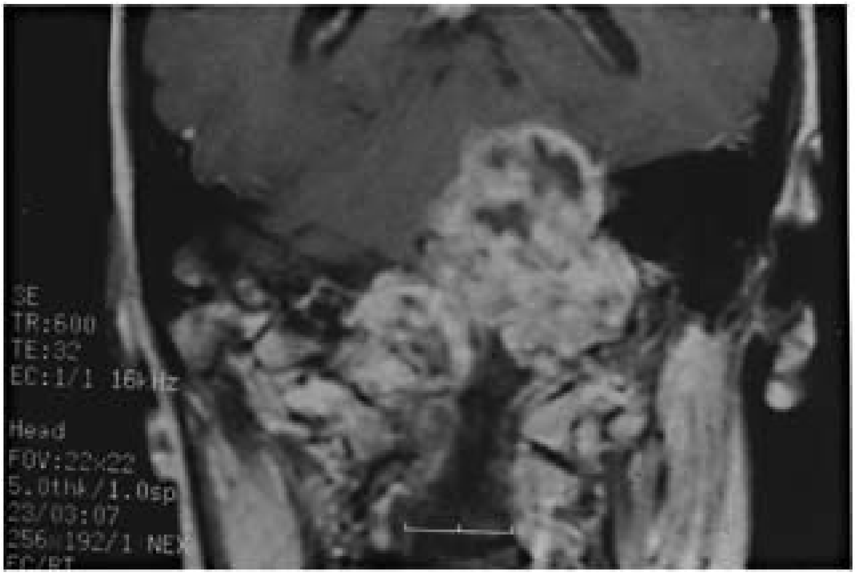


Figure 4

Clival chordoma approached by the type C approach. T1-weighted coronal MRI scan with gadolinium of clival chordoma with extension to pterygopalatine space

tumor extension, particularly regarding the dura and orbit. Staged intracranial and extracranial infratemporal fossa procedures can be performed for larger tumors that breach the dura.

Magnetic resonance angiography and interventional angiography are critical for assessment of the vascularity of the tumor and the status of the internal carotid artery when it is surrounded by tumor. Direct angiography is critical in vascular tumors to determine if there are both extracranial and intracranial blood supplies and to embolize the feeding vessels (Figures 2 and 7). Carotid angiography with balloon test occlusion is important in assessing the patency of the circle of Willis and the integrity of collateral circulation when the carotid is surrounded by tumor or otherwise put at risk during the approach.

ANATOMICAL CONSIDERATIONS

The translabyrinthine, retrolabyrinthine, and middle fossa approaches to the skull base, championed by Dr William House; provide ample exposure of the cerebellopontine angle and supra-and retrolabyrinthine areas. Regions below and anterior to the labyrinth call for alternative surgical strategies. Fisch compartmentalized the temporal bone into regions that lie above, below, behind, and in front of the labyrinth. These compartments correspond to the supra-, infra-, retrolabyrinthine segments and the petrous apex, respectively. While neoplasms of the temporal bone potentially occupy any one or more of these compartments, most will involve the infralabyrinthine and apical compartments of the temporal bone.

Fisch independently described his posterolateral (infratemporal fossa) approach to the infralabyrinthine and apical compartments in 1977. With this technique, labeled the type A approach, the facial nerve was mobilized from the Fallopian canal, allowing free and unobstructed access to the jugular bulb and jugular foramen. Cochlear function could be preserved, although the middle ear was sacrificed and the external auditory canal is closed, resulting in a conductive hearing loss. Resection of the mandibular condylar was initially required for exposure of parasellar and clival lesions. Later, dislocation of the temporomandibular joint was described. The mandibular nerve was routinely divided, but, as the technique evolved, repair often allowed reinnervation of the muscles of mastication on the affected side.

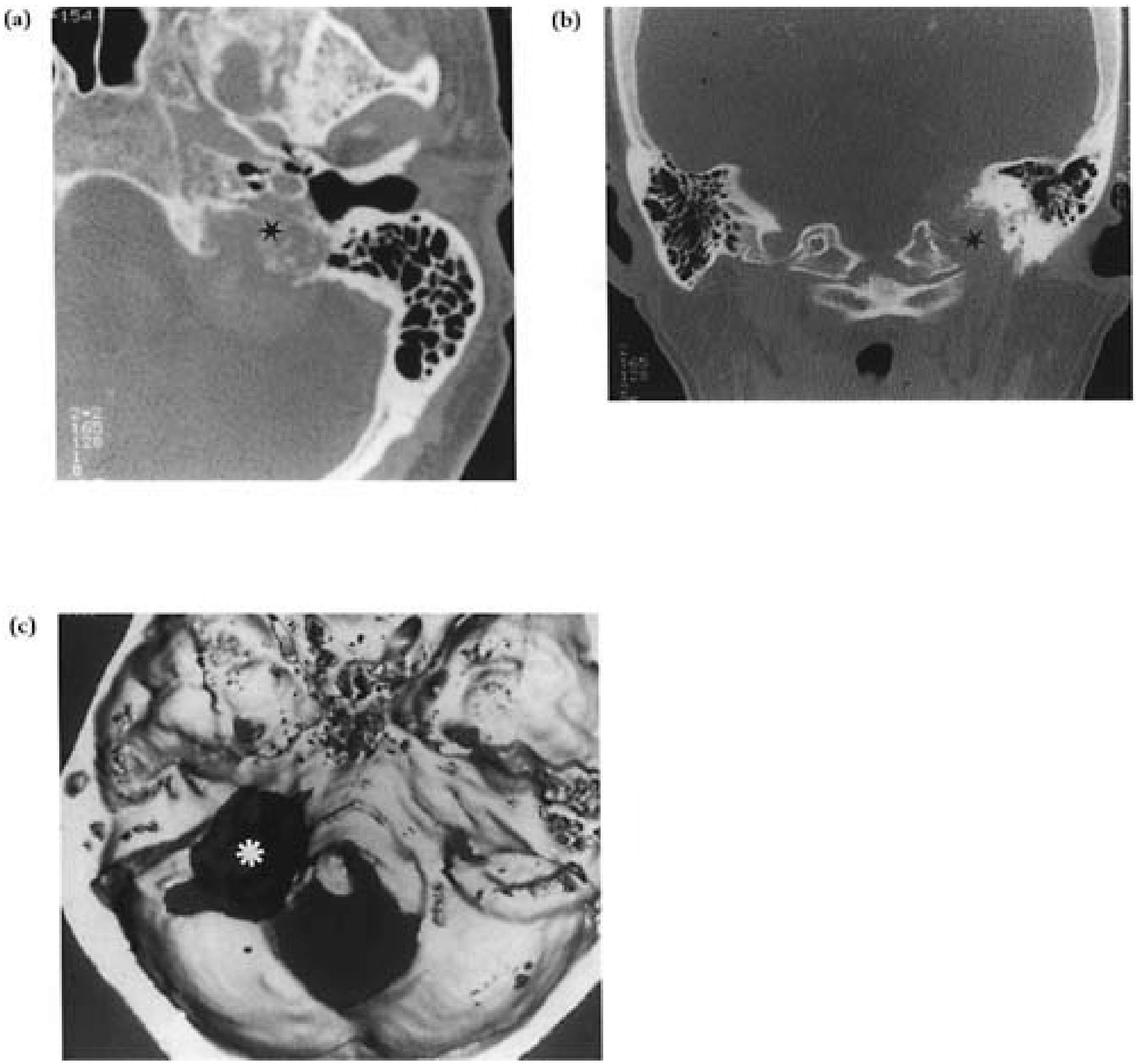


Figure 5

Left glomus jugulare tumor. (a) Axial CT scan of left glomus jugulare tumor with associated bony erosive changes; (b) coronal CT scan of same tumor. Most of the bony erosive changes occur beneath the labyrinth; (c) CT three-dimensional reconstruction of glomus tumor (*) emanating from jugular foramen, intracranial view

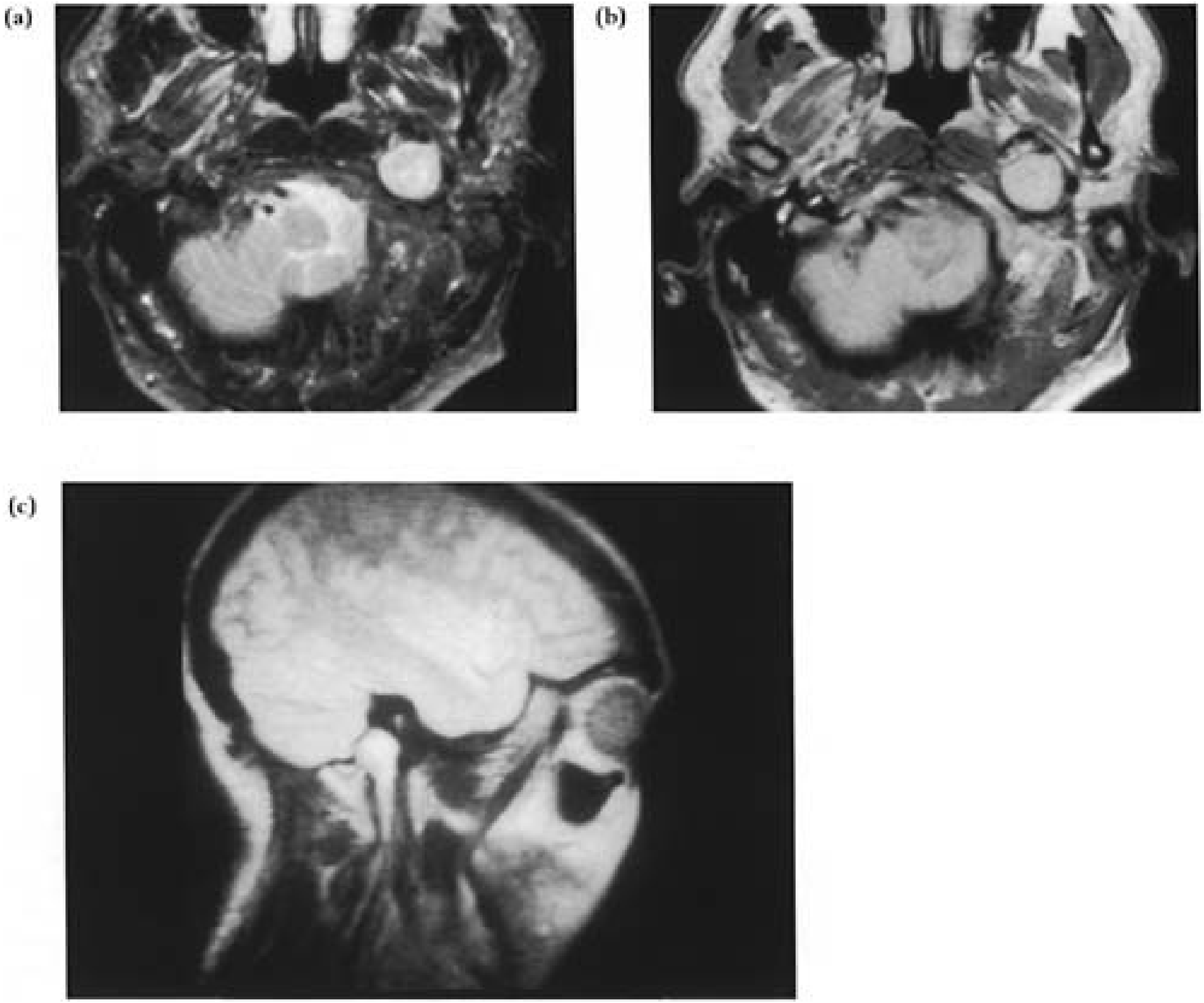


Figure 6

Schwannomas of the jugular foramen. (a) T2-and (b) T1-weighted axial MRI of vagal schwannoma. The jugular foramen is enlarged with such a tumor. There is a distinct border around the tumor, distinguishing it from the surrounding bone and soft tissue; (c) T1-weighted sagittal MRI of glossopharyngeal schwannoma

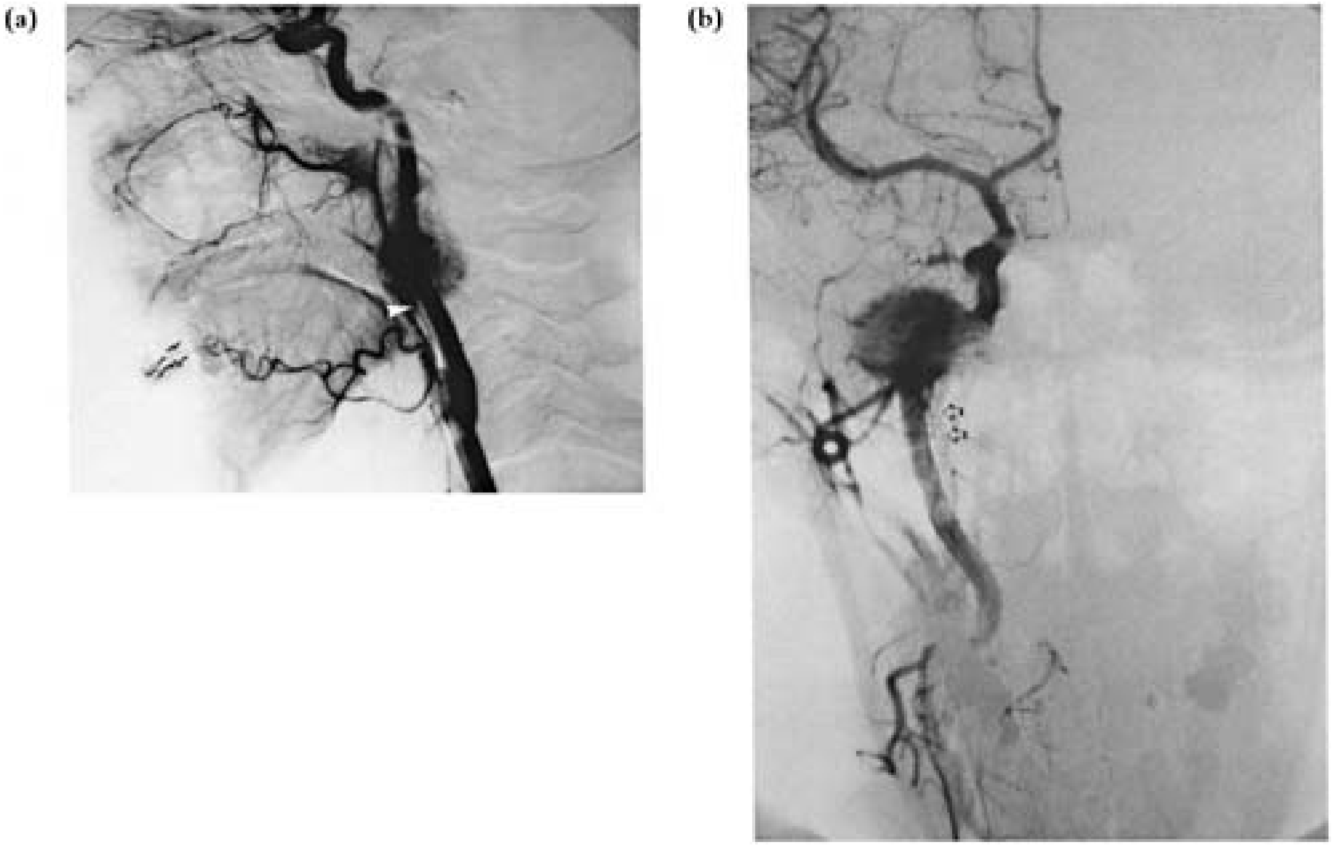


Figure 7

Digital subtraction angiographic image of glomus jugulare tumors with both internal and external carotid arterial contribution to the vascularity of the tumor, seen as the tumor blush with the principal arterial feeder (ascending pharyngeal artery) indicated by arrows. (a) Coronal view of 2.5-cm glomus jugulare; (b) posterior view of 3-cm glomus jugulare

Tumor extensions to the parasellar and clival regions are difficult to resect through any approach and, as a result, many approaches have been devised that have individual advantages and disadvantages in different situations. The transsphenoidal route is direct, but the lateral exposure is limited. Mid-line approaches, including transpalatal, and the mid-line mandibulotomy and glossotomy techniques, provide access to the clivus. However, they have the disadvantage of poor control of the carotid arteries and cavernous sinus and also carry the risk of meningitis if a cerebrospinal fluid leak should ensue. These approaches also have other disadvantages, including potential problems of cosmesis and difficulty with malocclusion.

Neurosurgical procedures usually combine some form of craniotomy in the suboccipital or frontotemporal region to approach these areas. The amount of brain retraction required and extra-axial extension will limit the amount of tumor successfully removed. We have tried these techniques and have found that each may have advantages and disadvantages in individual situations. The surgeon’s familiarity with a particular surgical approach often influences the decision as to which is the optimal approach. However; facility with the infratemporal approach and its extensions provides a uniquely direct approach to selected tumors involving the lateral skull base. These regions are addressed more directly with infratemporal fossa approaches.

The approach to the infratemporal fossa, jugular compartment, clivus and parasellar regions described is based on our interpretation of the elegant descriptions and insights provided by Fisch. It is to his great credit that surgeons have been stimulated into thinking in terms of possible resections for these deep lesions that are often both extensive and destructive. The hallmark of infratemporal approaches type A, type B, and type C is positive identification of the facial nerve and internal carotid artery. Positive identification of these landmarks employs the principle of working from ‘known to unknown’ tissue planes; to ensure complete and safe extrication of tumors.

PROCEDURE

Type A approach
The patient is placed on the operating room table in a supine position, with the face turned toward the opposite shoulder. The head is shaved totally or, if desired, for a distance of 4 inches in all directions from the ear. The area is prepared and sterilely draped.

A generous C-shaped postauricular incision is made through the skin and subcutaneous tissue, which is elevated to expose underlying fascia, periosteum, and muscle (Figure 8). The incision is extended down to the temporalis fascia above, to the mastoid periosteum postauricularly, and through the subcutaneous tissues and sternocleidomastoid muscle over the mastoid tip. Extension of the incision into the cervical region allows exposure of the sternocleidomastoid muscle, great auricular nerve, carotid artery bifurcation, jugular vein, and the caudal cranial nerves.

Soft-tissue elevation in the postauricular region is continued anteriorly to the level of the conchal perichondrium. A second anteriorly based flap of deeper fascia, postauricular muscle, and periosteum is elevated anteriorly in the subperiosteal plane. The cartilaginous external auditory canal is transected and the soft tissues elevated to expose the parotid fascia. Cerebellar self-retaining retractors facilitate exposure.

The skin of the external auditory canal is closed by mobilizing the skin from the canal cartilage, everting it through the canal, and suturing the anterior and posterior edges together. Closure is double-layered: the everted skin is closed with interrupted chromic catgut suture and the second (inner) layer, composed of the postauricular periosteal flap, is sutured over the cut edge of the cartilaginous canal to reinforce the closure.

A radical mastoidectomy is performed with complete exposure of the mastoid and tympanic segments of the facial nerve (Figure 9). The canal skin and tympanic membrane are removed after disarticulation of the incudostapedial joint. All mucosa from the middle ear and residual skin of the ear canal and drum are removed. Residual rests of squamous epithelium from the tympanic membrane and ear canal, or loculated areas of potentially infected mucous membrane should be removed. These measures prevent the late formation of mucocele and cholesteatoma. The pneumatic spaces of the mastoid and temporal bone are exenterated and the remaining external auditory canal skin and tympanic membrane resected. This results in a ‘subtotal petrosectomy’ as described by Fisch.

If the lesion involves the jugular bulb and internal carotid artery, the carotid artery can be controlled in the neck with vascular loops, and the internal jugular vein divided and ligated.

When the jugular bulb is invaded and bulb resection is likely the lateral sinus should be divided and ligated inferior to the take-off of the mastoid emissary vein after the dura is opened for visualization of the posterior fossa arachnoid.

Management of the facial nerve is key to optimal exposure and minimizing postoperative morbidity. The vertical segment of the Fallopian canal obstructs direct access to the apical and infralabyrinthine compartments, particularly at the level of the dome of the jugular bulb and the genu of the carotid artery. The infratemporal approach relies on judicious management of the facial nerve to enable complete exposure of the carotid artery from the carotid foramen to petrous portions of the horizontal carotid artery. Transposition of the facial nerve is accomplished by elevating it from the Fallopian canal from the geniculate ganglion to the stylomastoid foramen (Figure 10). Removing all the bone from the lateral 180° of its surface safely exposes the nerve. The vertical segment is addressed first. The mastoid tip lateral to the digastric muscle is removed. Using the digastric ridge as a guide to the stylomastoid foramen, microsurgical drilling is employed to uncover the fascia at the stylomastoid foramen and the facial nerve in its vertical segment. A ‘barber pole’ bone removal strategy with the drill for exposure of the vertical segment of the facial nerve facilitates decompression without injuring the lateral semicircular canal. Fine diamond drills are then used to

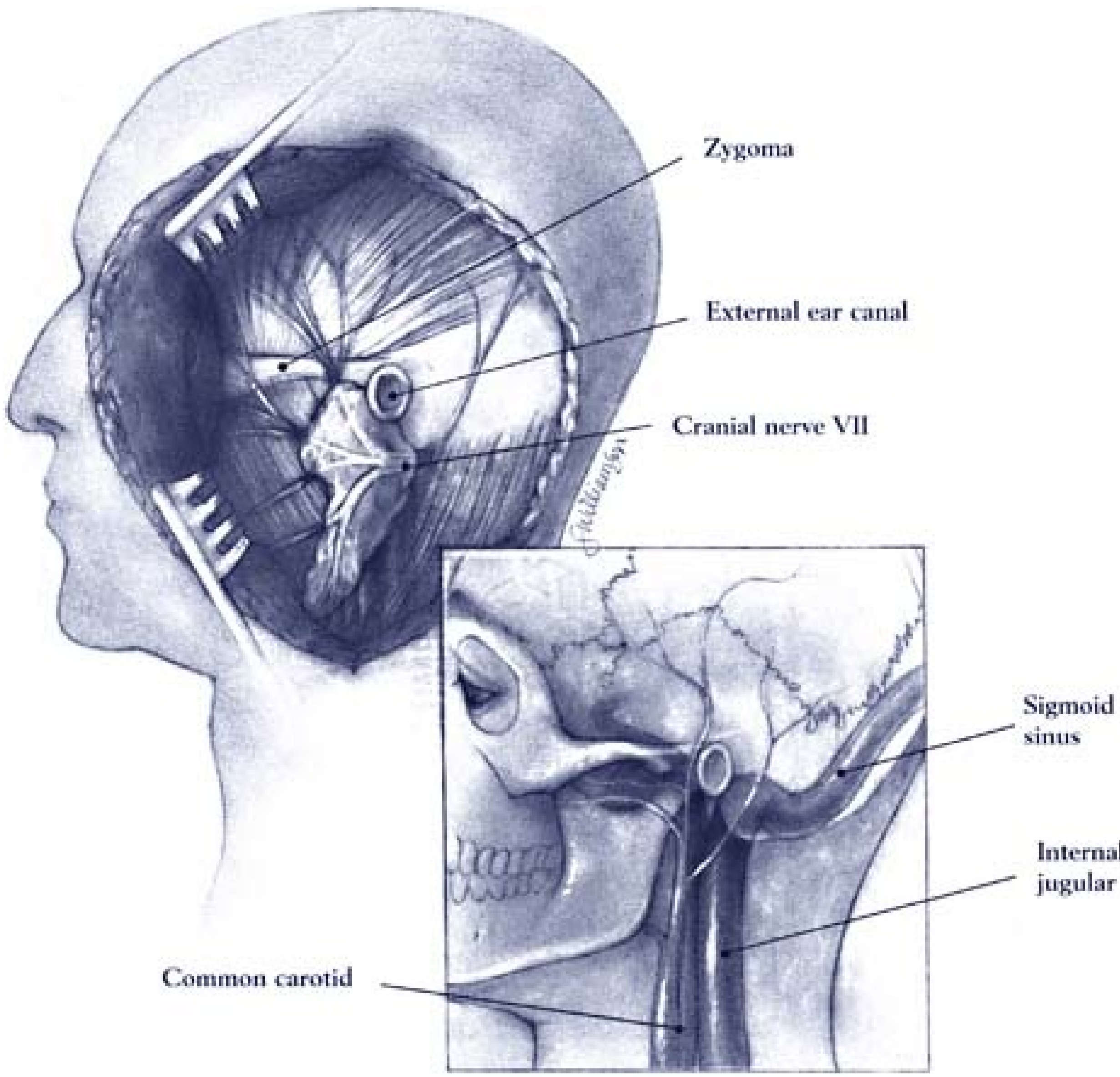


Figure 8

Schematic diagram of the surgical anatomy encountered in wide exposure of the left infratemporal skull base. The dissection requires management of the temporoparietal and upper cervical musculoskeletal structures, the parotid gland, the carotid artery, and jugular and sigmoid vessels, and cranial nerves VII, IX–XI

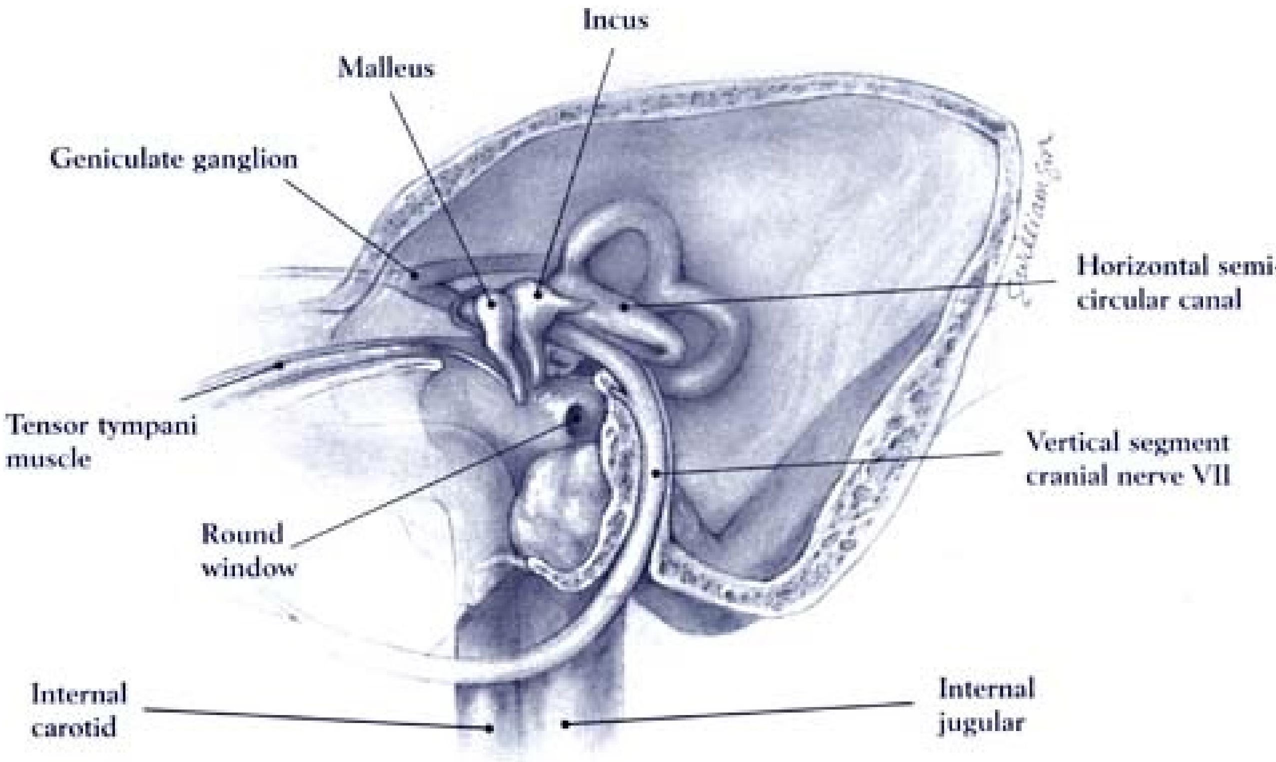


Figure 9

Subtotal petrosectomy. A radical mastoidectomy has been performed (removal of tympanic membrane and ear canal) with identification of the landmarks for the facial nerve and isolation. The tympanic and mastoid segments of the facial nerve have been identified. The sigmoid sinus and jugular bulb with contained tumor have been skeletonized

decompress the tympanic segment of the facial nerve. Bone over the nerve is thinned with diamond burrs until the last layer can be picked away with a small hook. Sectioning of the chorda tympani and stapedius branches and stylomastoid periosteum enables mobilization of the facial nerve.

A partial parotidectomy is performed to expose the extratemporal facial nerve and its main branches. Soft tissues of the parotid are elevated from the mastoid tip and the anterior surface of the external auditory canal cartilage. The main trunk of the nerve is found approximately midway between the cartilaginous pointer of the external auditory canal and the mastoid tip, approximately 1 cm deep to the pointer. The nerve is followed to its bifurcation. The nerve is separated from the deep lobe of the parotid gland and its cervical branches can be transected to aid in mobilizing the nerve trunk superiorly.

The nerve is elevated from the Fallopian canal and mobilized from the parotid gland and the soft tissues beneath the stylomastoid foramen. The nerve is lifted and stabilized within a new bony canal fashioned in the root of the zygoma and a groove in the parotid gland. Transposition of the nerve may be accompanied by some paresis of the nerve, but

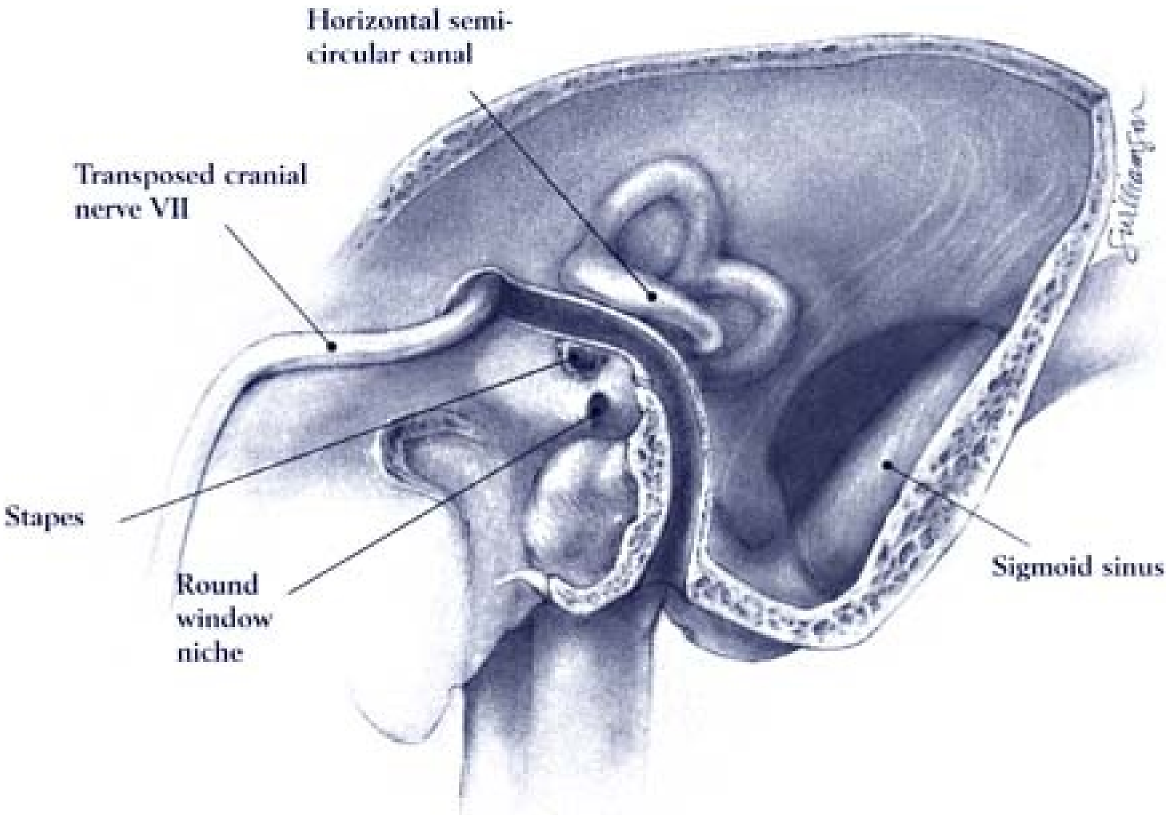


Figure 10

Transpositon of the mastoid and tympanic segments of the facial nerve to gain exposure of the hypotympanum and infralabyrinthine area. The internal carotid artery is skeletonized within the carotid canal to discern whether tumor has encroached upon the arterial wall and to facilitate tumor removal without carotid injury

usually not a complete paralysis. Meticulous and gentle technique with absolute avoidance of stretching of the facial nerve is imperative to obtaining a good postoperative result.

If disease extends anteriorly, the carotid artery is exposed with microsurgical drilling. Tympanic bone is removed anterior to the jugular bulb to skeletonize the internal carotid artery. The surface of the carotid artery should be exposed inferiorly, at the carotid foramen, and then followed superiorly to the genu of the artery.

All pneumatized cell tracts are removed to fully expose the infralabyrinthine space. This requires a complete drill-out of perilabyrinthine, posterosuperior (sinodural angle), and posteromedial (retrofacial) air cell tracts. Surgical access to the apical compartment is achieved by opening peritubal air cells anterior to the basal turn of the cochlea, adjacent to the genu of the internal carotid artery.

Complete tumor removal, typically of a glomus jugulare tumor, is performed after distal and proximal control of the

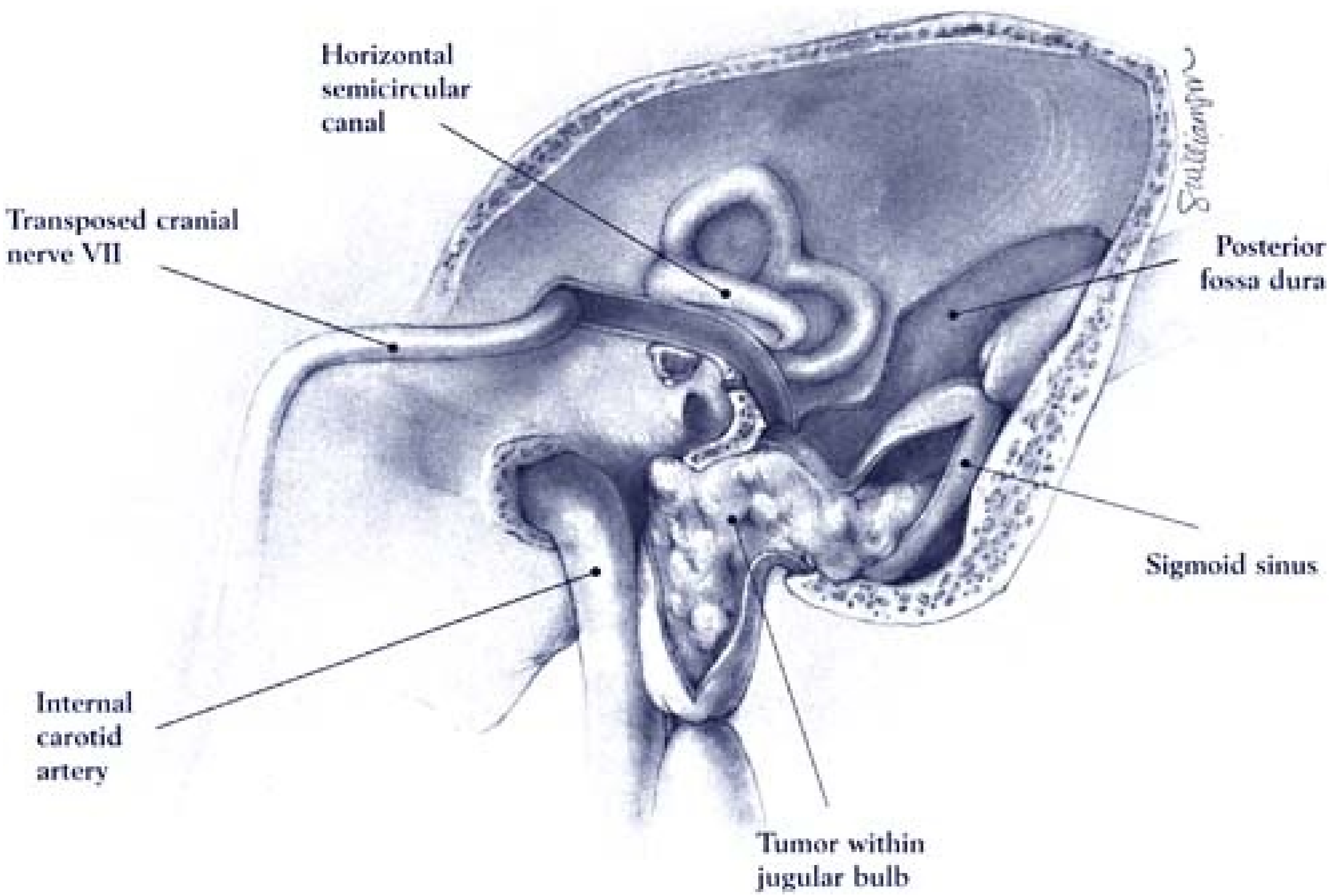


Figure 11

Schematic diagram of the removal of glomus jugulare tumor after proximal and distal control of the sigmoid sinus and internal jugular vein lateral sinus and internal jugular vein by ligature (Figure 11). Removal of tumor extension into the middle ear is facilitated by microdissection with fine micro-bipolar cauterization.

An abdominal fat graft is used to fill in the mastoid defect. A suction drain is placed in the wound and brought out posterior to the incision.

Modifications of the type A approach
The necessity of removing the tympanic membrane and posterior canal wall is dictated by the degree of carotid artery, jugular bulb and facial nerve involvement by the tumor. The exposure of the internal carotid artery is surprisingly good through an extended facial recess with an

intact canal wall when combined with an extended hypotympanotomy. However, canal wall preservation is ill-advised if tumor extension requires clival or infratemporal fossa dissection anteromedial to the internal carotid artery.

Tumor invasion of the epineurium of the facial nerve in its vertical segment calls for a complete petrosectomy resection of the appropriate portion of the nerve, and autogenous nerve grafting.

Creation of a facial nerve bridge without rerouting is an alternative in exposing the hypotympanum and jugular bulb, but should be considered in light of its limitations. The facial nerve is completely skeletonized as a bridge based at the second genu inferomedial to the lateral semicircular canal and extending to the stylomastoid foramen. This is feasible when tumor does not extend beyond the posterior aspect of the carotid artery or deep into the jugular fossa and when the facial nerve epineurium is free of disease. The facial nerve bridge technique may be employed with an extended facial recess approach or removal of the posterior external auditory canal wall with canal closure, as one would for a modified radical mastoid procedure. As always, close attention must be paid to avoid stretching of the bridged segment of nerve.

The modifications described above should be considered in light of the associated risks. Preservation of the facial nerve and posterior canal wall in situ invariably entails less exposure, and increased risks of incomplete resection. Leaving the nerve in situ is not a good alternative unless preoperative assessment reveals the lesion to be small with minimal bone erosion and the tumor can be fully visualized through a facial recess or (when the canal is removed) over/under the facial ridge. The nerve is at risk of transection or compression by the shafts of instruments while the surgeon’s attention is focused on the deep dissection. The surgeon should not consider these modifications until he has become skilled with complete temporal bone dissections and is familiar with patterns of tumor growth and extension.

Type B approach
The infratemporal type B procedure provides access to the anteromedial skull base that lies adjacent to the horizontal segment of the internal carotid artery. This surgical approach does not directly access the more medial aspect of the infralabyrinthine compartment. Rather; the type B approach exposes the anterior aspect of the petrous apex and the clivus. The trajectory of this approach obviates the need for facial nerve translocation. Subtotal petrosectomy is required to gain adequate anterior exposure, ultimately providing exposure of the infratemporal fossa, proximal (cartilaginous) eustachian tube, and petrous portion of the internal carotid artery.

In the type B approach, the only branch of the facial nerve in jeopardy is the frontal branch because its superficial course over the zygomatic arch places it in danger of being stretched by retraction. This branch of the facial nerve is protected from inadvertent injury by identifying the main trunk and exposing the superior branch as it crosses the zygomatic arch. The main trunk of the nerve is identified in the parotid gland and the superior (temporal) branch is followed peripherally as it crosses the zygomatic arch.

Anterior exposure is obtained by reflecting the temporalis muscle, zygomatic arch, and mandibular condyle inferiorly The zygomatic arch is separated from the orbital root of the malar bone and from its attachment above the external ear canal. The arch is left attached to the masseter muscle and mobilized inferiorly. The entire temporalis muscle is mobilized from the parietal skull and reflected inferiorly over the zygomatic arch and masseter muscle.

A subtotal petrosectomy exposes the mastoid and tympanic segments of the facial nerve. All of the pneumatic spaces of the mastoid are drilled away, including the supralabyrinthine, retrolabyrinthine, retrofacial, infralabyrinthine, and pericarotid cell systems. The canal skin and tympanic membrane are removed. All mucosa from the middle ear and residual skin of the external ear canal and drum are stripped to prevent formation of mucocele and cholesteatoma, respectively. Obliteration of the middle ear space entails a conductive hearing loss; however, resection of most clival lesions requires removal of portions of the eustachian tube; and the subtotal petrosectomy will prevent problems with chronic otitis media in an ear without adequate eustachian tube function.

Drilling away the overlying temporal bone enables identification of the internal carotid artery between the carotid foramen and its genu at the orifice of the eustachian tube in the protympanum. In the absence of tumor invasion, a thin shell of bone is preserved over the artery for protection. Dissection proceeds anteromedially along the medial aspect of the eustachian tube. The internal carotid artery is traced to the foramen lacerum by removal of peritubal air cells that lie medial to the eustachian tube. The internal carotid artery is thus identified both above and below its genu. In all but the smallest of lesions, the carotid artery should be controlled in the neck with vascular loops before the dissection in the petrous apex.

The floor of the middle cranial fossa is exposed by separation of the temporomandibular joint and glenoid fossa. The mandibular condyle and capsule of the temporomandibular joint are separated from the glenoid fossa and pushed inferiorly The articular cartilage is left attached to the condyle. The thick bone of the glenoid fossa is drilled away and displaced inferiorly with retraction. The internal and external pterygoid muscles and the stylomandibular ligament are divided to mobilize the mandible, and the mandibular condyle is displaced inferiorly with a self-retaining retractor. The surgeon should bear in mind the position of the superior branch of the facial nerve as it is checked periodically to prevent injury from the retractor.

Drilling the skull base anterior and medial to the glenoid fossa will reveal the middle meningeal artery entering the foramen spinosum. The artery is cauterized and divided. Anterior and medial to the foramen spinosum is the foramen ovale, containing the relatively large sensory and motor roots of the mandibular branch of the trigeminal nerve (V3). This nerve can be divided to facilitate anterior exposure as needed.

For lesions of the anterior clivus that lie deep within the type B exposure, the internal carotid artery may be followed anteriorly by drilling out the distal eustachian tube lateral to the carotid artery If further exposure is required, the base of the pterygoid plates can be drilled away.

Elevating the epipharyngeal soft tissues exposes the clivus. Ideally, this elevation is performed within the plane between the clival bone and periosteum. These tissues are attached to the skull base by a strong fibrous band attached at the petrooccipital fissure. This attachment should by divided sharply. Often a portion of the tumor becomes visible as the soft tissues are elevated. Full exposure of the tumor is obtained by removing all the bone around the horizontal and vertical segments of the internal carotid artery with a diamond burr.

Tumor dissection is performed with cup forceps, curettes, or by aspiration. A diamond burr is used to drill out eroded bone until a solid layer of cortical bone or dura lining the roof of the clivus is reached. Bleeding vessels, which are often venous sinuses within the clivus; are waxed or controlled with collagen hemostat (Avitene). Drilling bone across the mid-line into the opposite clivus must be performed with extreme care because the contralateral internal carotid artery enters the foramen lacerum nearby.

Removal of tumor superior to the horizontal segment of the internal carotid artery is hampered by a lack of mobility of the artery, even when fully decompressed. Tumor in this area can be dissected with a curved blunt curette and the area inspected with a nasopharyngeal mirror.

If the dissection has remained extramucosal in the nasopharynx, the wound is obliterated with abdominal fat and the temporalis muscle is used to provide vascularized tissue to further obliterate the dead space. The zygomatic arch is replaced in its original position and wired anteriorly If the mucosa has been violated, abdominal fat is not used because of the risk of salivary contamination causing infection of the fat. In this instance, the wound is entirely obliterated with the temporalis muscle flap, a sternocleido-mastoid muscle flap, or, possibly even a free tissue transfer with a musculofascial free flap.

Modifications of the type B approach (Fisch type D1)
Small lesions, especially those in the inferior clivus, do not require resection of the eustachian tube for full exposure, and the middle ear space and hearing can be preserved. The incision is made preauricularly rather than postauricularly The facial nerve is identified and protected as described above, the zygomatic arch and temporalis muscle are mobilized, and the temporomandibular joint is separated from the glenoid fossa and pushed inferiorly. The bone of the infratemporal fossa is removed for tumor exposure as described above.

The disadvantage of this method of exposure is that the location of the carotid artery is not identified from the

Figure 12

Large glomus jugulare tumor with cervical extension that effaced the left oropharynx. The tumor extends from the jugular foramen to the foramina ovale and lacerum, into the cavernous sinus and middle cranial fossa floor, and nasopharynx and masticator space. Removal required dissection of the middle cranial fossa and parapharyngeal space as an extension of the type C infratemporal fossa approach outset, but it can be identified in the neck and traced to the carotid foramen. The anterior portion of the tympanic ring can be drilled away to expose the vertical segment of the carotid anterior to the middle ear space. Bone is removed from the skull base over the infratemporal fossa exactly as described above.

Type C approach

If there is parasellar involvement, the carotid artery is followed anteriorly and the exposure is extended to the type C approach. The exposure is extended by drilling away additional bone of the skull base, including the pterygoid plates, to identify the foramen rotundum and the maxillary division of the trigeminal nerve (V2). This nerve is divided if necessary.

Inferior extensions of clival tumors to the upper cervical spine are approached by cervical extension of the incision into the upper neck (Figure 12). The neurovascular structures of the carotid sheath as well as cranial nerves X, XI, XII are identified in the neck. The only obstacle to complete exposure of the tumor from the infratemporal fossa to the neck is the facial nerve. The nerve may be managed by leaving it in situ and working on either side of it, mobilizing it from the Fallopian canal and temporarily transposing it superiorly or by dividing the nerve and repairing it after the tumor is removed.

Modifications of the type C approach

A planned two-stage procedure may be used when tumors have radiographic evidence of intradural or intracranial spread. Staging the resection is especially important in tumors that are highly vascular and derive their blood supply from intracranial vessels, typically the vertebral-basilar arterial system. Fisch first described a two-stage approach for removing glomus jugulare tumors that had intra-axial extensions. He performed an initial tumor resection from the infratemporal approach and provided a sealed barrier to cerebrospinal fluid with the closure of the external auditory canal and obliteration of the cavity with fat and vascularized muscle. Small intracranial remnants of tumor could be followed with imaging studies and resected with a neurosurgical approach if needed.

An alternative is to perform the neurosurgical exploration first and place a fascia lata as a barrier against cerebrospinal fluid leak during a subsequent lateral approach (Chapter 14, Appendix I). A wide suboccipital craniotomy is used, extending down to the rim of the foramen magnum in large tumors. Our surgical goal is to interpose a fascia graft between tumor on the outside and brain stem, blood vessels, and cranial nerves on the inside.

Once the brain stem and vascular structures have been mobilized off the tumor and all cranial nerves identified and traced, the size of the required fascial graft can be determined. A fascia lata graft is harvested from the lateral thigh. The graft should be large enough to provide complete overlap for the tumor with a 1-cm margin. Incisions in the graft must be fashioned to allow the graft to surround cranial nerve exit foramina. A typical graft goes from just above the porus acusticus to the foramen magnum and has slits cut to accommodate the VII/VIII nerve complex, and the XIIth nerve. The goal is to place the brain stem with its vessels inside a new watertight dural substitute, which effectively externalizes the tumor and makes it completely extradural.

During the second phase of the surgery, 3–6 weeks later, the goal is tumor removal. Now, however, the surgeon works with the protection of the brain stem and important vessels and has a cerebrospinal fluid seal postoperatively. If the tumor is extremely large, gradual bipolar coagulation will shrink the mass so that the graft can be placed.

We have found three techniques helpful.

(1) If a neodura is created to line the inner aspect of the jugular bulb, sigmoid, and lateral sinuses, the placement of a ligature between the natural inner dural layer and the neodura does not result in cerebrospinal fluid leak.

(2) If tumor invasion does not extend into the mastoid emissary take-off from the lateral sinus, the sinus can be packed with Gelfoam inferior to the emissary vein. This obviates the need for complete circumferential ligation of the sinus and lessens the likelihood of increasing intracranial pressure as a result of venous hypertension.

(3) Although the medial wall of the sigmoid sinus can be seen histologically as endothelial-lined dura, the inner dural layer can occasionally be split by careful dissection with a Rosen knife, without encountering bleeding or leakage. A ligature can then be passed to accomplish ligation. Inadvertent cerebrospinal fluid leak or sinus bleeding is possible if the procedure is

unsuccessful. The surgeon must be ready to open the posterior fossa should inadvertent entry and intracranial bleeding occur. When successfully performed, this sinus is selectively ligated just below the mastoid emissary vein without leakage.

COMPLICATIONS

Removal of lesions via extended infratemporal approaches entails resection of the eustachian tube. In order to prevent chronic tympanomastoiditis, the middle ear is exenterated and the external auditory canal is closed. This causes a conductive hearing loss in all patients. Most patients accept the resultant conductive hearing loss following tumor control, but this can be a problem to patients with preexisting contralateral hearing deficits. Implantable bone-conducting hearing aids have been used with excellent results in expanding the sound field on the side of canal closure.

Infection is a real concern when an extended surgical defect is in close proximity to both the nasopharynx and dura.

When the mucosa has not been violated, the cavity can be obliterated with abdominal fat. However, when the mucosa has been opened, it is safer to obliterate the cavity with vascularized flaps from the temporalis or sternocleidomastoid muscles.

The remaining important sequelae are predictable on the basis of which cranial nerves are involved by the tumor and must be sacrificed. Resection of V3 will cause anesthesia of the lower face and weakness of the muscles of mastication. The anesthesia will make partial recovery over time and anesthesia dolorosa after V3 section has not been seen. Stretching of the superior branch of the facial nerve will lead to temporary paresis of the forehead.

Mastication and jaw opening are not severely impaired, despite the fact that the glenoid fossa is drilled away. The articular disk is left attached to the mandibular condyle and it forms a pseudarthrosis with the remaining bone of the middle cranial fossa. Any temporary restriction of mandibular opening can be remedied with progressive stretching with stacked tongue blades. Transection of the mandibular nerve at the foramen ovale has produced some degree of mandibular drift, but is usually only a minor concern for patients.

There is a negligible cosmetic deformity considering the magnitude of the procedure. The zygomatic arch is replaced and wired, thus re-establishing mid-facial contours. Rotation of the temporalis muscle into the defect leaves slight dimpling of the temple region. Staged cranioplasty with alloplastic materials is an option if the patient desires. Postauricular depression from the mastoidectomy may become evident.

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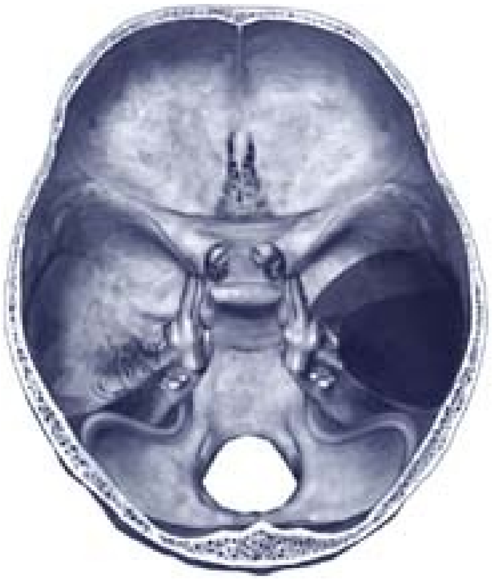
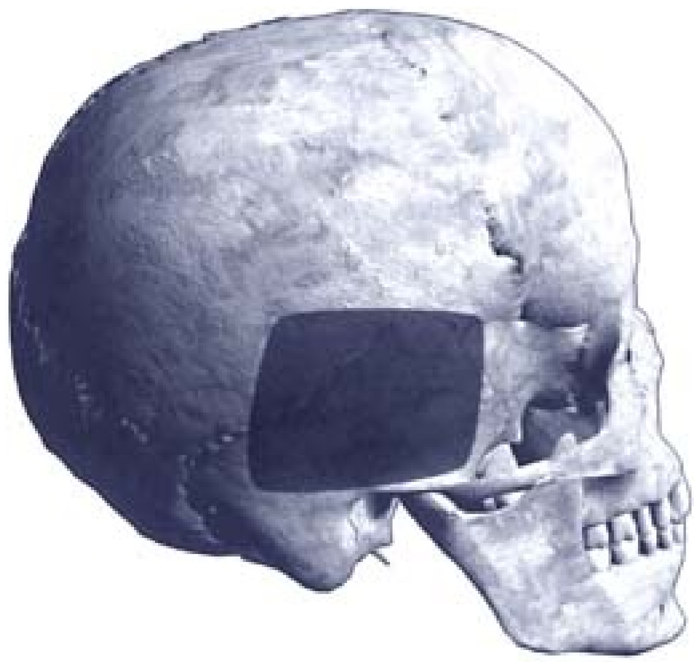
9
Middle fossa approach

JohnK.Niparko, Matthew Ng and Donlin M.Long





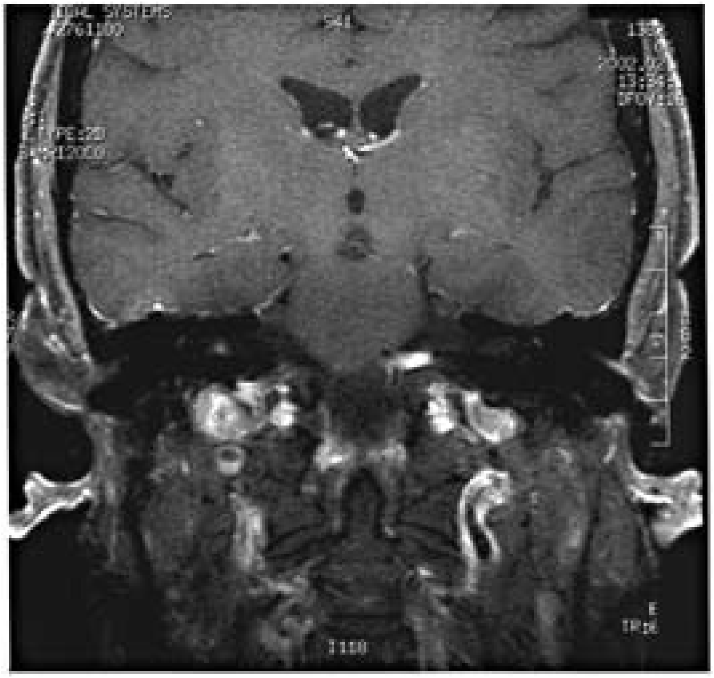


Figure 1

Coronal T1-weighted MRI demonstrating right 3-mm; intracanalicular vestibular schwannoma in a patient with normal hearing. The amount of bone overlying the internal auditory canal to be removed for tumor access can be estimated

INDICATIONS

Surgical approaches to the skull base via middle fossa craniotomy are useful for access to the foramina of the middle fossa floor, including the internal auditory canal and proximal segments of the facial nerve, and, rarely, the petrous apex. Middle fossa approaches are most commonly employed for:

(1) Simple and durable repairs of bony defects of the tegmen mastoideum and tegmen tympani;

(2) Acoustic neuroma removal for lesions occupying the internal auditory canal which do not extend beyond 1–2 cm medial to the porus acousticus (drill-out of the anteromedial extension of the internal auditory canal may facilitate the exposure of tumors with greater medial extension);

(3) Vestibular nerve section within the internal auditory canal;

(4) Facial nerve decompression and repair.

The middle fossa approach is particularly useful when preservation of hearing and vestibular function is a clinical goal.

PATIENT EVALUATION

Preoperative imaging can contribute valuable information in orienting and choosing the surgical approach. For instance, the thickness and pattern of aeration of the bony tegmen of the internal auditory canal evidenced on MRI scans can guide the initial dissection and location of landmarks for orientation to the internal auditory canal (Figure 1). MRI with gadolinium enhancement will delineate the extent of the tumor and contribute valuable information toward the decision tree as to which surgical approach to take for removal of the tumor (Figure 2). The decision to proceed

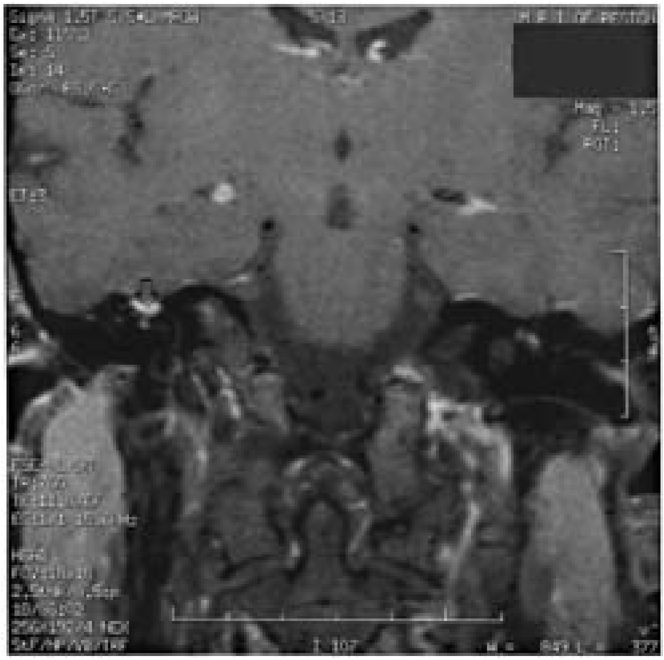


Figure 2

T1-weighted coronal MRI of facial neuroma. T1-weighted coronal MRI scan with gadolinium demonstrating enhancing mass along floor of middle fossa corresponding to facial nerve adjacent to the geniculate ganglion

with a middle fossa craniotomy is based on the tumor’s location primarily within the internal auditory canal with no to minimal extension (less than 5 mm) into the cerebellopontine angle, presence of useful hearing, and tumors which originate from the superior vestibular nerve. In temporal bone trauma, longitudinal and transverse fractures (Figure 3) may produce facial nerve paralysis that requires decompression and possible neurorrhaphy. In such cases, access to the greater superficial petrosal nerve afforded by the middle cranial fossa approach can allow for release of an entrapped nerve. Facial nerve neuromas, suggested by fasciculations and facial spasms, may be addressed via the middle cranial fossa approach (Figure 4). Techniques of decompression or resection with grafting of facial schwannomas can be applied via the middle fossa approach.

ANATOMICAL CONSIDERATIONS

Exposure via lateral temporal craniotomy provides supralabyrinthine access to the tegmen mastoideum and tympani, Fallopian canal, petrous apex, and internal auditory canal. The surgeon should be familiar with the temporal bone anatomy from the superolateral perspective unique to the middle fossa approach. Understanding the temporal bone anatomy from this perspective requires familiarity with landmarks that aid orientation to the internal auditory canal, the intratemporal facial nerve, and the labyrinth within the underlying temporal bone.

The external auditory canal provides an initial guide to the location of the internal auditory canal. Although not co-linear; the internal auditory canal lies within the same coronal plane as the external auditory canal. The internal auditory canal lies approximately 1 cm superiorly relative to the external canal.

Success in safely decorticating the internal auditory canal via the middle fossa route requires serial identification of landmarks (Figure 5). Removal of the tegmen tympani from above exposes the underlying ossicular heads that lie lateral to the tympanic segment of the facial nerve. More laterally, the tympanosquamous suture line courses posterolateral to anteromedial toward the tegmen tympani, pointing to the

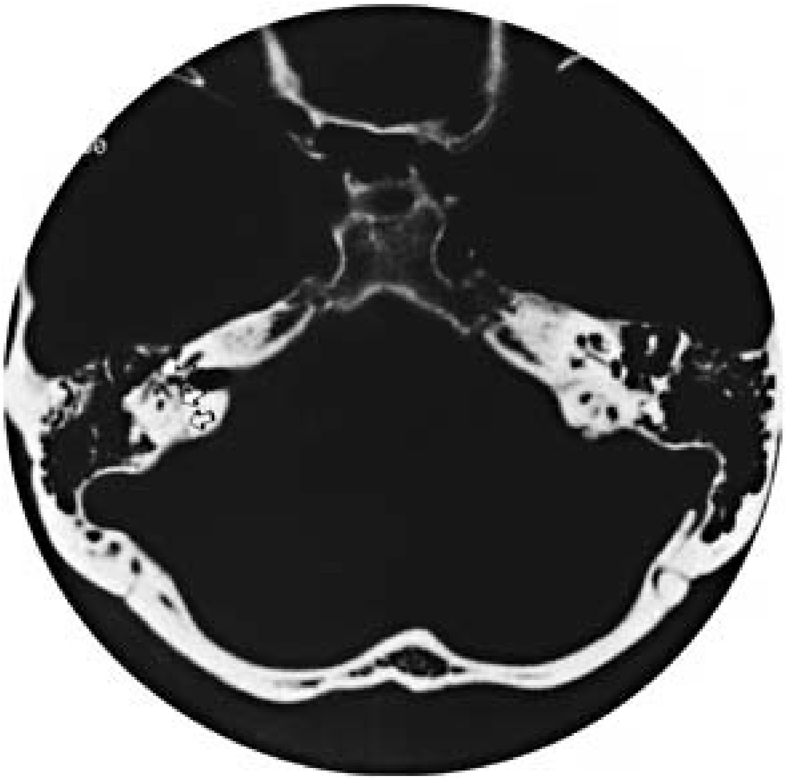


Figure 3

Transverse temporal bone fracture involving the perigeniculate segment of the facial nerve producing facial paralysis. Surgical decompression via the middle cranial fossa approach enabled access to the geniculate ganglion and sectioning of the greater superficial petrosal nerve to reduce nerve tension

area of several critical landmarks in close proximity: the arcuate eminence, foramen spinosum (carrying the middle meningeal artery), tympanic canaliculus (carrying the lesser petrosal nerve), and the facial hiatus (carrying the greater superficial petrosal nerve). The arcuate eminence is visualized as a bony prominence along the surface of the middle fossa floor and provides a guide to the underlying superior semicircular canal. Bone of the arcuate eminence is removed to expose the subjacent superior semicircular canal, thus providing the key landmark to the lateral internal auditory canal, as will be discussed below. Note that this bony landmark for the superior semicircular canal is absent or greatly reduced in size in 15% of cases.

Another landmark that is used is the foramen spinosum; where the middle meningeal artery enters the cranium, taking its origin from the internal maxillary artery from the external carotid arterial system. This is the most anterior landmark used in middle fossa surgery The foramen spinosum sits at the lowest point in the middle cranial fossa floor. This will form one lateral limit of the exposure in the surgical position.

The greater superfical petrosal nerve; originating anteriorly from the geniculate ganglion; carries presynaptic parasympathetic fibers to the pterygopalatine ganglion. It is found traversing its own bony canal called the facial hiatus. The facial hiatus may or may not be covered with bone. The greater superficial petrosal nerve is located approximately 1cm medial to the foramen spinosum. The axis of the facial hiatus is parallel to the petrous ridge. Within its groove, it lies in an area of dural thickening.

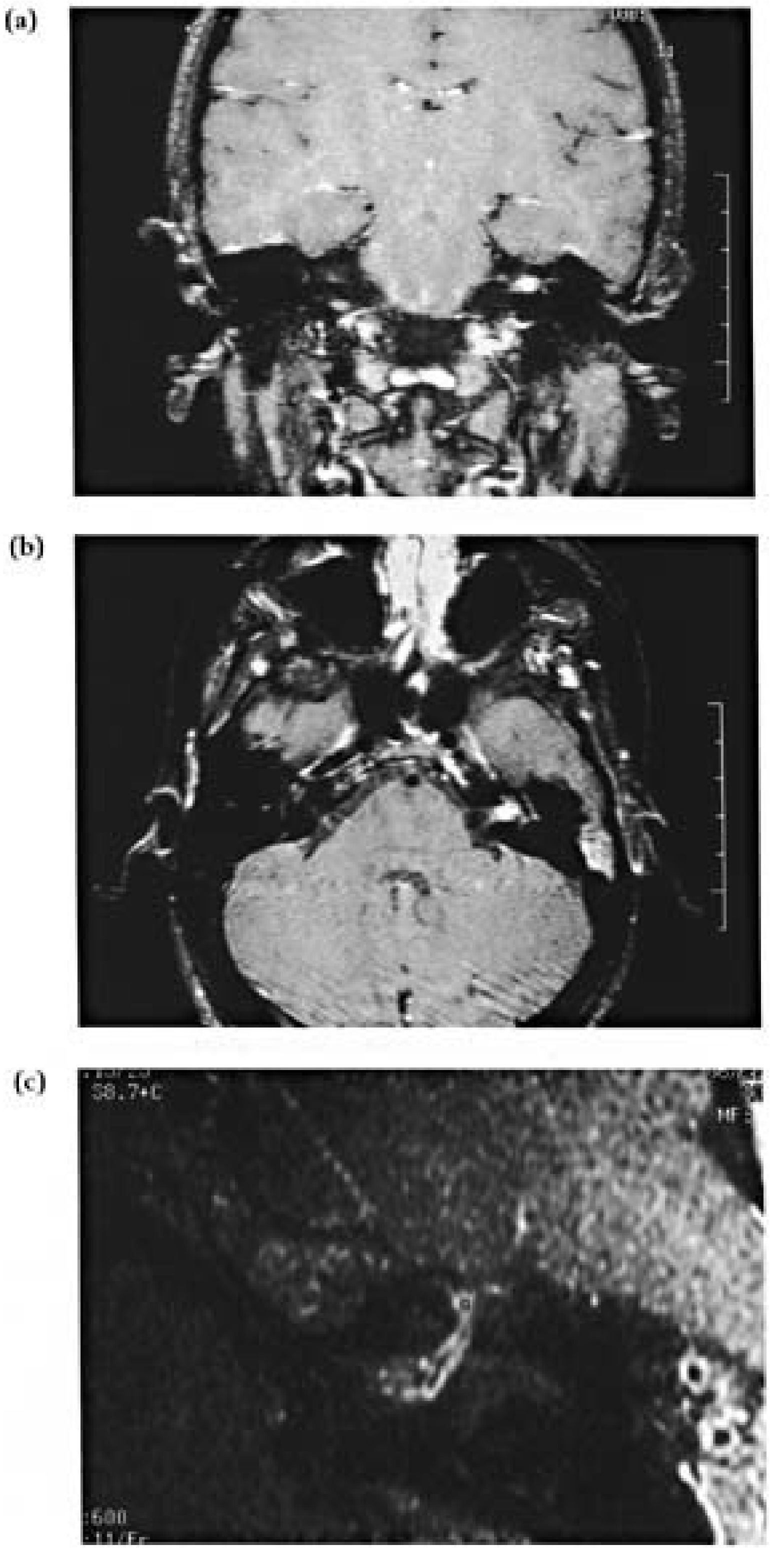


Figure 4

T1-weighted coronal (a), axial (b), and high-resolution (c) MRI scans with gadolinium of facial schwannoma manifesting fasciculations of the orbicularis oculi muscle; (c) high-resolution MRI demonstrating extension of lesion from internal auditory canal through meatal foramen extending to the geniculate ganglion (g)

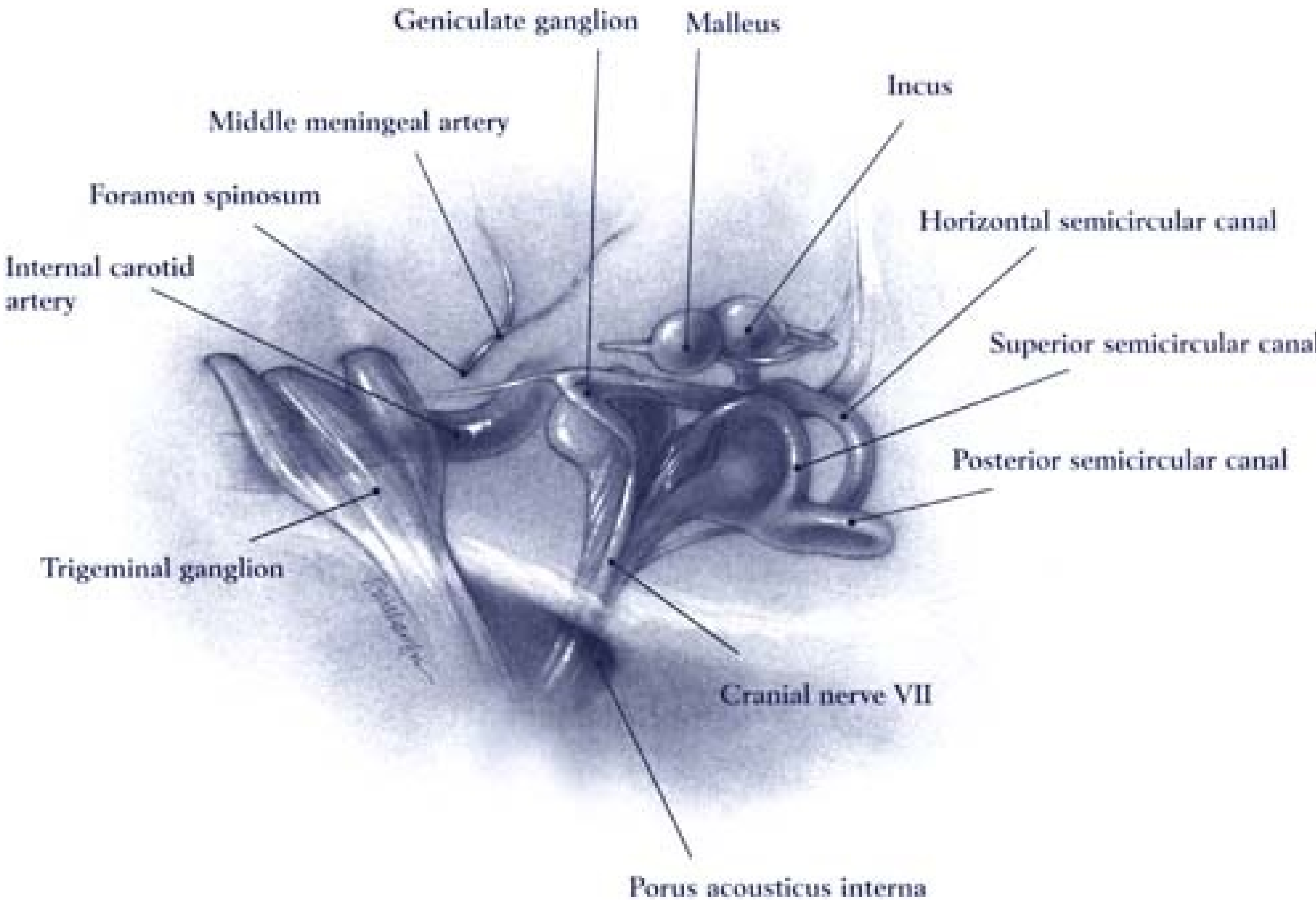


Figure 5

Key neurovascular structures within the floor of the right middle fossa

The lesser petrosal nerve courses lateral and almost parallel to the greater superficial petrosal nerve within the tympanic canaliculus, along the floor of the middle fossa. Just like the greater superficial petrosal nerve; the lesser petrosal nerve may or may not reside within its own bony canal.

PROCEDURE

The surgeon is seated at the head of the operating table, facing the patient's feet. The patient's head is turned just short of 90° to expose the ear of interest.

The incision and craniotomy should be sufficiently anterior to allow exposure of the middle ear space and the more medially located internal auditory canal. A common misconception is to visualize the internal and external auditory canals as co-linear. In fact, the anterior aspect of the porus of the internal canal lies 4–6 mm anterior to the anterior wall of the external canal. Therefore, the skin incision for a middle fossa approach should facilitate a craniotomy that will expose the middle fossa floor over and well anterior to the external canal (Figure 6).

A 3×3 cm bone flap is created with drilled, linear osteotomies with cutting and diamond burrs (Figure 7).

Care is taken to avoid shredding the underlying dura while drilling the troughs surrounding the bone flap.

Once the bone flap is elevated, the dura surrounding the margins of the craniotomy is separated from the medial aspect of the temporal squamosa. Margins of the craniotomy are cleared of overhanging bone with rongeurs to enhance the view medially. However, the ledge of bone along the inferior margin of the craniotomy should be maintained to provide a separation between the mastoid and the craniotomy defect. This bony ledge, which constitutes the inferior margin of the craniotomy, is beveled with a drill to ease access and the line of vision parallel to the middle fossa floor.

Dura is elevated from the middle fossa floor. Dural elevation often reveals attachments to the bone from arachnoid granulations and insertion of the dura into suture lines of the middle fossa floor. Attachments are particularly dense above the external auditory canal along the tympanosquamous suture line. These attachments often carry venules and bleeding points on the dural surface with elevation, and should be cauterized with bipolar cautery. Pressure from cerebrospinal fluid is relieved with hyperventilation, mannitol diuresis and a small dural incision to allow egress of cerebrospinal fluid with temporal lobe retraction. While dural elevation should be adequate for the intended surgical exposure, over-zealous elevation potentially invites bleeding from bridging veins and subdural hematoma formation. Elevation of dura should proceed from the posterior to the anterior direction. Therefore, elevation should extend only as far as is necessary to adequately view the intended landmarks.

Saucerizing the bone of the arcuate eminence exposes the dome of the superior semicircular canal. The more anterior aspect of the superior semicircular canal is further established by saucerizing the overlying bone over the arcuate eminence, progressing anteriorly towards the fundus of the internal auditory canal. In performing this drilling, the surgeon should keep in mind that the long axis of the superior semicircular canal forms 60° with

Anatomical landmarks to localize the internal auditory canal (IAC) from the middle fossa approach

• The long axis of IAC lies approximately 60° from the arch of the superior semicircular canal

• The long axis of IAC lies on the line that bisects the angle subtended by the superior semi circular canal and the greater superficial petrosal nerve (Garcia-Ibanez line)

• The longitudinal axis of the IAC is parallel to the longitudinal axis of the external auditory canal, but not co-planar

• Trace the facial nerve proximally from the tympanic segment to the geniculate ganglion after removal of the tegmen tympani, then to the labyrinthine portion to the meatal and canalicular segments. The lateral canalicular segment of the facial nerve traverses anterior to the superior vestibular nerve and superior to the cochlear nerve

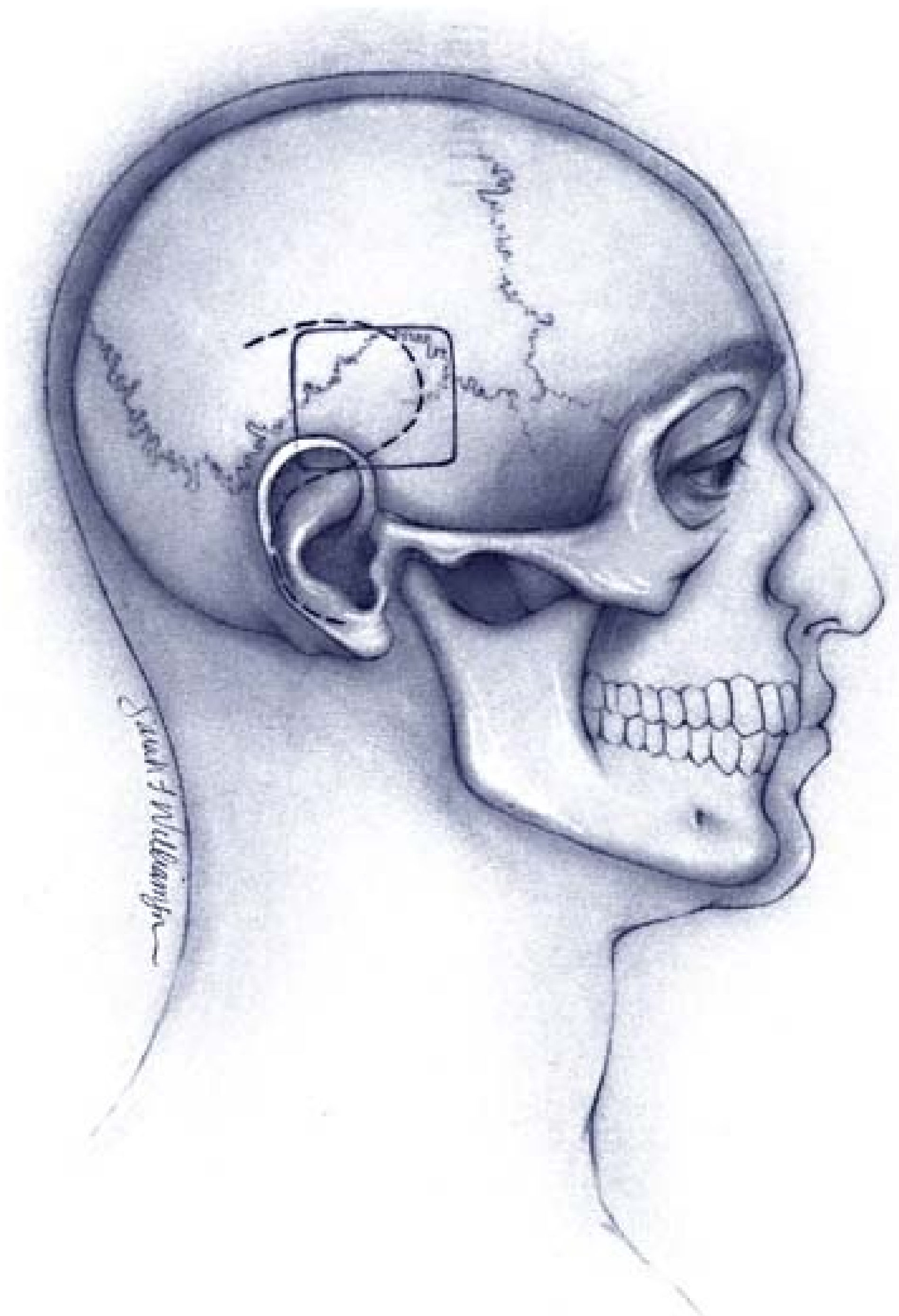


Figure 6

View of patient with head turned laterally, with surgeon at head. The skin incision is made to maximize exposure anterior to the bony external auditory canal to provide an adequate anterior exposure needed to unroof the internal auditory canal. The outlines of the bony craniotomy for the middle fossa approach are shown

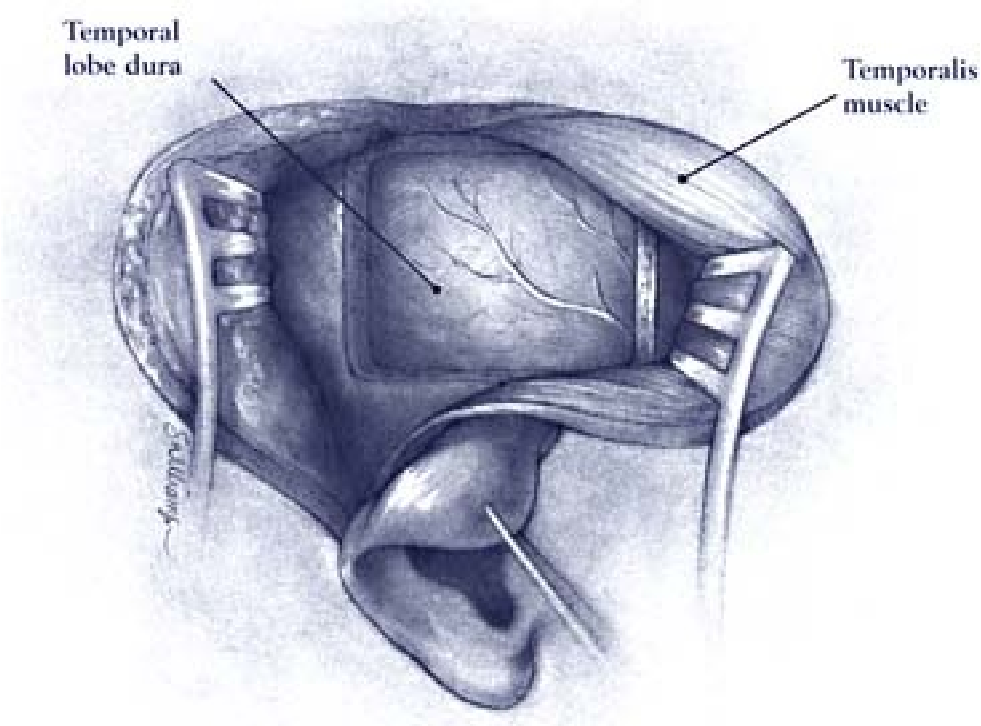


Figure 7

The temporal skin flap and temporalis are retracted to expose the temporal squamosa for middle fossa craniotomy

the long axis of the internal auditory canal (Figure 8). The canal is blue-lined in an anterolateral direction to expose the ampullated end of the canal. Visualizing the dome, arch and ampullated end of the superior semicircular canal, the surgeon can best establish the long axis of the superior canal and accurately orient drilling to skeletonize the dura of the internal auditory canal. The ampullated end of the superior semicircular canal is used as a landmark for saucerizing bone of the meatal plane—bone that overlies the geniculate ganglion and the lateral aspect of the internal canal medial to the heads of the middle ear ossicles. Elevation of dura anterior to this region should be performed with caution as excessive bleeding often ensues.

Exposure of the greater superficial petrosal nerve may help to further orient the surgeon to the geniculate ganglion. The greater superficial petrosal nerve is followed anteriorly to the geniculate ganglion by carefully removing the overlying bone with a diamond burr. Tracing the facial nerve in a posteromedial direction exposes the labyrinthine portion of the nerve as it courses toward the internal auditory canal.

As bone of the meatal plane is saucerized; again using the ampullated end of the superior semicircular canal and the ossicles as landmarks, the underlying geniculate ganglion comes into view. The dissection can be further developed to expose tympanic and labyrinthine segments of the facial nerve.

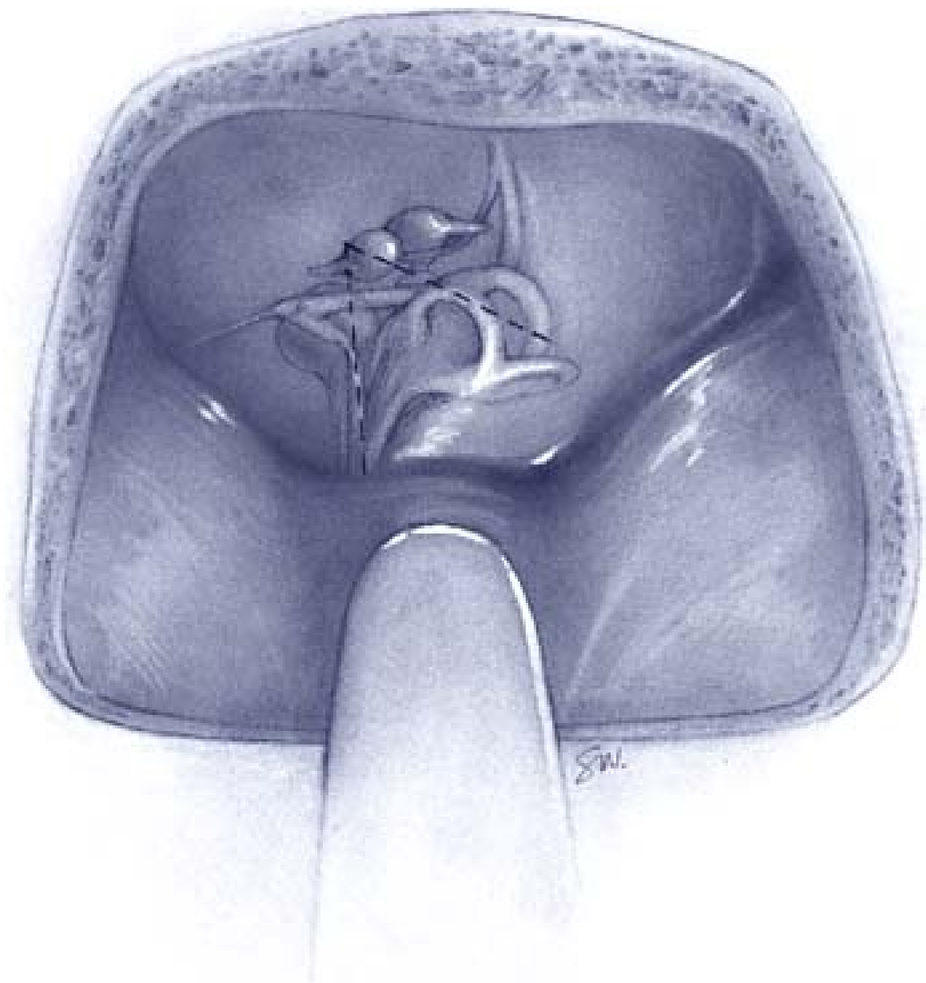


Figure 8

View of middle fossa craniotomy and fossa floor with temporal lobe retracted. Note the position of the arcuate eminence and underlying superior semicircular canal. Note the 60° relationship between the 'blue-line' of the superior semicircular canal and the internal auditory canal

The middle fossa floor is then further dissected in a medial direction to expose dura of the internal auditory canal (Figure 9). Dura is skeletonized in the direction of the porus acousticus, using the ampullated end of the superior semicircular canal, the labyrinthine segment of the facial nerve and meatal foramen as landmarks. Note that dura of the canal lies substantially deeper than the dome of the superior canal. Bone removal should therefore proceed with care taken not to damage the superior semicircular canal posteriorly, labyrinthine segment of the facial nerve anteriorly, or the cochlea anterolaterally.

Bony exposure is continued to completely expose the superior 180° of the internal auditory canal. At the lateral end of the internal auditory canal, 'Bill's bar' or the vertical crest is identified between the facial nerve anteriorly and the

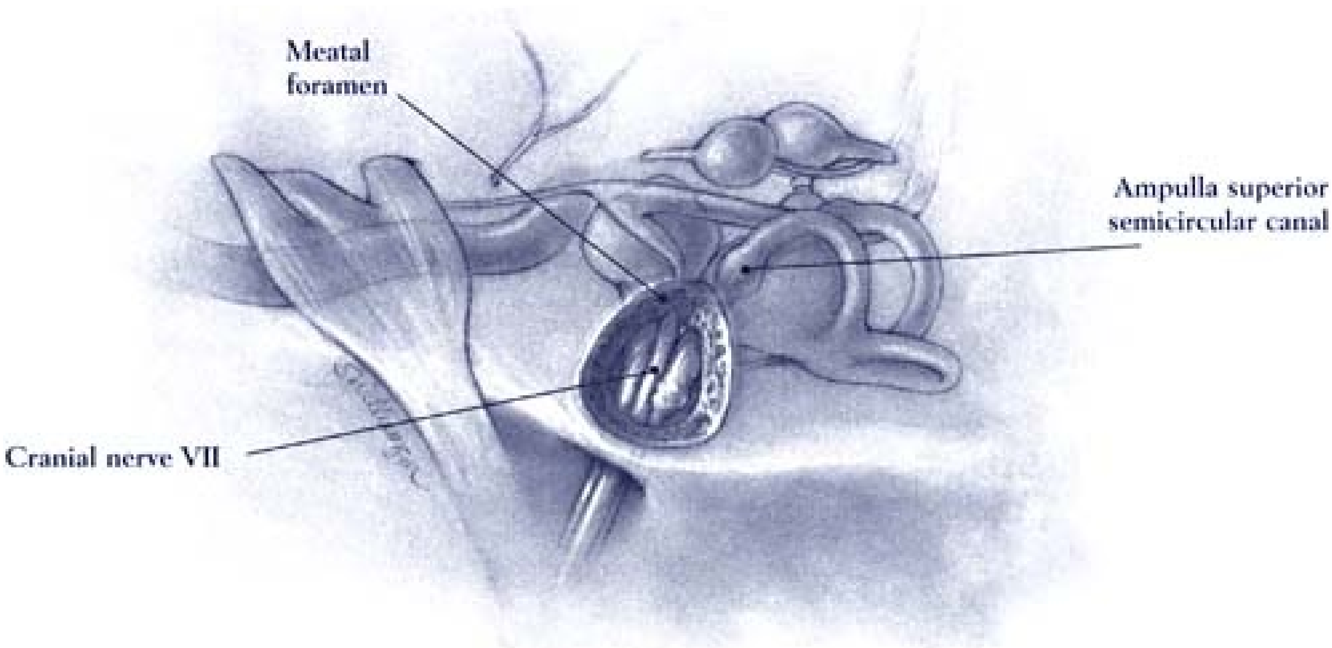


Figure 9

View of middle fossa floor with dura of internal auditory canal opened. The tumor emanating based on the superior vestibular nerve within the internal auditory canal is exposed

superior vestibular nerve posteriorly. The dura is then opened posteriorly, parallel to the long axis of the internal auditory canal. Remember that the VIIth cranial nerve will lie immediately beneath the dura and can be easily injured during the dural opening. A fine dural knife and high magnification are required. When the dura is opened and the flaps dissected free of the underlying nerves and tumor, further dissection of the tumor proceeds after identification of the intracanalicular segment of the VIIth nerve (Figure 9).

Small tumors are dissected from the overlying cranial nerves and then debulked by piecemeal intracapsular removal (Figure 10). This allows the capsule to be separated, sparing the nerves, although division of the nerve of origin is required. Once the tumor is out, the dural flaps are replaced, the temporal lobe allowed to return to its normal position, and the bone flap replaced and stabilized with replacement of the temporalis muscle in its anatomic location, and suturing the tendinous attachment superiorly

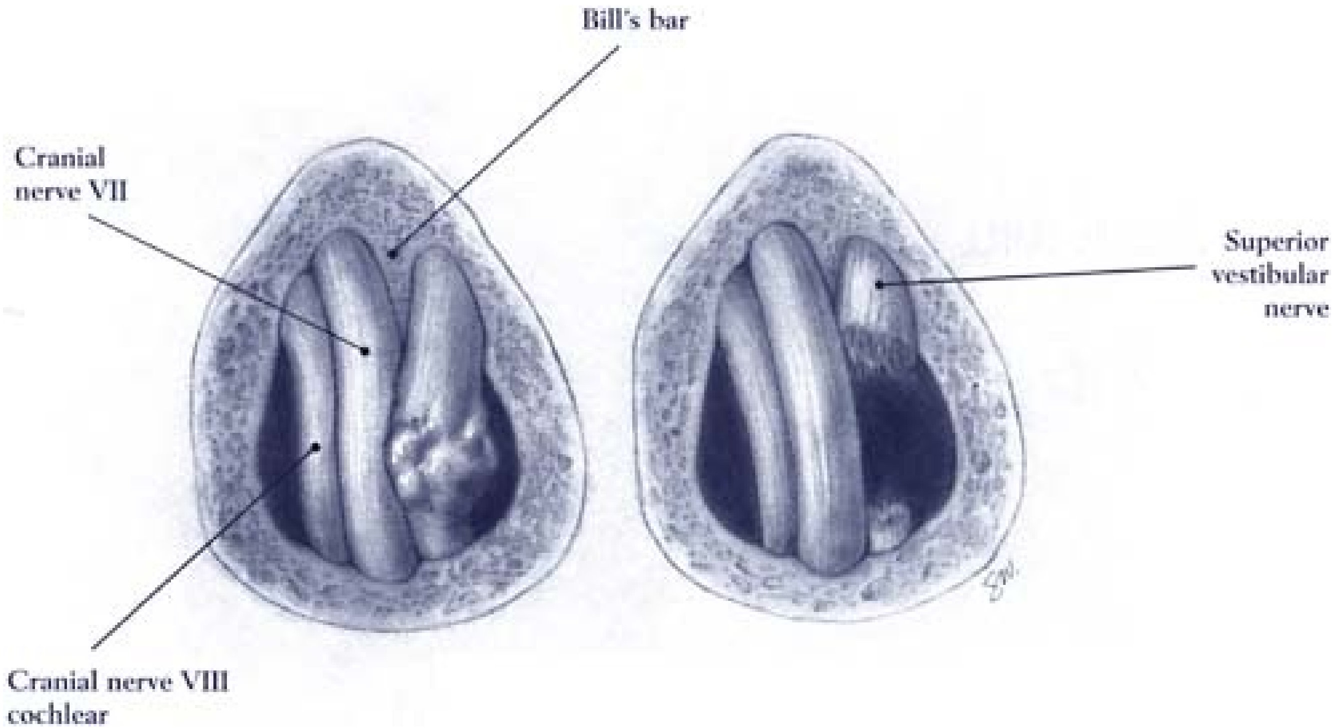


Figure 10

Tumor resection with division of superior vestibular nerve and posteriorly. The skin is then close with subcuticular and external sutures.

Tumors arising from the superior vestibular nerve are superficially located, facilitating their removal. When the tumor originates from the inferior vestibular nerve, it lies beneath the VIIth nerve and the superior vestibular nerve, both of which must be manipulated during tumor removal. Inferiorly located tumors demand strict attention to avoiding both traction and compression of the intracanalicular segment of the facial nerve while removing tumor. For this reason; we prefer to remove inferior vestibular tumors by the translabyrinthine or the suboccipital (retrosigmoid) routes, as the facial nerve results achieved with these approaches are not achieved with the middle fossa approach to these tumors.

EXTENDED MIDDLE FOSSA APPROACH

The extended middle fossa approach has taken different meanings, depending on the area of interest the surgeon desires to access. However, in the context of this chapter, the extended middle fossa approach is applied to surgical removal of bone of the perilabyrinthine air cell system and the petrous apex (Figure 11) to access disease extension beyond the internal canal into the petrous apex (Figure 12) or the cerebellopontine angle (Figure 13). Bony removal over the internal auditory canal allows access to intracanalicular tumors. However, for larger acoustic tumors extending out of the porus acousticus, additional bone removal anterior and posterior to the internal auditory canal may be performed to expand the exposure. The limit of bone dissection posterior to the internal auditory canal is the superior semicircular canal. After the arcuate eminence is located, the superior semicircular canal 'blue-lined', and after the internal auditory canal is located, the bone between these two landmarks may be removed. Bone removal anterior to the internal auditory canal toward the petrous apex is performed as necessary for exposure around the tumor. Ligation and transection of the superior petrosal sinus with tentorial incision allow a wider window of access to the anterior-superior cerebellopontine angle in the posterior fossa. Preservation of hearing is still achieved with such bone removal as long as the the cochlea and semicircular canals are not violated.

These areas of safe bone removal in the anterior and posterior petrous bone have been described by Kawase as a surgical construct (Figure 11). Kawase's triangle is bordered by the petrous ridge of the temporal bone medially arcuate eminence posteriorly and a line formed by the greater superficial petrosal nerve, cochlea, and intrapetrous carotid artery anterolaterally. Bone removal in these areas with and without transtentorial entry will allow extended access to the cerebellopontine angle.

Further access to the petroclival area; upper clivus, and posterior cavernous sinus areas may be obtained with additional anterior bony dissection and transtentorial transpetrosal techniques (extended anterior petrosectomy). This allows access to additional cranial nerves III–VI, basilar artery, posterior cerebral artery superior cerebellar artery, and anterior inferior cerebellar artery.

During anterior petrosectomy bone removal for access to the above structures, the horizontal petrous course of the internal carotid artery should be identified, in addition to the usual topographical landmarks of the middle fossa floor, to facilitate the safe removal of lesions of the petrous apex (Figure 11). The horizontal petrous carotid artery is located medial and posterior to the foramen spinosum, below the greater superficial petrosal nerve. Bony removal through Glasscock's triangle will uncover the carotid artery. Glasscock's triangle is bordered by the line from the foramen spinosum to the facial hiatus laterally the greater superficial petrosal nerve medially, and the base of the mandibular division of the trigeminal nerve anteriorly.

The middle fossa craniotomy may be extended posteriorly and incorporated with a wide mastoidectomy for access into the posterior fossa (posterior petrosectomy). After skeletonization of the sigmoid sinus, posterior fossa dura, and middle fossa dura during the mastoidectomy, dural entry through the posterior fossa dura exposes the cerebellum, brain stem, and caudal cranial nerves. The extended middle fossa approach can be combined with suboccipital (retrosigmoid), retrolabyrinthine, and translabyrinthine dissection to achieve supratentorial-infratentorial exposure (Figure 13). Such combinations enable communication of the middle and posterior fossae by totally dividing the tentorium as much as necessary. Both sigmoid and superior petrosal sinuses are divided.

COMPLICATIONS

Complications from the middle fossa craniotomy come from attempts at localizing and uncovering the length of the internal auditory canal, temporal lobe retraction, tumor removal, and wound closure. Structures important to hearing and balance surround the internal auditory canal on each side. The basal turn of the cochlea lies anterior to the internal auditory canal in close association with the labyrinthine segment of the facial nerve. The ampulla of the posterior semicircular canal lies posterior to the long axis of the internal auditory canal at its lateral extent. Violation of any of these structures will result in hearing loss or vestibular dysfunction. Care is taken in the initial identification of the arcuate eminence, to localize the superior semicircular canal, not to remove bone past the point of the ‘blue line’. The middle fossa floor bone around the arcuate eminence must be removed over a wide surface to avoid puncturing the membranous labyrinth with the burr of the drill.

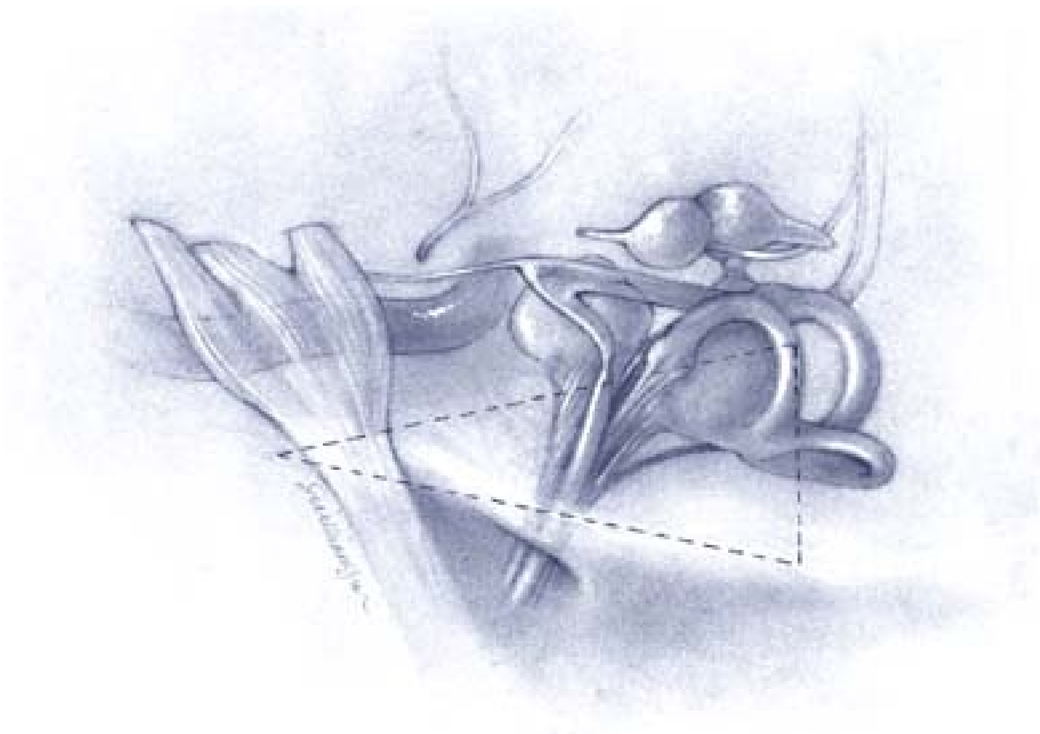


Figure 11

Anatomic regions accessed by extension of the middle fossa dissection to the petrous apex and cerebellopontine angle

Due to the need to retract the temporal lobe medially after the craniotomy is created, there is always a risk of seizures resulting from an irritative focus on the cerebral cortex. Excessive retraction on the temporal lobe may be reduced with the adequate amount of bone removal from the margins of the craniotomy. If dissection is prolonged, intermittent release of the retractor may help to reduce the compressive effects on the temporal lobe cortex.

Injury to the cochlear and facial nerve resulting in hearing loss or facial weakness/paralysis may occur if the dissection of the tumor becomes difficult and the planes of dissection between the nerve and tumor become indistinct. Frequent reference to bony landmarks, such as the vertical crest, will aid in identification. Interruption of an already tenuous blood supply may have similar effects.

Meticulous wound closure is crucial to avoid complications of cerebrospinal fluid leak, meningitis and wound infection. If the tegmen tympani is uncovered to help to localize the ossicular heads lateral to the geniculate ganglion, the roof must be reconstructed with bone (usually from the inner cortex of the bone flap) and temporalis fascia in a layered fashion. This is performed to prevent an encephalocele and a communication for cerebrospinal fluid to the middle ear space. Any dural incisions are best reapproximated and

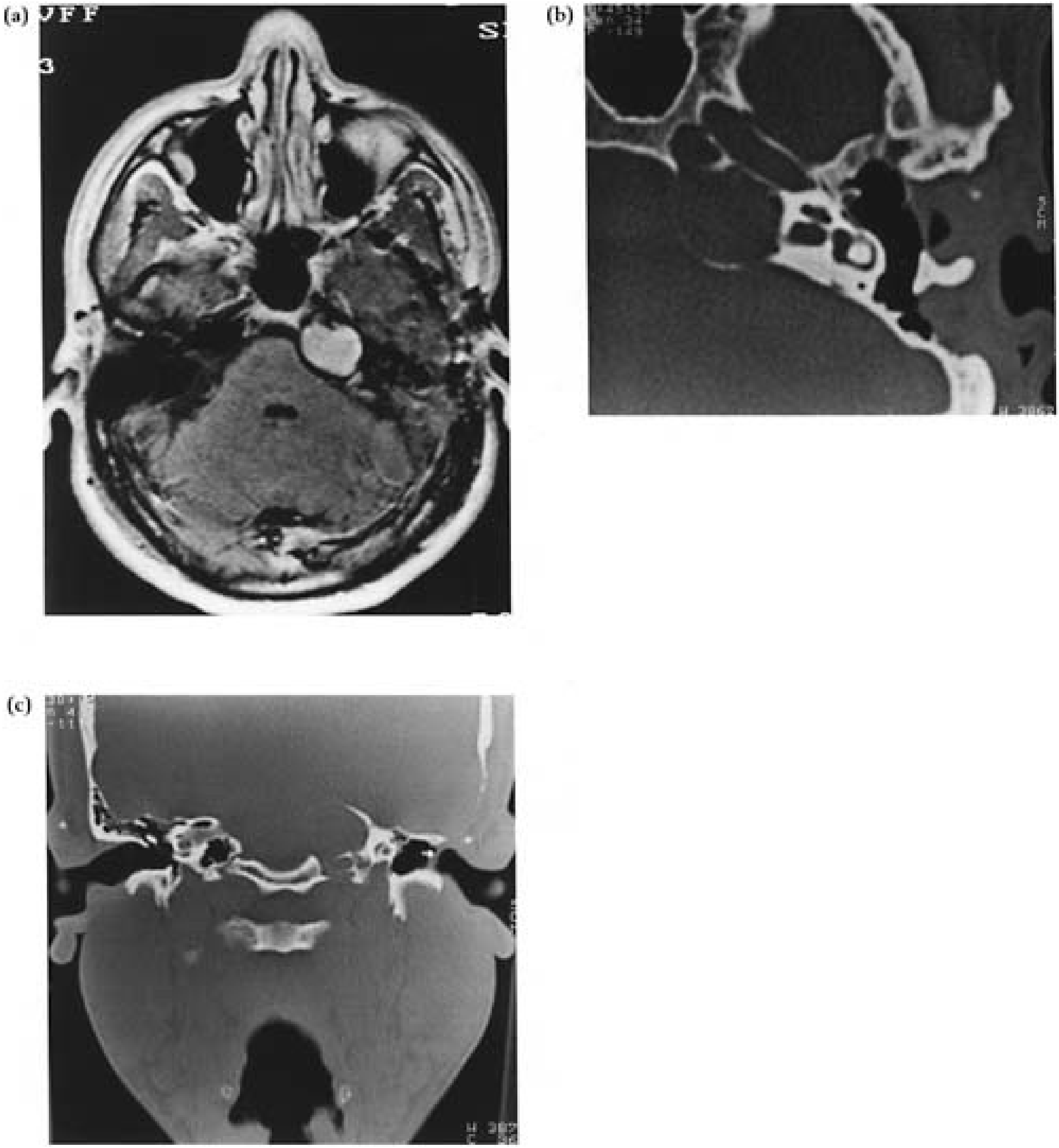


Figure 12

Cholesterol cyst of petrous apex drained via middle fossa craniotomy, anterior petrosectomy. (a) T1-weighted axial MRI of cholesterol granuloma; (b) axial CT of same lesion. Note medial position relative to the carotid artery; (c) coronal CT of same lesion

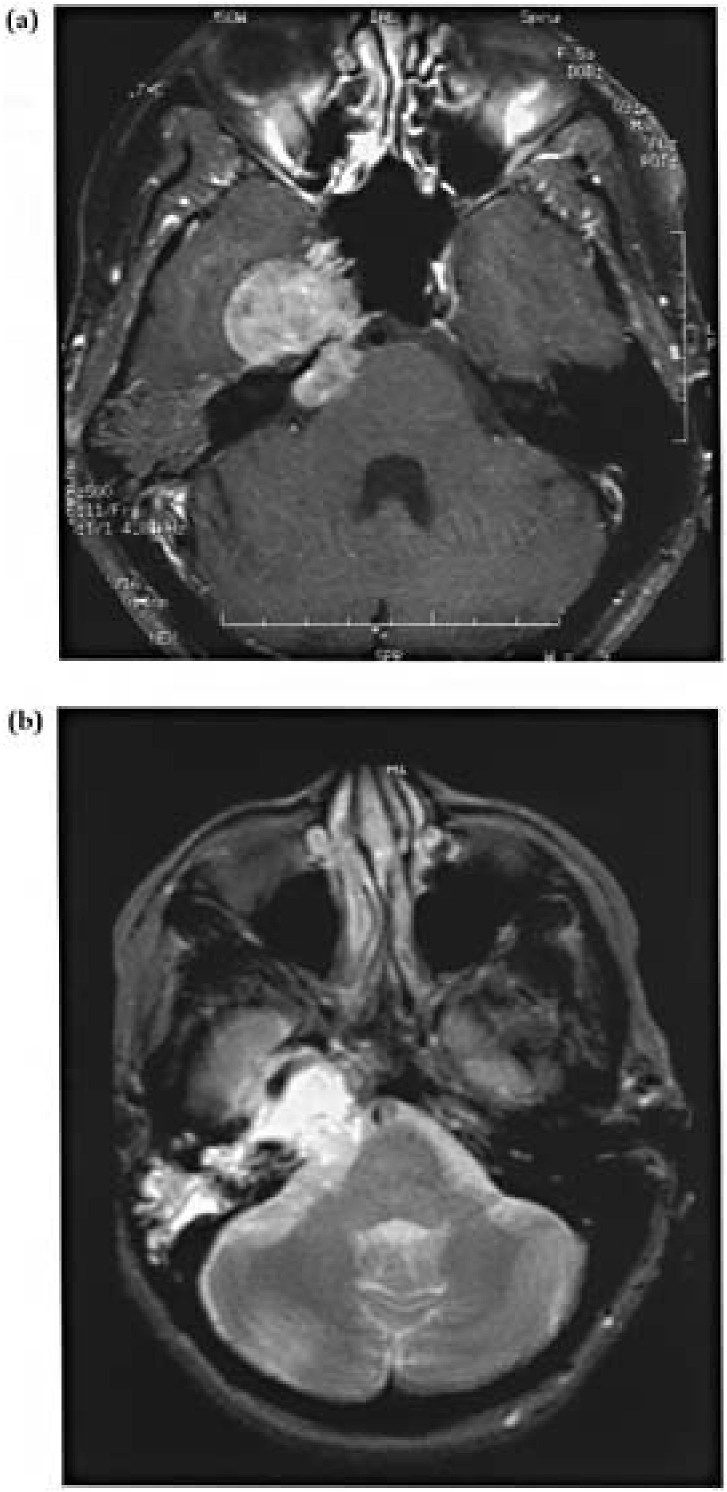


Figure 13

Chondrosarcoma of the petrous apex extending along the middle fossa floor and into the cerebellopontine angle. The tumor is accessible via the extended middle cranial fossa (subtemporal) dissection. Tumor lying medial to the internal carotid artery and that portion of the tumor with intradural extension into the pre-pontine space requires a (combined) posterior approach to achieve combined supratentorial-infratentorial exposure. (a) T1-weighted axial MRI scan with gadolinium showing tumor extending into middle fossa and cerebellopontine angle; (b) T2-weighted MRI scan demonstrating petrous apex involvement medial to internal carotid artery. Incidental note is made of mastoid and middle ear inflammation associated with eustachian tube obliteration by tumor

sutured together. The portal for cerebrospinal fluid release made from incising the temporal dural is now closed. Abdominal free fat graft may be placed over the middle fossa floor defect if it is large. Anatomy is restored by replacing the craniotomy bone plate. Titanium mesh may be used to help to secure the bone plate. The wound is closed in layered fashion.

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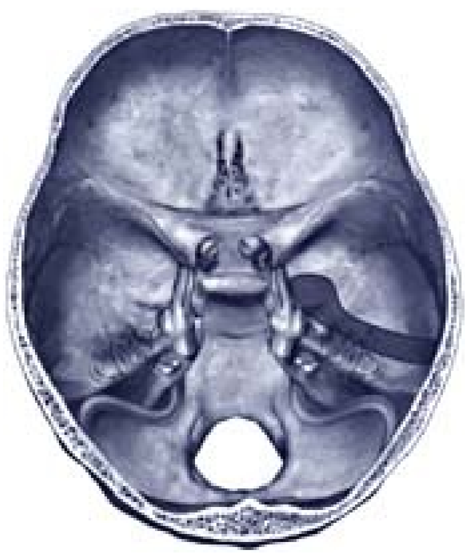
10
Infracochlear approach

John K.Niparko and Matthew Ng



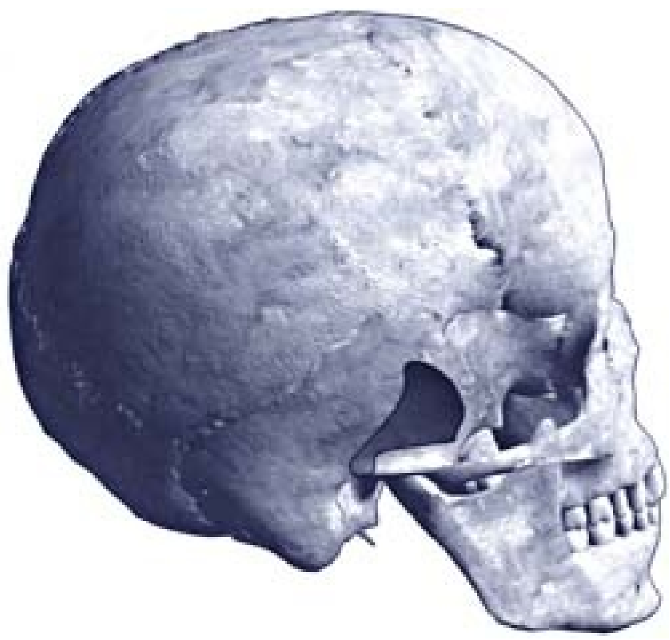


Figure 1

Axial CT scan of the temporal bone demonstrating the surgical trajectory of the infracochlear approach to the petrous apex. The vector of the surgical approach runs medial to the carotid canal, approximately 30° off axis of the external auditory canal, anteromedially

INDICATIONS

Access to lesions of the petrous apex can be gained through several approaches. The transmastoid infralabyrinthine, middle fossa, transcochlear and transethmoid-transsphenoidal approaches allow for petrous apicotomy, with varying levels of surgical ablation of intervening tissues. These approaches differ in their approach, either above the labyrinth, through the labyrinth (the subarcuate tract), and beneath the labyrinth. The infracochlear approach creates a limited opening through which inflammatory and cystic lesions of the petrous apex may be addressed. The infracochlear approach enables a petrous apicotomy, tracking inferior and anterior to the labyrinth; and allows for drainage and aeration of this remote portion of the temporal bone (Figures 1 and 2).

PATIENT EVALUATION

The occult nature of the disease localized to the petrous apex and the poorly localizing clinical features often delay diagnosis. Presenting symptoms usually consist of retrorbital or temporal discomfort, and changes in hearing and balance, and extraocular or facial nerve dysfunction. In cases of suspected involvement, the petrous apex is best evaluated by correlating CT and MR images. Lesions of this site are typically primary cholesteatomas (epidermoids), mucoceles, and cholesterol granulomas (Figures 3, 4 and 5). Rarely, neurogenic and metastic lesions will involve the petrous apex. Certain signal characteristics on MRI and radiodensities on CT scan will often lend a clue as to the nature of the lesion. This will, in turn, dictate the best surgical approach. Therefore, thorough assessment requires both imaging modalities.

The petrous apex region of the temporal bone can either be pneumatized or filled with bone marrow. Therefore, inspection of the petrous apex on CT may reveal pneumatization. Like the mastoid air cell system or paranasal sinuses, the petrous apex can be opacified as a result of impaired aeration and inflammation (petrous apicitis). If the petrous apex contains bone marrow, there will be a high signal on the T1-weighted images, highlighting the high fat content of bone marrow.

Figure 2

Coronal CT scan of temporal bone demonstrating the infracochlear approach through bone intervening between the basal turn of the cochlea and the internal carotid artery

Jackler and Parker (1992) described key features on CT and MR imaging to help identify particular petrous apex lesions. On CT scan, bone erosion will be noted in cholesterol granuloma, mucocele, cholesteatoma, petrous apicitis, and neoplasia. The margins of the erosion for cholesterol granuloma, cholesteatoma, and mucocele are usually smooth, while the margins of erosion for petrous apicitis and neoplasia are irregular to variable. Differentiation of the above lesions is improved with the help of MRI. The cholesterol granuloma is hyperintense on T1-and T2-weighted imaging and does not enhance with gadolinium. Cholesteatomas are hypointense on T1 and hyperintense on T2, without gadolinium enhancement. The signal characteristics of petrous apicitis are similar to cholesteatomas, but there is rim enhancement with petrous apicitis. Neoplasia is similar to cholesteatomas and petrous apicitis on T1-and T2-weighted images, but the entire lesion, not just the rim, enhances with gadolinium. The mucocele is hypointense on T1, hyperintense of T2, and rim-enhancing on gadolinium, similar to petrous apicitis. However; the mucocele is usually an expansile-type lesion.

The infracochlear approach is used to treat lesions that require drainage only. These lesions include mucoceles and cholesterol granulomas. Wider exposure, achieved with petrous apicotomy with radical mastoidectomy or a lateral subtemporal approach, is required for removal of soft tissue lesions. Occasionally the infracochlear approach may be used to obtain diagnostic material from the petrous apex without requiring extensive bone removal or craniotomy with temporal lobe retraction.

ANATOMICAL CONSIDERATIONS

The site of the petrous apex, deep to the labyrinth and facial nerve, and its proximity to the internal carotid artery and brain stem presents surgical risks. To preserve neurologic function while providing adequate surgical exposure requires extensive knowledge of temporal bone anatomy and surgical approaches.

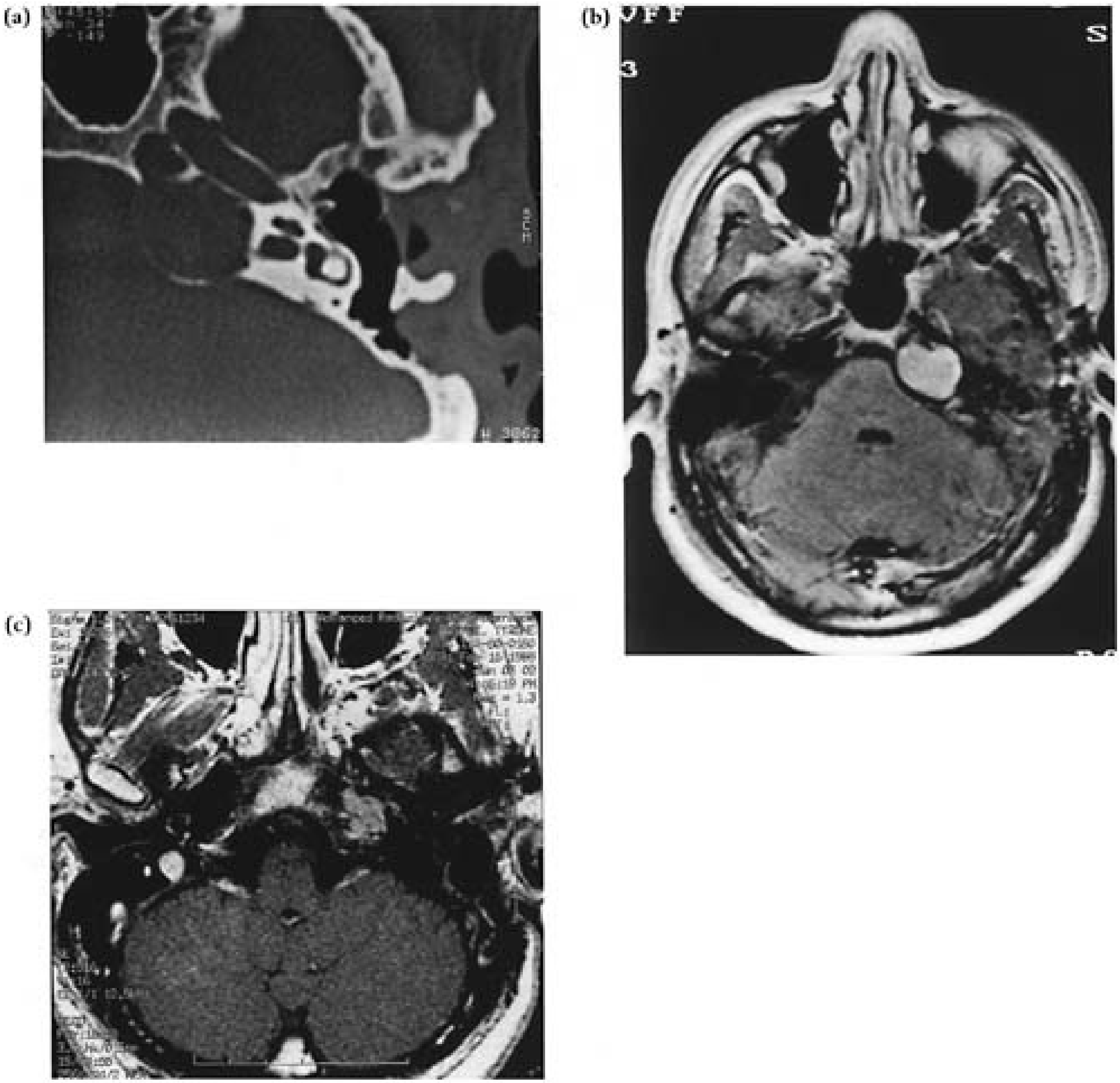


Figure 3

Cholesterol granuloma of left petrous apex producing left hemifacial spasm. (a) CT scan of the temporal bone demonstrating cyst expansion of petrous apex, medial to horizontal segment of internal carotid artery; (b) T1-weighted axial MRI of cholesterol granuloma; (c) postopera-tive T1-weighted axial MRI demonstrating reduction of signal within the petrous apex associated with resolution of facial spasm

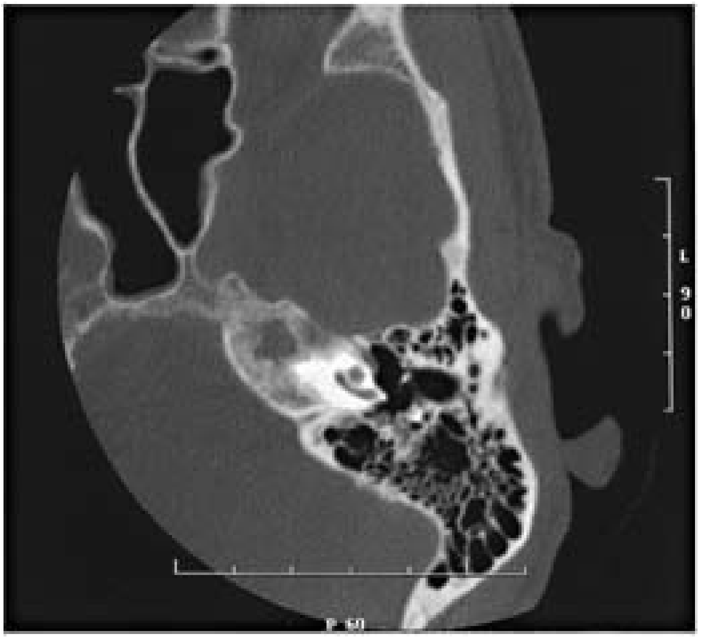


Figure 4

CT scan demonstrating a mucocele of the right petrous apex drained via the infracochlear approach

The petrous apex is divided into the peritubal area that surrounds the eustachian tube and lies anterolateral to the carotid canal, and the apical area that lies anteromedial to the carotid canal. Infracochlear exposure of the petrous apex requires full utilization of the limited space of air cells bounded by the cochlea superiorly, the jugular bulb posteroinferiorly, and the carotid artery anteromedially (Figures 1 and 2).

Access to lesions occupying the petrous apex and the clivus from a lateral trajectory is limited by the labyrinth and facial nerve. The infracochlear and transcochlear approaches offer access to these areas and enable access to lesions that lie anterior to the cranial nerves and brain stem, *i.e.* those lesions situated anteromedial to the internal auditory canal.

Transcanal approaches to the petrous bone require knowledge of the relationship between the external and middle ear (Figure 6). The transcanal infracochlear approach exposes a narrow oval of bony opening into the petrous apex bounded by the basal turn of the cochlea above, and the jugular bulb and genu of the internal carotid artery below. The infracochlear approach effectively addresses only cystic lesions that can be drained and subsequently stented through limited exposure. Alternative approaches to the petrous apex are the retrofacial (retrolabyrinthine) approach from behind, and lateral infratemporal approaches, and middle fossa approaches from above, described elsewhere in this text. The transcochlear approach discussed as an extension of the translabyrinthine approach exposes a substantially larger region of the petrous apex. Medial extension of the transcochlear approach exposes the petrous apex, clivus, and prepontine space between the superior petrosal sinus and trigeminal ganglion above, and the inferior petrosal sinus below.

PROCEDURE

The membranous ear canal is incised to enhance exposure. A Lempert Type I incision can be used to facilitate placement of self-retaining retractors for maximal lateral exposure of the bony external ear canal without the use of an aural speculum (Figure 7).

(a)
(b)

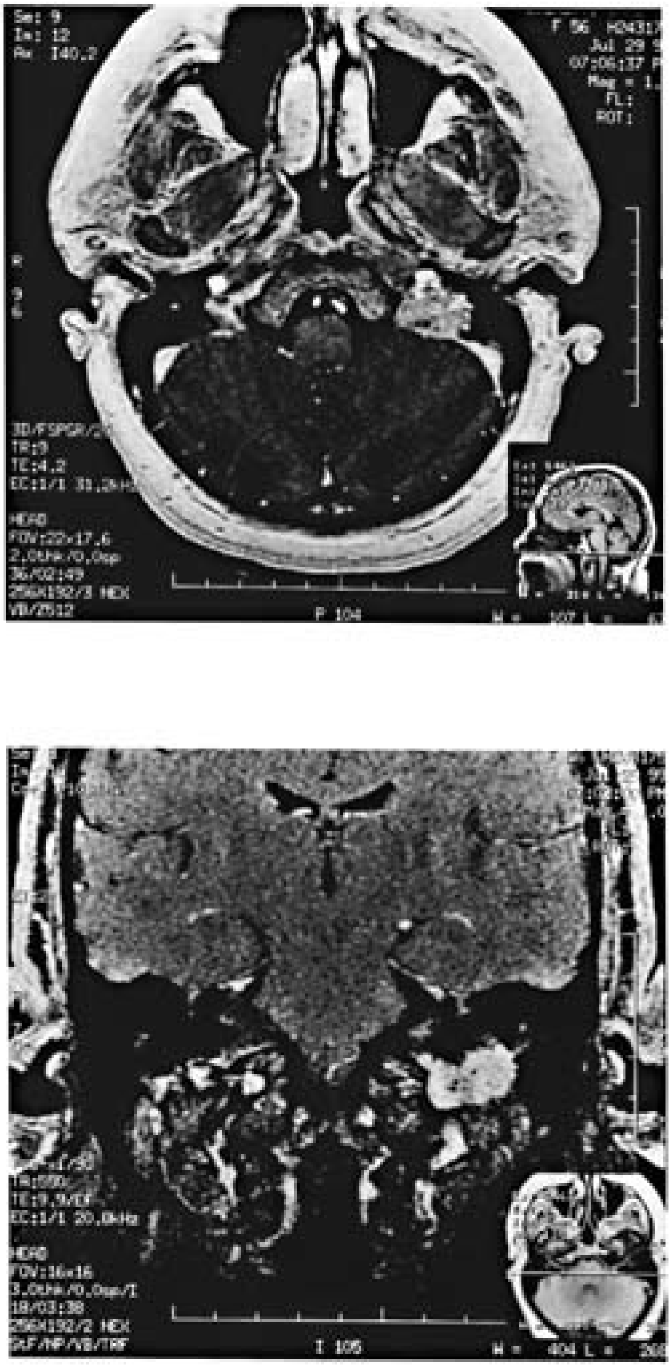


Figure 5

Petrous apicitis. The infracochlear approach may be used to open a tract into the anterior petrous apex to promote aeration of air cell tracts within the petrous apex. (a) T2- weight-ed axial MRI; (b) T1- weighted coronal MRI

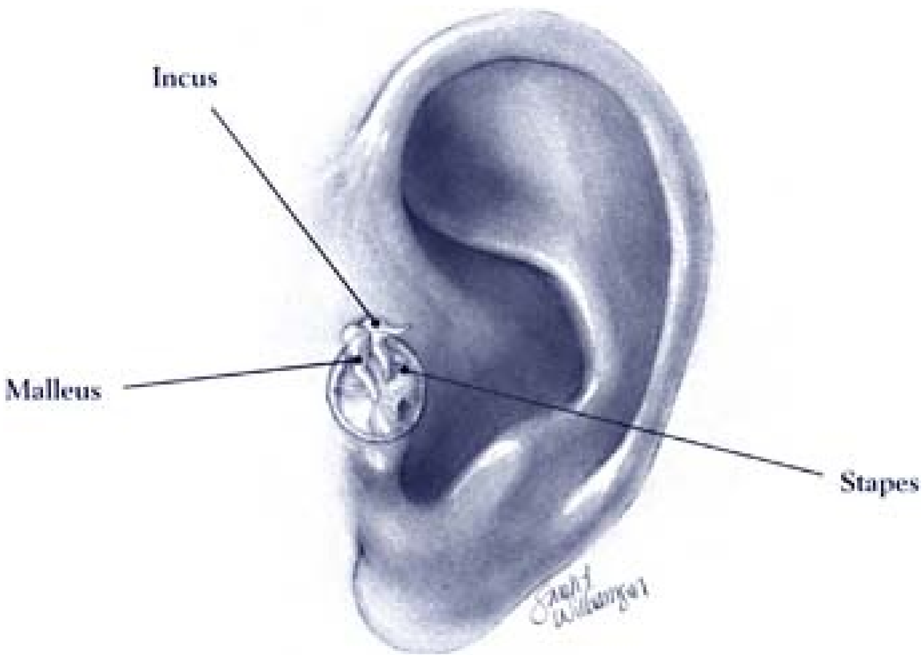


Figure 6

Schematic diagram demonstrating left tympanic membrane, ossicular chain, and round window relative to auricle to consider in transcanal approaches to the petrous bone

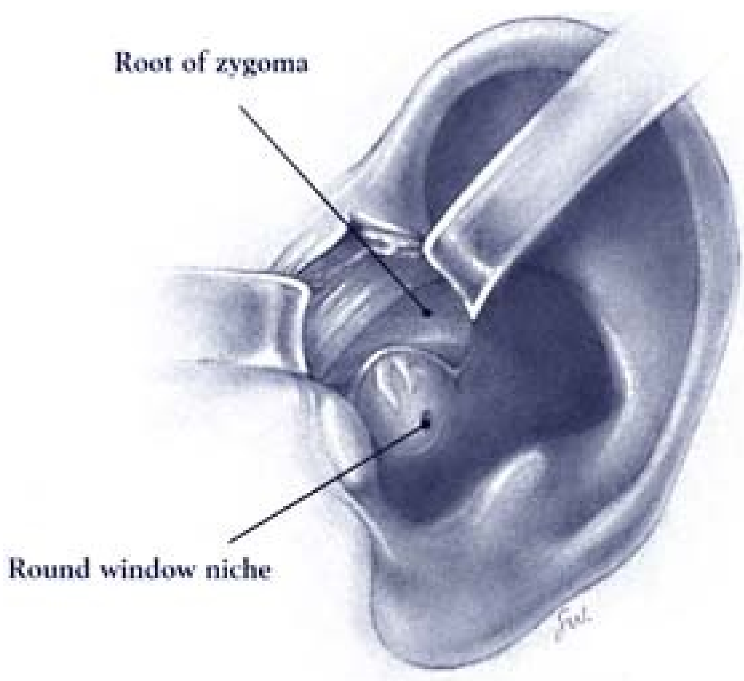


Figure 7

Lempert-type incision through the incisura terminalis performed to expand the lateral (membranous) external auditory canal to facilitate visualization of the canal and tympanic membrane

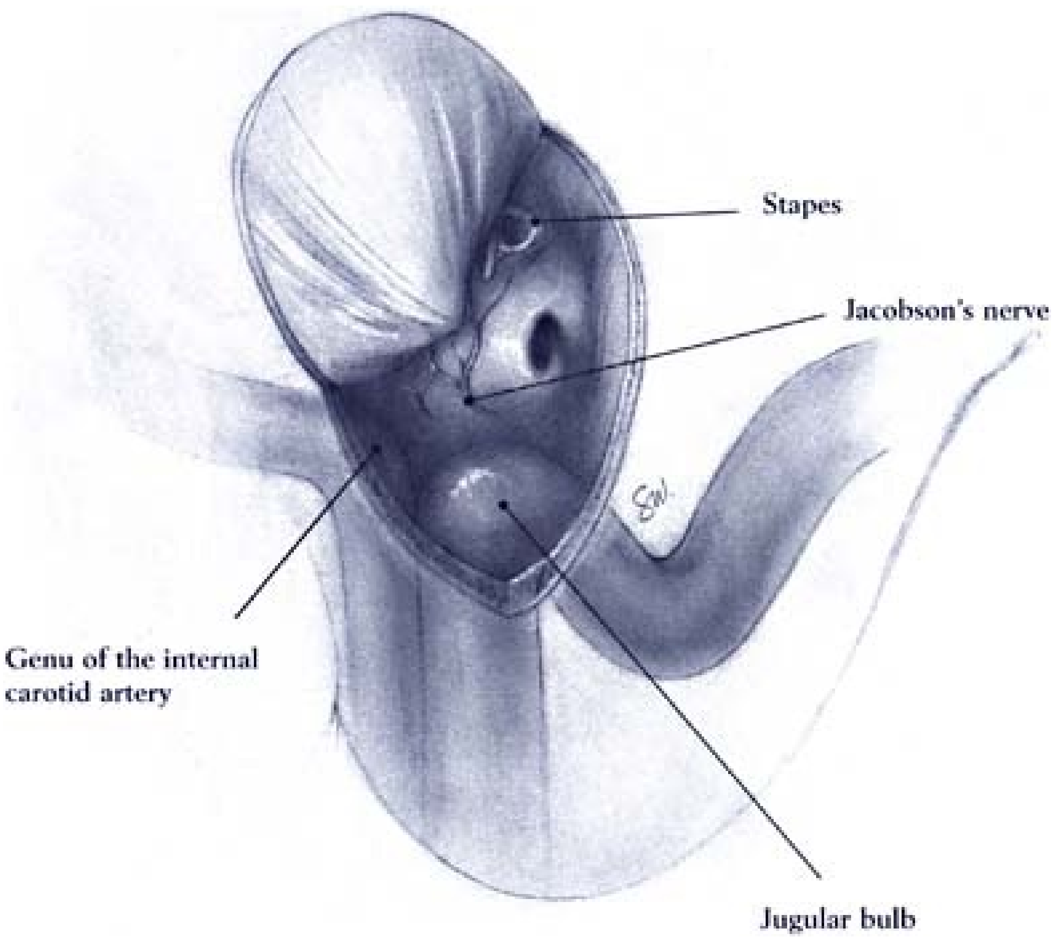


Figure 8

Transcanal view showing raised left tympanomeatal flap. Outlines for a superiorly based tympanomeatal flap are shown. Ossicles, cochlear promontory, internal jugular vein and internal carotid artery are shown in a view of the hypotympanum A superiorly based tympanomeatal flap, from 10 to 2 o'clock, is raised and the middle ear exposed for access to the hypotympanum and protympanum areas. Canal skin is incised and extended 15 mm laterally (Figure 8).

After elevation of the tympanomeatal flap, a microdrill is used to saucerize the bony canal at the level of the tympanic annulus. Saucerization continues until a full view of the cochlear promontory is achieved. Drilling in the hypotympanum skeletonizes the dome of the jugular bulb.

Drill-out to expose the petrous apex is accomplished by dissecting the peritubal air cell tract. Bone between the jugular bulb (posteroinferiorly), the internal carotid artery

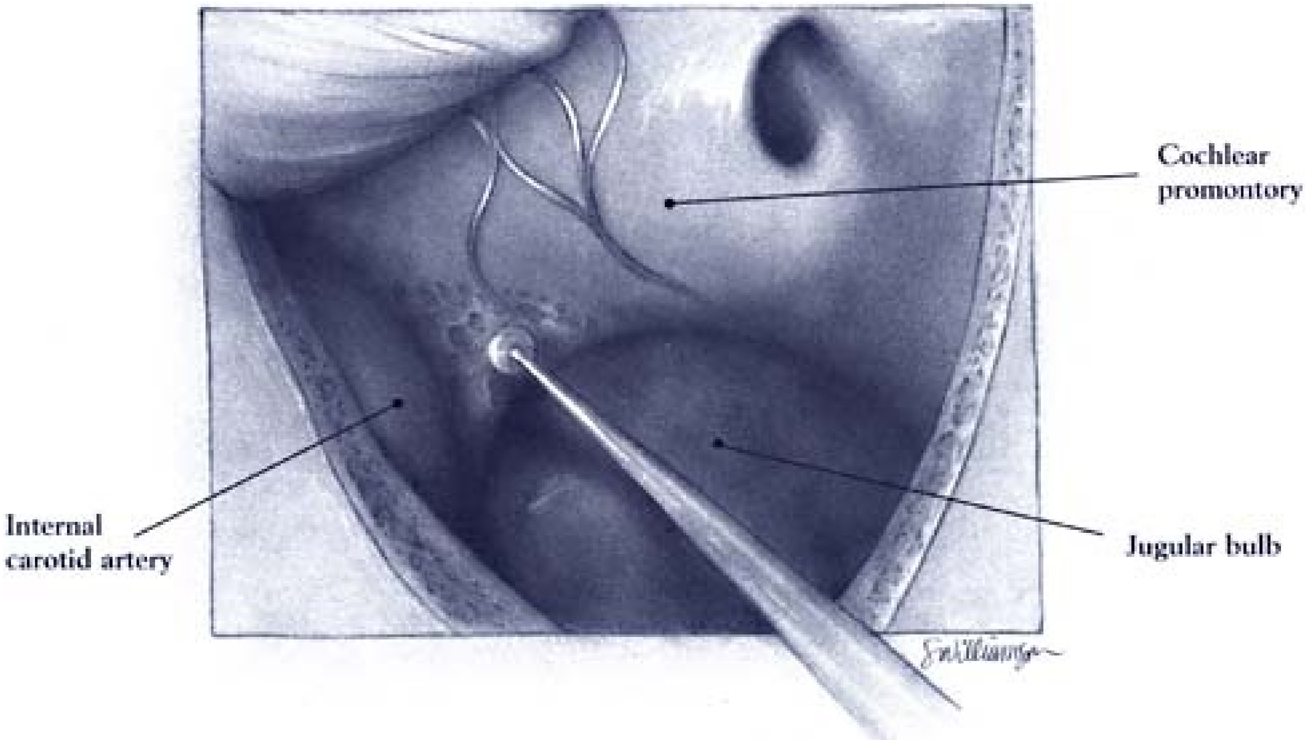


Figure 9

The left middle ear is entered to expose the hypotympanum and protympanum areas. The surgical portal to the petrous apex is bordered by the basal turn of the cochlea above, carotid artery anteroinferior, and jugular bulb posteroinferior. Drilling the keel of the bone, while gradually decorticating the great vessels, creates a petrous apicotomy. The apicotomy is expanded to boundaries defined by the cochlea and great vessels (anteroinferiorly), and the basal turn of the cochlea (superiorly) is progressively removed to expose the petrous apex. The course of the internal carotid artery is followed anteromedially from the region of the bony 'keel' between the internal carotid artery and dome of the jugular bulb (Figure 9). Jacobson's nerve, located on the promontory, can often lead toward this area if it is traced anteroinferiorly.

Once the cyst wall is entered, the opening is enlarged to facilitate drainage. Entry through the cyst wall is usually heralded by spillage of a dark brownish fluid consistent with old blood, in the case of a cholesterol cyst, or mucus, in the case of a mucocele or petrositis. A Silastic catheter tube is placed into the petrous apex, leading out toward the middle ear, to help aerate the petrous apex.

COMPLICATIONS

Intraoperative complications arising during the transcanal infracochlear approach include potential violation of the major vascular structures (petrous carotid and jugular bulb) and cochlea which border the portal into the petrous apex. As this is a narrow window, adequate bone over each of the three structures must be removed equally to maximize exposure. Entry into the cochlea is usually preceded by uncovering of the dense white bone of the otic capsule and the 'blue line' of the membranous labyrinth of which the surgeon must take notice. If entry into the cochlea is made, immediate repair by placing fascia over the bony fistula, secured by bone wax, is performed. Major vascular injury to the jugular bulb is treated by immediate packing with Avitene (bovine collagen) or Surgicel (oxidized cellulose). Often, the bleeding will halt and allow continuation of the dissection. Bleeding from the carotid artery is more troublesome. It is usually heralded by bleeding from the adventitia of the carotid artery. Similar packing is immediately performed over the bleeding site and stabilized. The danger of air embolism is ever present for both the carotid artery and jugular vein; and preparations should be made at all times to be ready to occlude the bleeding site.

Postoperative complications include recurrence and recollection of either the cholesterol cyst or mucocele, occlusion or displacement of the drainage catheter, conductive hearing loss from fibrous middle ear adhesions, or petrous apicitis.

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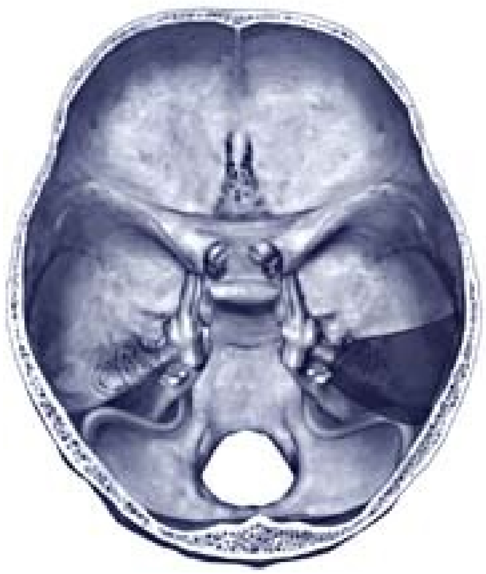
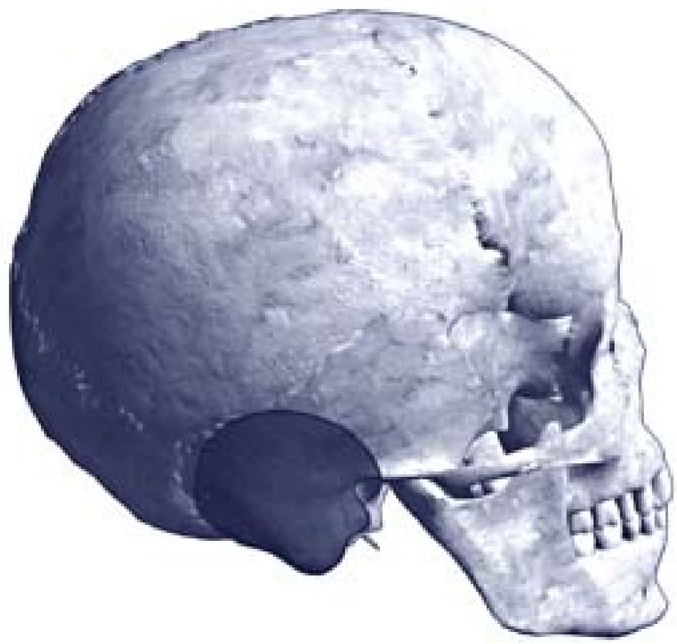
11
Translabyrinthine approach

John K.Niparko, Michael J.Holliday and Donlin M.Long





INDICATIONS

Skull base surgeons employ the translabyrinthine approach most frequently to remove acoustic schwannomas when useful hearing is absent. The translabyrinthine approach is also applicable for removing other neural-and petrous-based tumors, including meningiomas, non-acoustic neurilemmomas, sarcomas and vascular tumors. Vestibular nerve section and post-traumatic facial nerve repair can also be performed via this transtemporal approach. The utility of this approach lies in the relatively short distance from the mastoid cortex to the internal auditory canal and cerebellopontine angle. Given that the surgical trajectory to the internal auditory canal and cerebellopontine angle is through the bone of the mastoid and vestibular portion of the labyrinth, the need for retraction of the contents of the posterior fossa is reduced.

Acoustic schwannomas are benign, slow-growing neoplasms that most commonly arise from Schwann cells of the distal portion of the superior vestibular division of the VIIIth cranial nerve. These tumors develop most frequently at the junction of the central and peripheral portions of the nerve (Oberstein-Redlich zone), as defined by the junction of peripheral and central myelin, those of Schwann cell and oligodendrocyte derivation, respectively. The epicenter of the acoustic schwannoma will lie within or outside of the internal auditory canal, depending on the medial-lateral position of this junction. Use of the translabyrinthine approach to tumors that are displaced medially (with extensive involvement of the angle) calls for experience in order to manage vascular structures of the posterior circulation and cranial nerves at the root entry zone that are likely to be involved with the tumor.

PATIENT EVALUATION

The translabyrinthine approach is appropriate for the patient with an acoustic neuroma and poor to non-serviceable hearing. Therefore, standard audiometry documenting the level of hearing must be performed. One previously established informal guideline uses auditory thresholds greater than 50 decibels and speech recognition scores worse that 50% to help to determine hearing which is not useful. Determination of the level of hearing in the contralateral ear will help in preoperative counseling for aural rehabilitation needed postoperatively.

Routine imaging for acoustic neuromas includes MRI with gadolinium enhancement to indicate the extent of the tumor relative to the internal auditory canal, cerebellopontine angle, and brain stem. The translabyrinthine approach is suitable for tumors varying widely in size and position. The approach can facilitate the safe removal of those tumors situated within the vestibule of the labyrinth (Figure 1), those situated in the internal auditory canal (canalicular)

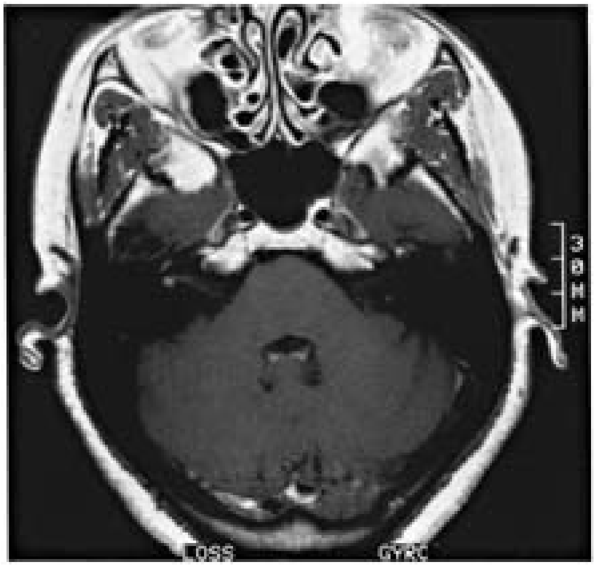


Figure 1

MRI demonstrating 2-mm vestibular schwannoma within the vestibule of the labyrinth of the right ear. Despite the small size of the tumor, preoperative hearing was absent, suggesting direct labyrinthine injury from growth into the vestibule

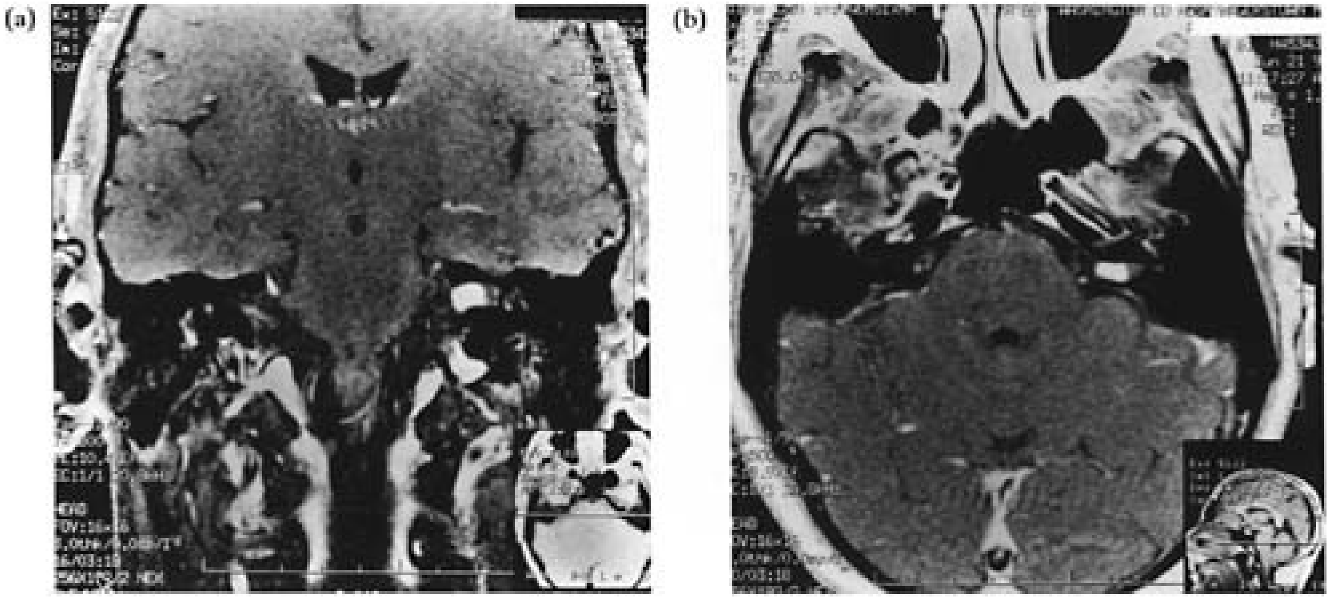


Figure 2

MRI scan demonstrating left intracanalicular acoustic neuroma in a patient with non-serviceable hearing. (a) T1-weighted coronal MRI scan with gadolinium of left intracanalicular tumor; (b) T1-weighted axial MRI scan with gadolinium of the same tumor. The tumor was removed via the translabyrinthine approach

(Figure 2) and, with the stipulations noted above; in the cerebellopontine angle (Figure 3). Computed tomography of the temporal bone may provide additional information pertinent to the bone removal, for example, the degree of mastoid pneumatization, level of the tegmen mastoideum, and position of the sigmoid sinus and jugular bulb. CT scans of the temporal bone, however, are not a prerequisite for this approach.

ANATOMICAL CONSIDERATIONS

The surgical field should enable access to the entire mastoid and retrosigmoid areas. This facilitates complete mastoidectomy and decompression of the sigmoid sinus and posterior fossa dura, thus enabling full exposure of the region between the porus acousticus internus of the internal auditory canal and root entry zone of the pontomedullary brain stem. Contents of the internal auditory canal are thus fully exposed. Adequate exposure is obtained by expanding the margins of the surgical field to their fullest potential. The middle fossa dura should be saucerized at its lateral margin of the mastoidectomy and the tegmen mastoideum completely decorticated. Exposure to permit adequate visualization and surgical dissection of tumors that extend beyond 1 cm medial to the porus is facilitated by retraction of the sigmoid sinus and uncapping of the jugular bulb. Removal of at least 2 cm of retrosigmoid bone, from the transverse sinus above, to the digastric ridge below, facilitates posterior retraction if needed.

Translabyrinthine tumor removal occurs most efficiently when the operative team is facile with the anatomy of the VIIth cranial nerve. For the purposes of translabyrinthine dissection, the tortuous course of the VIIth cranial nerve can be divided into cerebellopontine (intracranial),

Figure 3

MRI scan of left acoustic neuroma with both a cisternal and a canalicular component resected via the translabyrinthine approach

intracanalicular and intratemporal segments. Within the cerebellopontine angle, the VIIth and VIIIth cranial nerves emerge from the pontomedullary root entry zone and course laterosuperiorly across the cerebellopontine angle to enter the internal auditory meatus, along with the anterior inferior cerebellar artery. Within the lateral internal auditory canal, the VIIth cranial nerve occupies the anterosuperior compartment, but may occupy other compartments of the canal depending on the pattern of tumor growth. The VIIth cranial nerve enters the temporal bone via the meatal foramen and courses laterally through the labyrinthine, tympanic and mastoid segments of the Fallopian canal.

PROCEDURE

Following administration of general anesthesia; with the patient in the supine position, intramuscular bipolar electrodes are placed for monitoring facial electromyographic responses of the orbicularis oculi and oris muscles.

A wide area of the postauricular scalp is thus shaved, surgically prepared and draped. A curvilinear incision extending from above the temporal line just above the superior attachment of the auricle, is directed posteriorly to the retrosigmoid area and extended inferiorly posterior toward the mastoid tip, staying within the confines of hair-bearing skin (Figure 4). This anteriorly based scalp flap is elevated lateral to the temporalis fascia superiorly and the mastoid periosteum inferiorly. The mastoid periosteum is divided vertically from the temporal line to the mastoid tip and elevated. Periosteal flaps offer a natural layer of tissue to stabilize the free fat graft to be placed within the mastoid defect at closure. In elevating the soft tissue layers, care is taken not to injure the skin of the external auditory canal.

A large fascial graft is harvested from the lateral aspect of the temporalis muscle to be used later to seal the internal

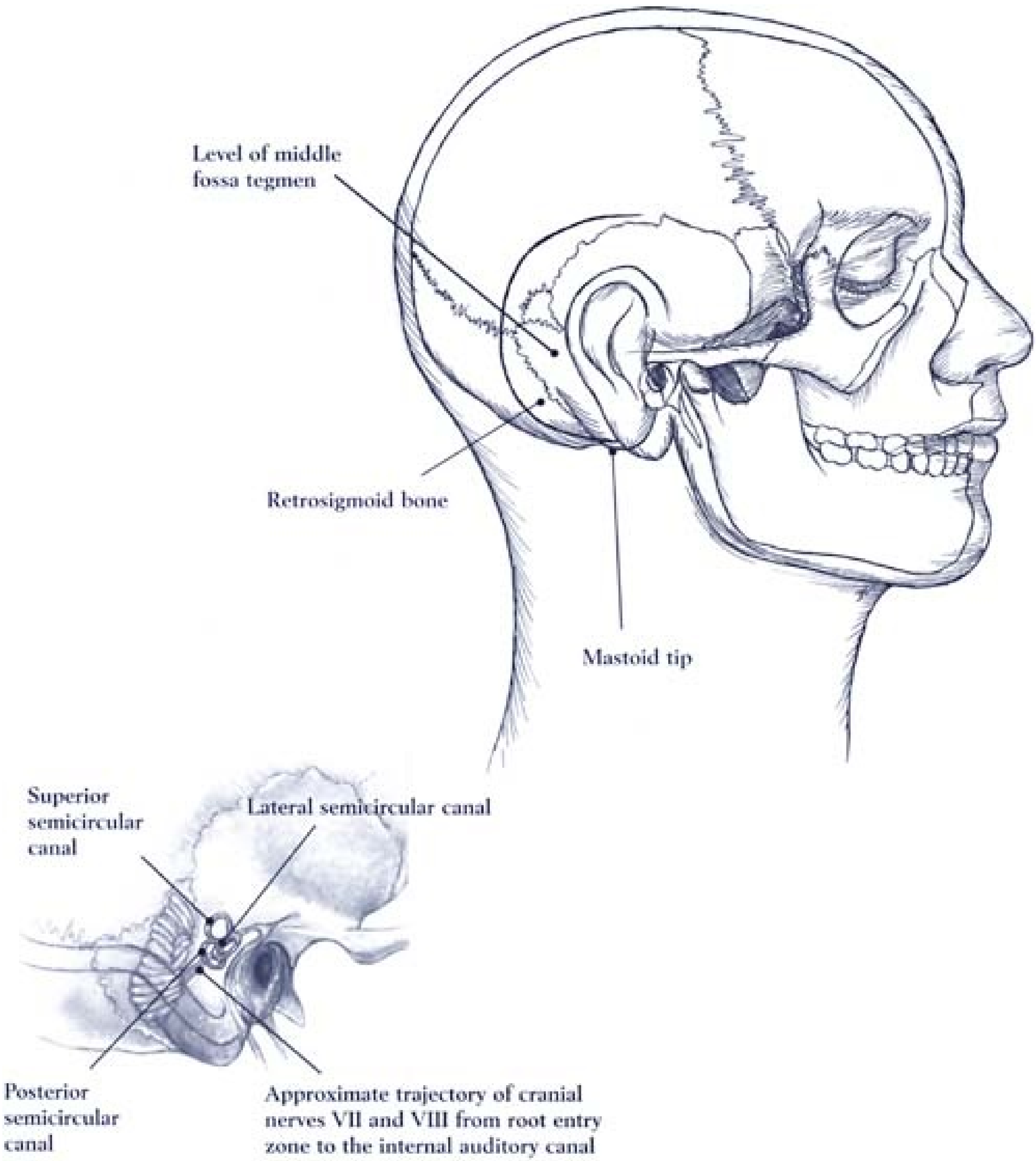


Figure 4

Incision for the translabyrinthine approach. The superior extent of the incision is slightly above the superior temporal line, extending over the retrosigmoid area toward the mastoid tip. The inset shows the relationship between the labyrinthine and the trajectory of cranial nerves VII and VIII from the brain stem into the temporal bone

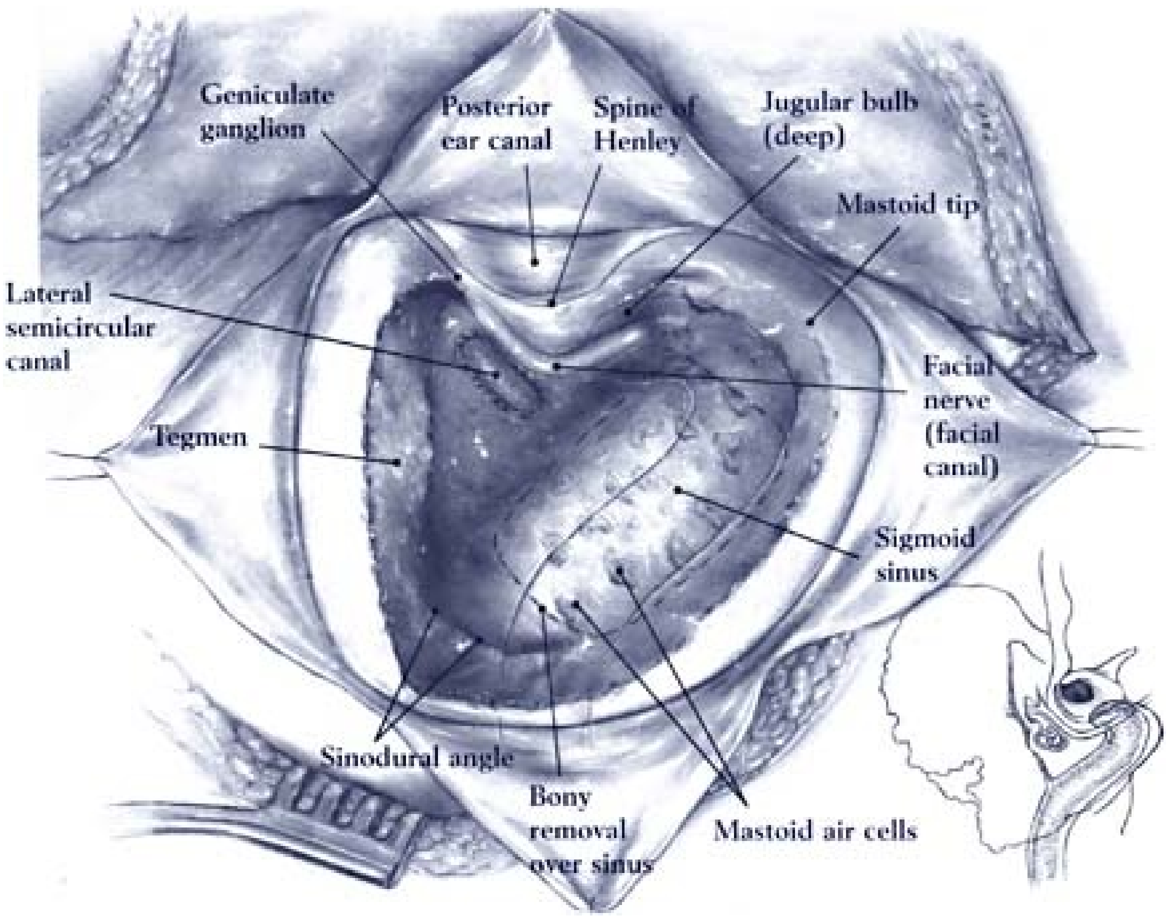


Figure 5 Complete mastoidectomy is performed in the right ear, bounded initially by the middle fossa tegmen (superiorly), the sigmoid sinus (posteriorly), and the bony external canal (anteriorly)

auditory canal and posterior fossa defect from the antrum and middle ear. Self-retaining retractors hold the periosteal and skin flaps anteriorly and the temporalis muscle superiorly.

A wide, complete mastoidectomy is performed with a rotating burr (Figure 5). The mastoidectomy is extended to expose the sigmoid sinus. Approximately 2 cm of dura posterior to the sigmoid sinus may be exposed if a need for wide posterior fossa exposure is anticipated. The entire sigmoid sinus is retracted posteriorly by a self-retaining retractor to expose the posterior fossa dura from the sinodural angle superiorly, to the retrofacial air cells inferiorly. The retrofacial air cells must be removed in the proximity of the jugular bulb to adequately expose the cranial nerve root entry zone in the cerebellopontine angle.

The semicircular canals visible deep to the antrum provide key landmarks for orientation to the internal auditory canal. The ampullated end of the superior canal corresponds to the superior aspect of the internal auditory canal, whereas the ampullated end of the posterior canal corresponds to the inferior limit of the internal auditory canal (Figure 6). The crus commune at the non-ampullated ends of the superior

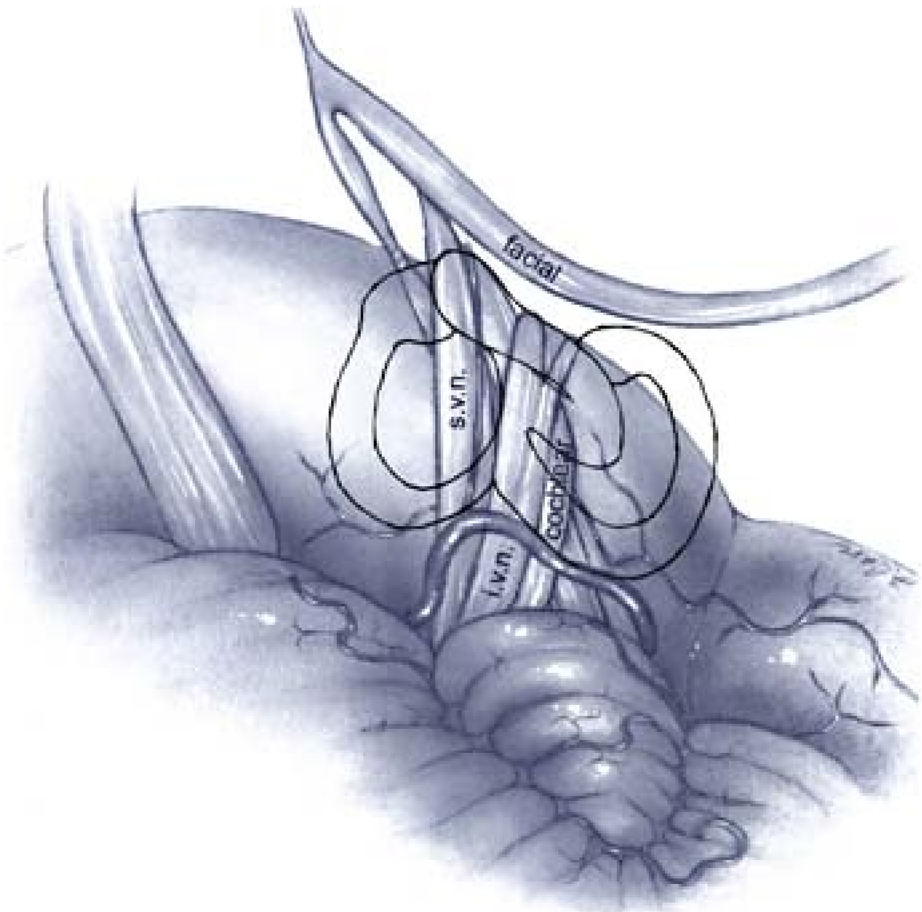


Figure 6

Relationships of the ampullae of the superior and posterior semicircular canals to the superior and inferior borders of the bony internal auditory canal, respectively

and posterior semicircular canals is usually 1–2 mm posterior to the mid-segment of the internal auditory canal.

A widely saucerized bone defect is created between the middle fossa plate superiorly and the sigmoid sinus posteriorly Exposure of the internal auditory canal and cerebellopontine angle is facilitated by bone removal over the sigmoid sinus and retrosigmoid areas to decorticate the posterior fossa dura. Full exposure of the posteroinferior pole of larger tumors requires sigmoid sinus and retrosigmoid decortication. Drilling the retrosigmoid bone is performed most efficiently if the mastoid emissary vein is controlled. This is best accomplished by exposing the vein with a diamond burr, and obliterating the vein with bipolar cauterization. Bone wax or Avitene® microfibrillar collagen and cotton are used to further control the divided emissary vein.

Preserving an island of bone ('Bill's island') over the lateral aspect of the sigmoid sinus is optional (Figure 7). Its potential value lies in eliminating prolonged occlusion of the sigmoid sinus with retraction. Using the suction-irrigator both for suction-irrigation and for depression of the bony island, one can quickly thin down the posterior fossa bony plate with an unobstructed view, as the entire sinus is retracted. Once decompressed; the sigmoid and retrosigmoid dural areas can be retracted when tumors extend into the cerebellopontine angle. If the tumor is smaller or completely intracanalicular, posterior fossa retraction may be unnecessary.

The posterior fossa dural bony plate is completely removed between the superior petrosal sinus and jugular bulb in the vertical direction; and from the sigmoid sinus to the porous internus of the internal auditory canal in the horizontal

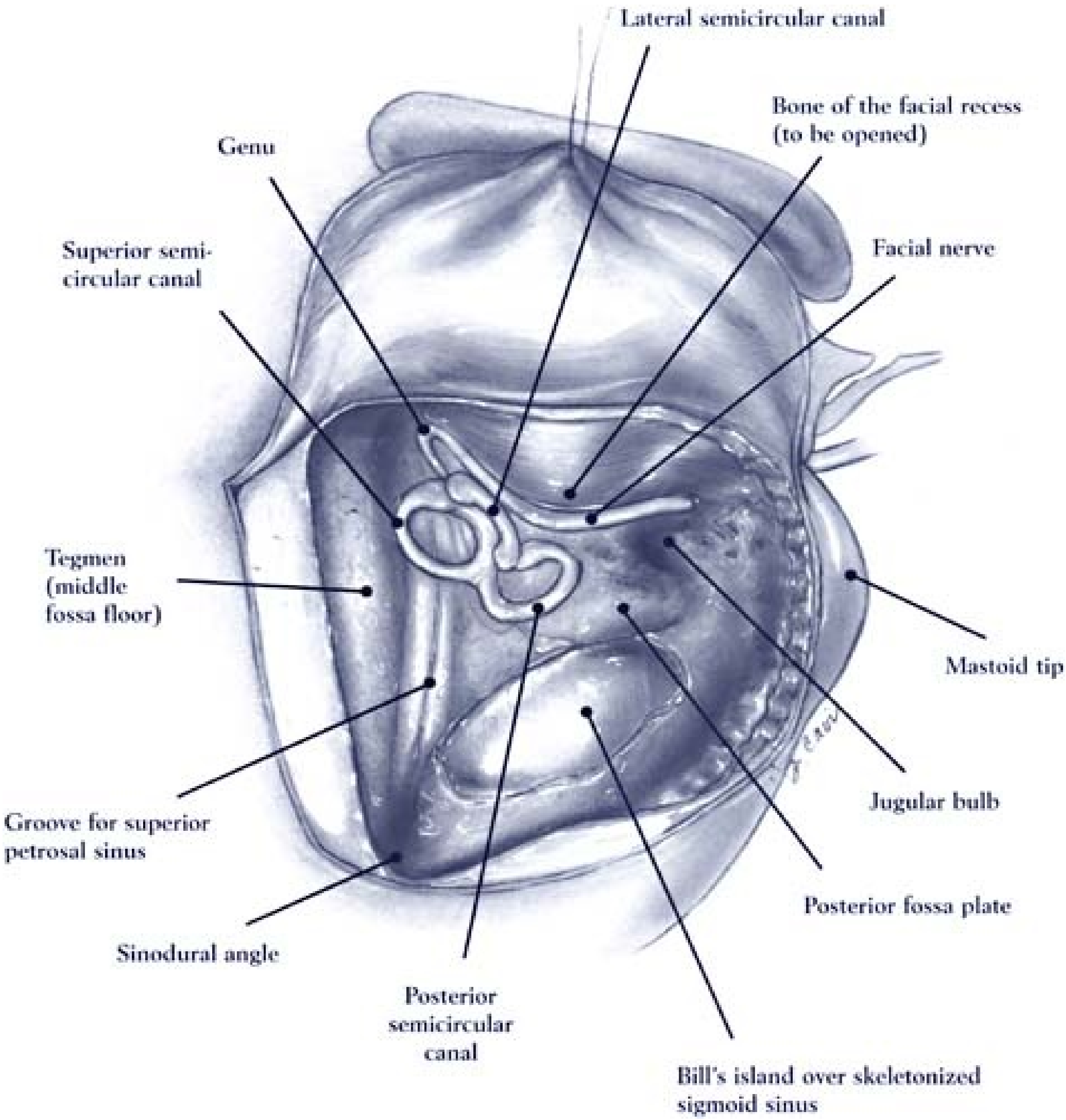


Figure 7

Mastoidectomy completed. The relationships of the sigmoid sinus with Bill's bar left on its lateral surface, superior petrosal sinus, labyrinth and facial nerve are shown

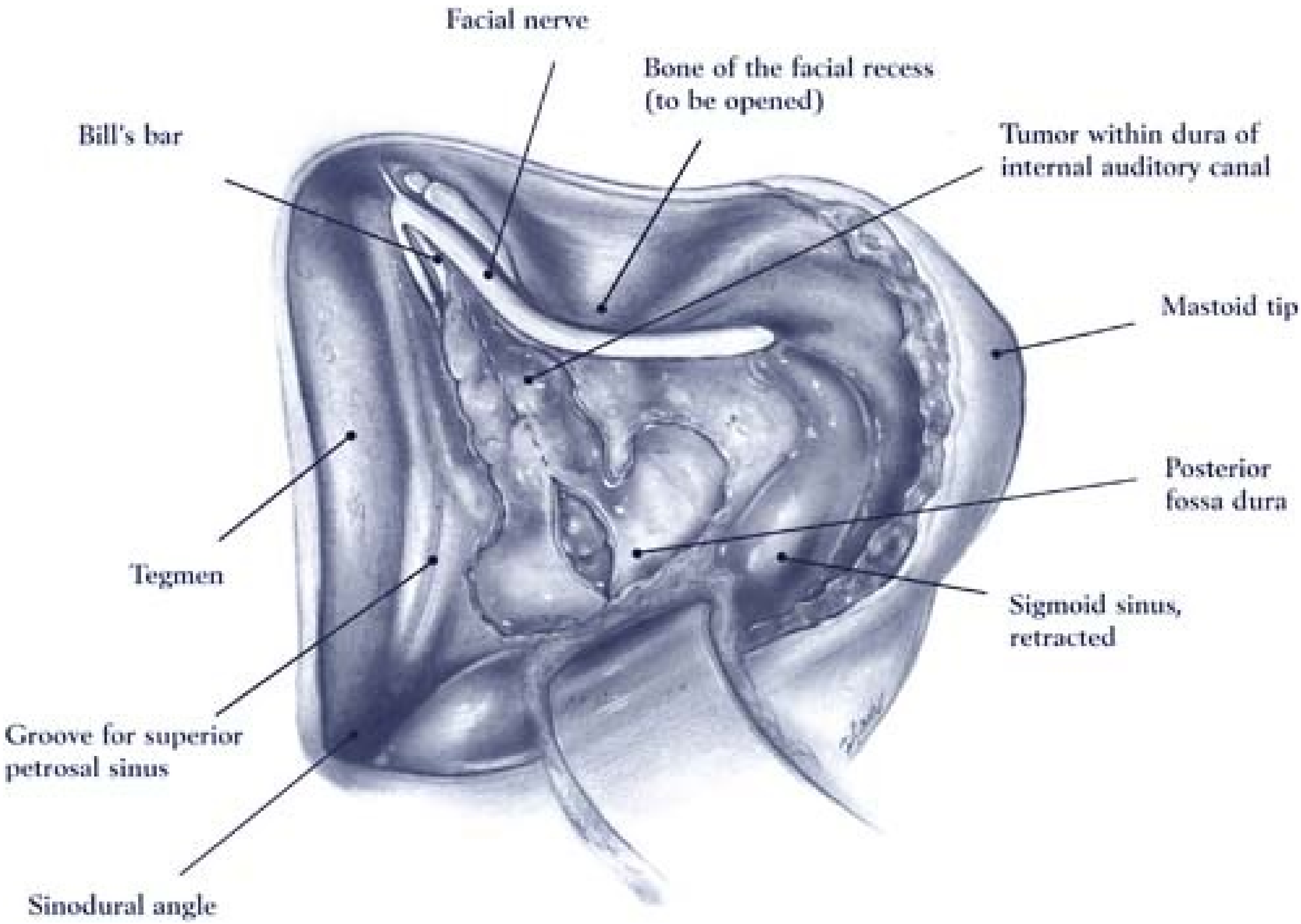


Figure 8

Vestibular schwannoma with posterior fossa extension. Bone removal over the internal auditory canal extending over the posterior fossa dura is completed. The intratemporal course of the facial nerve isuncovered. The incision is made along the dura in the long axis of the internal auditory canal

direction (Figure 8). Without adequate removal of this bone, visualization of the facial nerve is hampered at the critical site of the region of the porus internus: that segment of the facial nerve that is compressed and angulated by tumor growth in an anterior direction.

A complete mastoidectomy will facilitate visualization of all three semicircular canals. The superior canal is identified by progressively drilling bone superior to the lateral canal and by following the non-ampullated end of the posterior canal to the common crus. From this point, as the surgeon drills anteriorly to decorticate the dura of the internal auditory canal. Bleeding from the subarcuate artery often identifies the center of the arc of the superior canal. The superior canal is significantly more medially positioned than the other canals and lies closest to the internal auditory canal.

Peripheral segments of the VIIth cranial nerve are identified. The facial recess is widely opened to facilitate later obliteration of the middle ear. Removal of bone from the posterior aspect of the (vertical) mastoid segment and from the medial aspect of the (horizontal) tympanic segment of the facial nerve broadens the view of the ampullated portions of the semicircular canals.

The labyrinthectomy is performed by 'blue-lining' and uncapping the horizontal semicircular canal. The superior canal is identified by progressively drilling open 'Malcolm's cup' to expose the superior and posterior canal communications to form the common crus. Removing the overhanging bone on the posterior aspect of the posterior, second genu of the facial nerve by skeletonizing this segment broadens the view of the posterior canal ampullated end and floor of the internal auditory canal. The entire vestibular labyrinthine portion of the temporal bone is widely drilled out, with the exception of the medial aspect of the ampullated ends of the canals. A bony overhang typically develops as the vestibule is opened. The vestibule is opened and its roof is removed to allow visualization of the neuroepithelium of the macular end-organs. This expands the view of the lateral canal laterally.

Dissection is carried inferior to the internal auditory canal, opening and drilling out the retrofacial air cells to expose the dome of the jugular bulb. Dissecting bone above the bulb anteriorly typically opens the cochlear aqueduct. Working posterolateral to the cochlear aqueduct will protect the caudal cranial nerves from injury as they course through the pars nervosa of the jugular foramen.

After the vestibule is opened; the dural reflection of the internal auditory canal is skeletonized; leaving only an eggshell thickness of bone along the entire internal auditory canal dura except on its most anterior border. Bone should be completely removed medial to lateral: from the middle fossa plate extending between the tegmen of the internal auditory canal and the sinodural angle adjacent to the superior petrosal sinus. Without adequate removal of this bone, visualization of the facial nerve is hampered at the critical site of the porous region. Uncapping the dura of the internal auditory canal with medium to small diamond burrs should be performed with at least a 240° drill-out of the bony internal auditory canal in mind. A key portion of this part of the procedure is to extend the dissection of the superior lip of the internal auditory canal to the deep confluence of the middle fossa and internal auditory canal dura. This avoids developing a bony ledge that will hamper direct visualization of the facial nerve at the porus—a site where tumors are typically most adherent to the facial nerve epineurium. Bone left in this region can obscure the facial nerve and attached tumor at a critical point, where the Schwann-glial junction renders the nerve vulnerable to axial tension. Arachnoid adhesions often make separation of tumor and facial nerve most difficult at this site as well (Figure 9). This underscores the importance of widely opening the bone along the upper circumference of the porus.

The facial nerve is skeletonized along its tympanic segment to the geniculate ganglion; and along the labyrinthine segment with a diamond burr (Figure 9). This portion of the dissection mandates a refined drilling technique. The surgeon should use small diamond burrs, adequate suction-irrigation, high magnification, and gentle burring to avoid insult to the nerve. Positive identification of the nerve at the meatal foramen enables the surgeon to trace the nerve with certainty into the internal auditory canal, and separating the nerve from adjacent superior vestibular nerve and tumor at the vertical crest (Bill's bar). This step in the procedure constitutes the principal advantage of the translabyrinthine approach: the VIIth and VIIIth nerves are identified with certainty at their position within the lateral extent of the internal auditory canal where tumor compression of the nerves is minimal. The inferior vestibular nerve can be traced to the ampullated end of the posterior canal. The singular nerve branch of the inferior vestibular nerve is typically visible as well.

The transverse crest extends 2–3 mm medially from the lateral extent of the internal auditory canal (Figure 10). It can be identified as a keel of bone separating the superior and inferior compartments of the internal auditory canal. In skeletonizing the superior aspect of the internal auditory canal, the facial nerve is identified within the meatal foramen. Careful identification of the vertical crest using a small diamond burr enables greater accuracy in recognizing the course of the facial nerve in the transition from the intracanalicular to labyrinthine segments of the nerve.

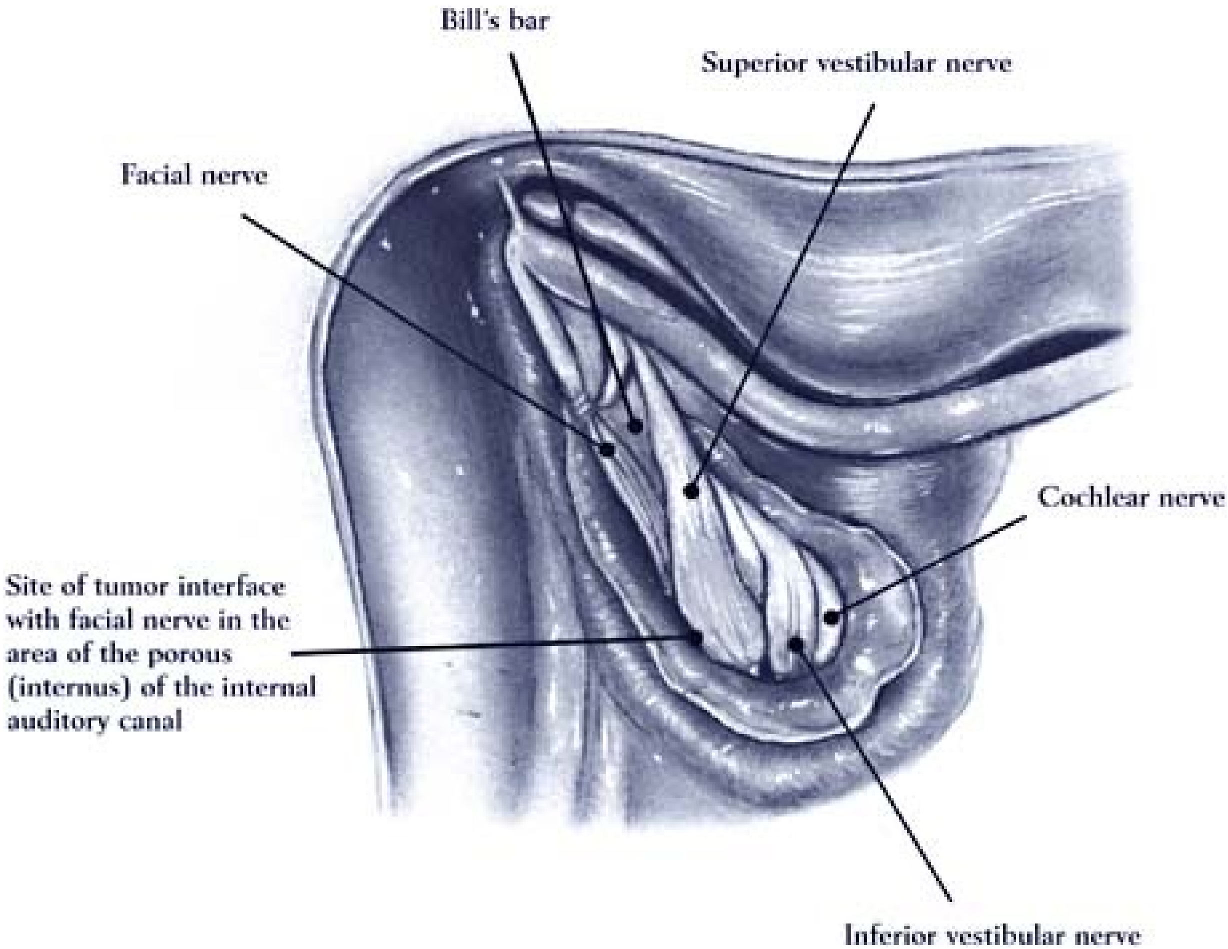


Figure 9

The dural opening is made, exposing an intracanalicular, superior vestibular nerve tumor. The facial nerve may be followed proximally into the meatal segment to help to identify its position within the internal auditory canal

INTRADURAL REMOVAL OF ACOUSTIC TUMORS

Once the bony exposure is complete, the dura overlying the length of the canal and the posterior fossa is opened until the cerebellum is exposed. If the dural flaps interfere with the surgeon's view, dural edges may be coagulated.

The VIIth cranial nerve is identified at its entrance into the temporal bone. It is then dissected from the tumor capsule to the porus acousticus. Even though the acoustic nerve is non-functional, it is left intact because it provides an

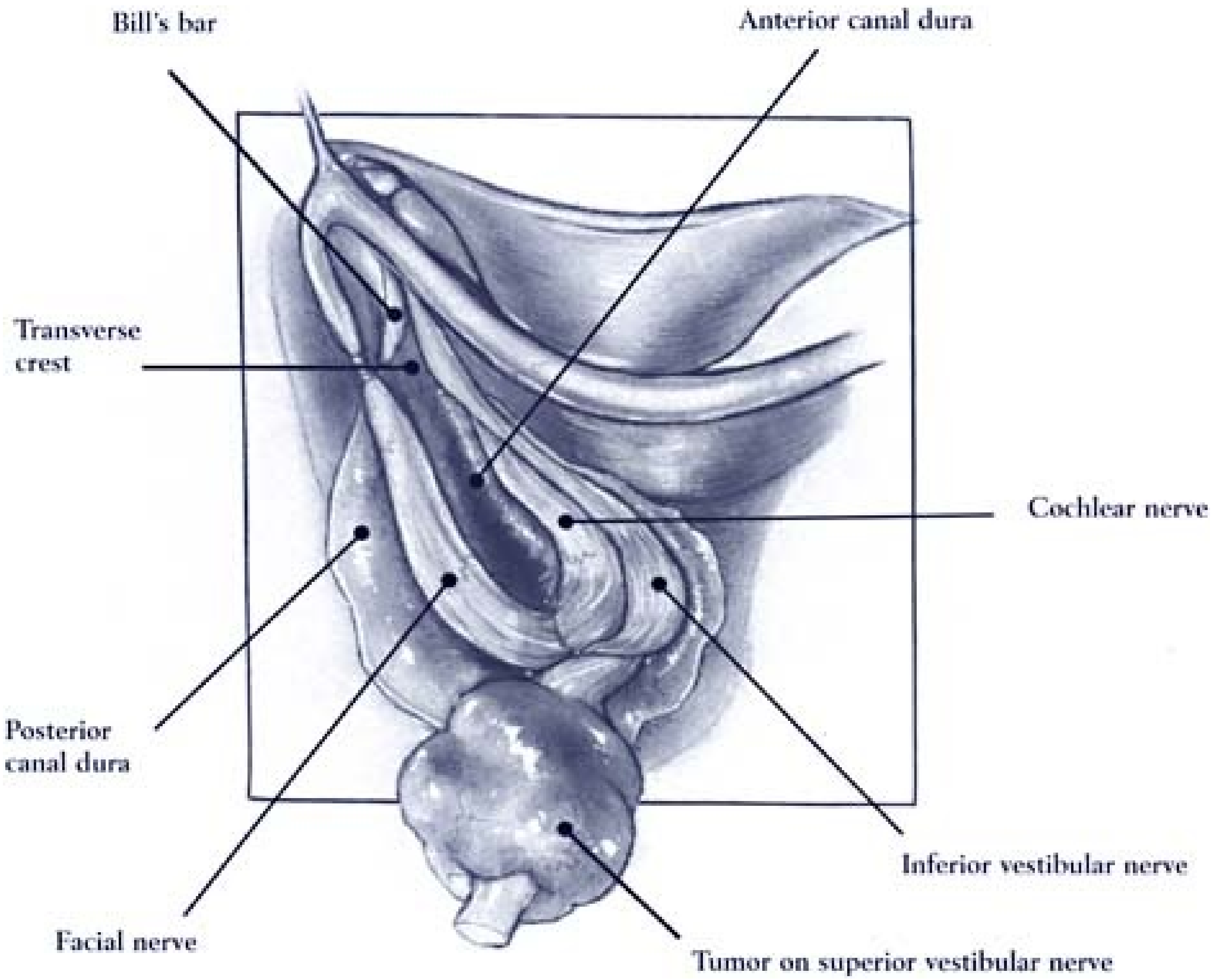


Figure 10

Removal of the acoustic tumor emanating from the superior vestibular nerve. The relationships of the remaining nerves of the vestibulocochlear bundle and facial nerve in the internal auditory canal are demonstrated

additional guide to the appropriate plane and some ballast of support for manipulation of the tumor in reducing axial tension on the VIIth nerve.

The cerebellopontine cistern is often encountered on the inferior aspect of the tumor with translabyrinthine exposure. Drainage of cerebrospinal fluid from the cistern provides greater exposure of the tumor capsule and often facilitates identification of the anterior inferior cerebellar artery and its separation from the tumor capsule.

The most difficult part of the translabyrinthine approach is often identification and removal of the anterior inferior cerebellar artery from the tumor capsule. A vascular injury with the bony exposure provided by the translabyrinthine approach can be disastrous. As long as the surgeon remembers not to cut any part of the capsule that has not been completely visualized, the artery should be safe and is dissected from the capsule when seen.

The reader is referred to the discussion of techniques of acoustic tumor dissection within the posterior fossa (Chapter 14) for further details.

Small tumors can be removed as a single mass (Figures 9 and 10). Tumors sized less than 1 cm do not require internal debulking. Larger tumors are best managed by internal debulking and gradual manipulation of the capsule from the lateral to the medial direction, slowly removing tumor and capsule under direct vision to reduce traction applied to the VIIth nerve. Intracapsular debulking to the point of collapse of the capsule allows the tumor capsule to be sequentially delivered into view and removed.

There have been long-standing debates about whether large tumors are best removed by the translabyrinthine or suboccipital route. This is really a matter of the surgeon’s choice. Even very large tumors can be removed by the translabyrinthine route as long as the principles of internal debulking, gradual delivery of the capsule, avoidance of compression and axial traction, and close attention to vascular involvement and hemostasis are observed. No part of the tumor can be delivered forcibly until it has been demonstrated unequivocally that the VIIth nerve and vessels are completely freed from any remaining tumor.

After tumor removal, hemostasis is obtained. The dura is reapproximated and sutured as best possible to reduce the size of the dural defect; however, this is often not possible.

An abdominal free fat graft is harvested and cut into longitudinal strips. The incus is removed and portions of the fat are used to fill the middle ear space, after a free muscle graft is used to plug the eustachian tube opening into the protympanum. Larger strips of fat are then layered into the mastoid defect, abutting the dural closure. Care is taken not to overpack the cavity with great force so as to create compression toward the cerebellopontine angle against the brain stem. Just enough fat is introduced into the cavity to slightly overfill it, so that, when the soft tissue is closed over the cavity there are no large areas of dead space. The wound is closed in layered fashion, first reapproximating the musculo-periosteal layer, then the scalp layer.

COMPLICATIONS

Thorough knowledge of the anatomy of the entire course of the facial nerve is necessary to successfully take advantage of this surgical approach. The translabyrinthine approach allows positive identification of the facial nerve using landmarks which should help to prevent inadvertent injury. The addition of intraoperative electrophysiologic facial nerve monitoring also helps in the positive identification of the facial nerve during tumor dissection.

Other potential complications from the translabyrinthine approach include cerebrospinal fluid leak, meningitis, postoperative hemorrhage, and wound infection. These are discussed in detail in Chapter 16.

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12
Transcochlear extension of the translabyrinthine approach

John K.Niparko and Lawrence R.Lustig

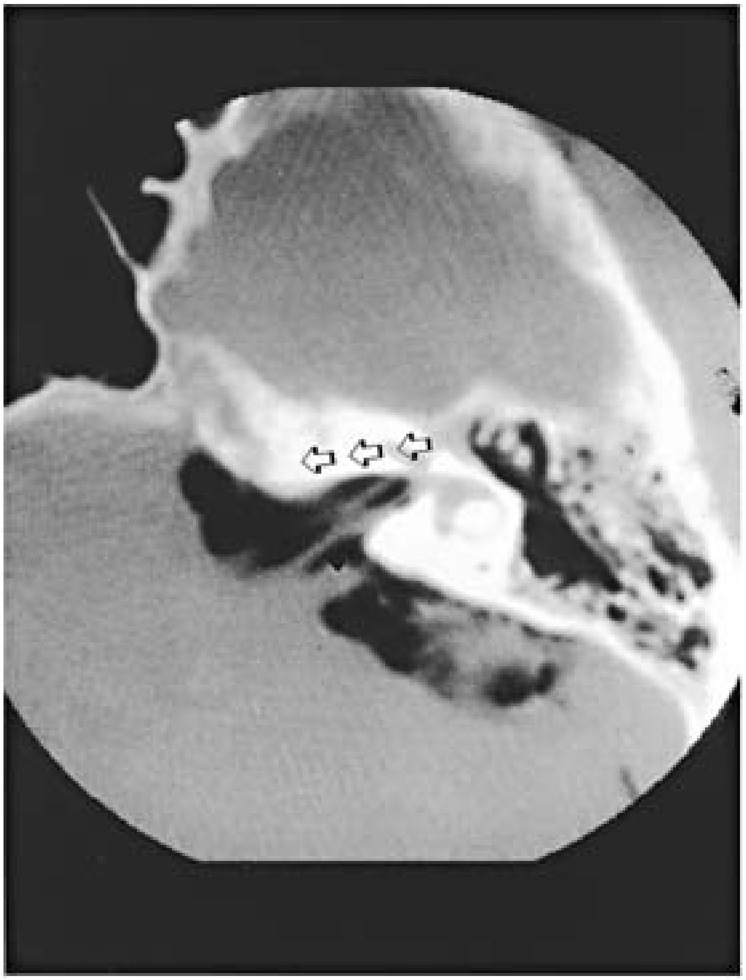

Figure 1

Axial air-contrast CT demonstrating the surgical trajectory of the translabyrinthine-transcochlear approach to the petrous apex and petroclival junction

INDICATIONS

Access to lesions occupying the petrous apex and extending medially toward the clivus often require a more lateral trajectory than that afforded by posterior, suboccipital exposure. Anterior approaches to lesions medial to the internal auditory canal often place the surgeon at a considerable distance from the surgical bed, and do not allow for adequate control of the internal carotid artery. Transtemporal approaches to the petrous apex and clivus are, however, limited by the labyrinth and facial nerve. The transcochlear approach offers access to lesions that lie anterior to the caudal cranial nerves and brain stem, *i.e.* those lesions situated medial to the internal auditory canal within the petrous apex. Transcochlear extension of the translabyrinthine approach can afford access to the prepontine space and petroclival junction (Figure 1).

The *infra*cochlear approach exposes an oval of bony opening into the petrous apex, bounded by the basal turn of the cochlea above, and the jugular bulb and genu of the internal carotid artery below. Whereas the infracochlear approach effectively addresses only cystic lesions that can be drained and subsequently stented through limited exposure, the

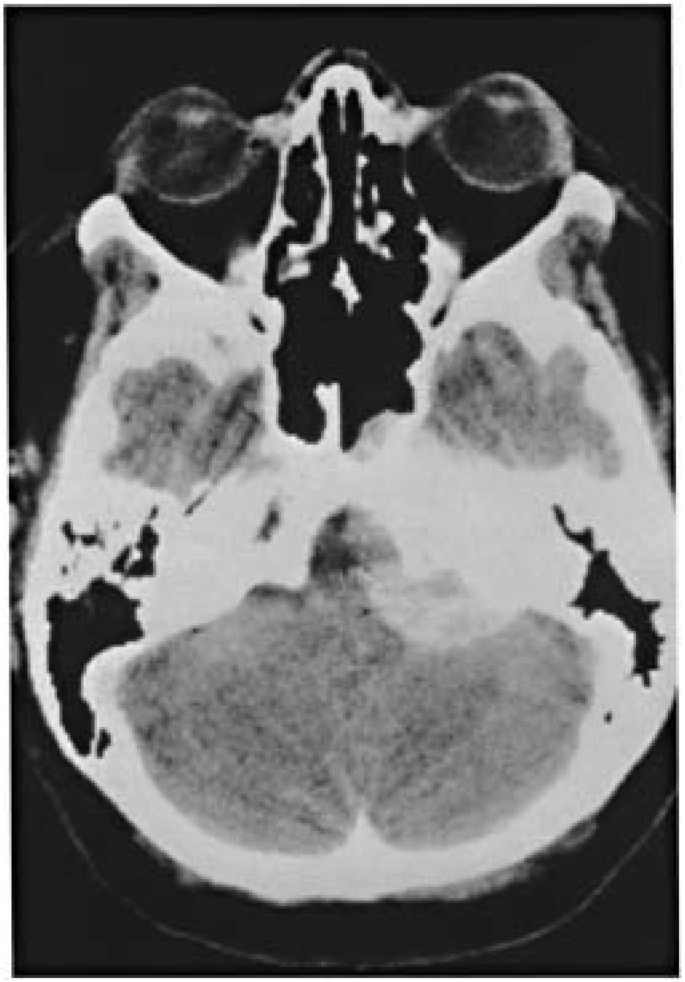

Figure 2

Axial CT of a meningioma based along the petrous ridge, anterior and posterior to the internal auditory canal. This patient had no serviceable hearing. The tumor was removed using a combined translabyrinthine-transcochlear approach

transcochlear approach exposes a substantially larger region of the petrous apex. Medial extension of the transcochlear approach exposes the petrous apex and prepontine space between the superior petrosal sinus and trigeminal ganglion above, and the inferior petrosal sinus below (Figures 2–4).

PATIENT EVALUATION

Radiologic imaging by MRI and CT should provide advance indication to the surgeon of the potential need to extend the area of dissection toward the petrous apex, anterior to the internal auditory canal. Preoperative imaging will also provide information regarding the relationship of the pathology to the petrous portion of the carotid artery. If the tumor to be removed is in intimate relationship to the carotid artery, provisions must be made to evaluate the collateral arterial circulation from the contralateral carotid artery and posterior vertebrobasilar circulation through the circle of Willis, in the case that the carotid artery is sacrificed. Angiography with balloon occlusion testing of the carotid artery is performed. Some centers will use adjunctive diagnostic testing, such as postocclusion xenon CT scanning to assess cerebral perfusion or SPECT functional testing. Preoperative angiography with embolization may be needed to reduce the vascularity of the tumor.

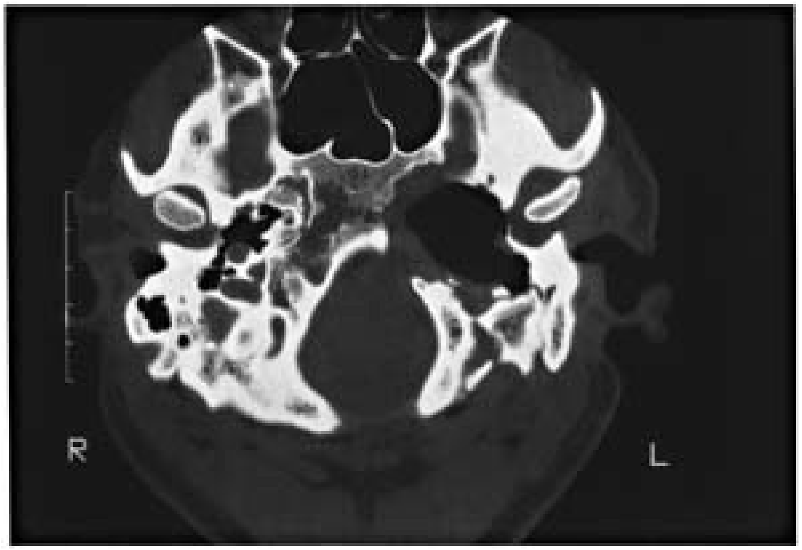

Figure 3

Axial CT scan demonstrating the surgical defect after removal of the cholesterol granuloma via the translabyrinthine-transcochlear approach. Note the access to the clival region in the medial extent of the dissection.

Due to the necessity to traverse through the cochlea, the loss of hearing must be included in the preoperative counseling. Often, an extensive lesion may have already destroyed the hearing so that this will not be an issue. Nevertheless, audiometry is performed to assess hearing in the contralateral ear to facilitate aural rehabilitation after surgery. Strict preservation of the blood supply to the facial nerve is essential to help to maintain normal facial function.

ANATOMICAL CONSIDERATIONS

Access afforded by the transcochlear extension of the translabyrinthine approach includes areas adjacent to the internal auditory canal and anterior cerebellopontine angle. Thorough knowledge of the course of the facial nerve, starting from the canalicular portion to the mastoid portion, is exercised when isolating its course through the Fallopian canal and mobilizing the nerve posteriorly after freeing the geniculate from its attachment to the greater superficial petrosal nerve. Landmarks to use include the identification of the meatal segment of the facial nerve anterior to Bill’s bar during the translabyrinthine portion of the procedure, as discussed in Chapter 11.

The geniculate ganglion may be identified from the underside in the transmastoid approach, using the cochleariform process. The cochleariform process is situated inferolateral to the geniculate ganglion. The ‘cog’, the vertical crest of bone located in the epitympanum, emanating from the tegmen, anterior to the head of the malleus, is an additional landmark. The cog lies just inferior to the geniculate ganglion.

The tympanic segment of the facial nerve may be followed from above the cochleariform process to above the pyramidal eminence, coursing superior to the oval window. The transition of the tympanic segment of the facial nerve to the mastoid segment of the facial nerve at the second genu is located inferior to the horizontal semicircular canal. The facial nerve’s exit out of the stylomastoid foramen may be found from within the temporal bone in the mastoid, if the digastric ridge is followed forward.

The anterior limit of the transcochlear dissection is the petrous carotid artery (Figure 5). The superior limit of the dissection is the superior petrosal sinus, and the inferior limit of the dissection is the inferior petrosal sinus leading toward the jugular bulb.

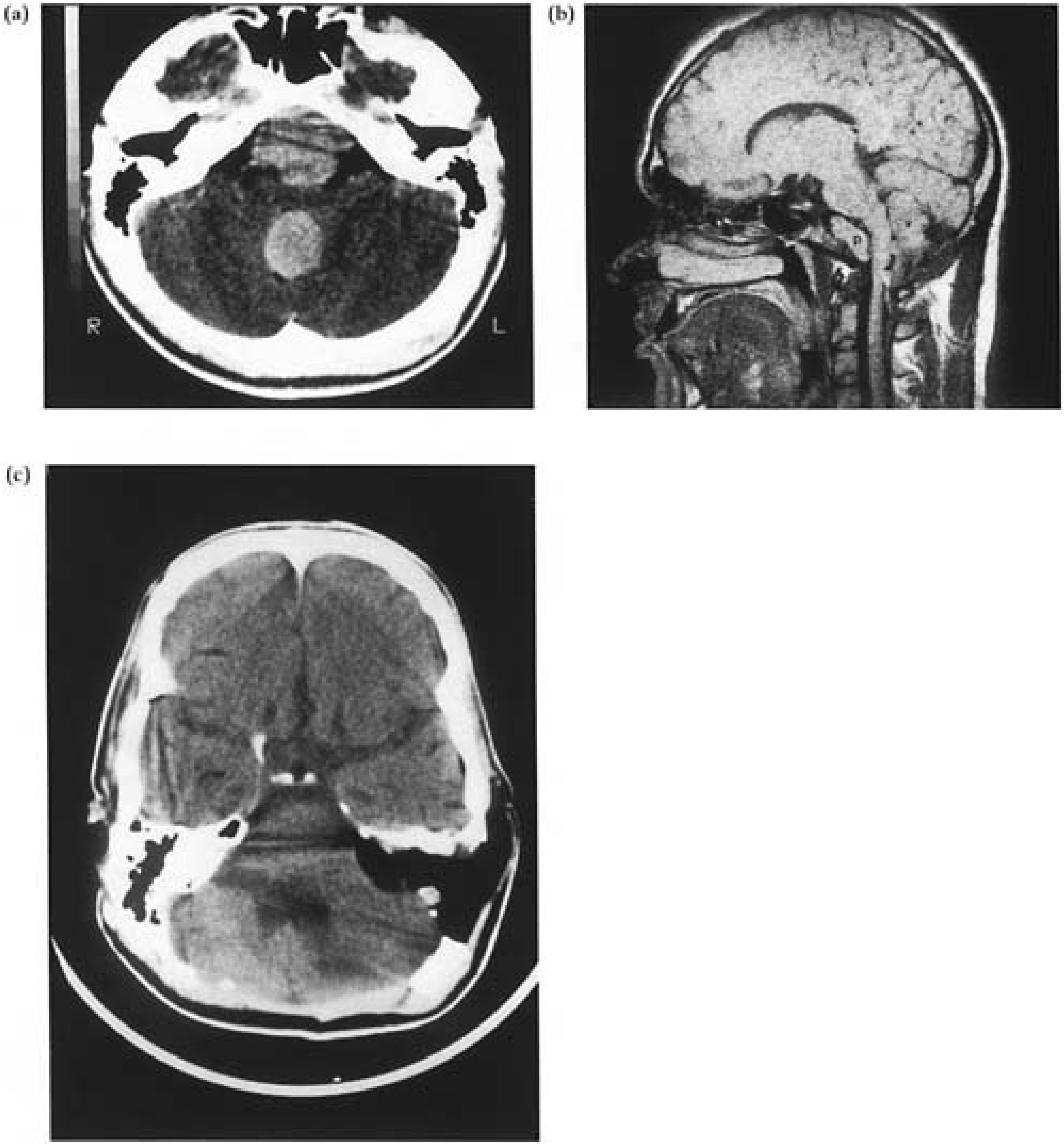

Figure 4

Scans depicting metastatic nevi associated with blue nevus syndrome. (a) Enhanced axial CT demonstrating lesions involving the prepontine space and fourth ventricle; (b) T1 sagittal MRI scan demonstrating prepontine lesion (p) and tumor within the ventricle (v); (c) axial CT scan obtained after translabyrinthine-transcochlear resection of the prepontine tumor and posterior mid-line removal of the tumor in the ventricle, demonstrating decompression of the pontomedullary brain stem and the surgical defect in the temporal bone

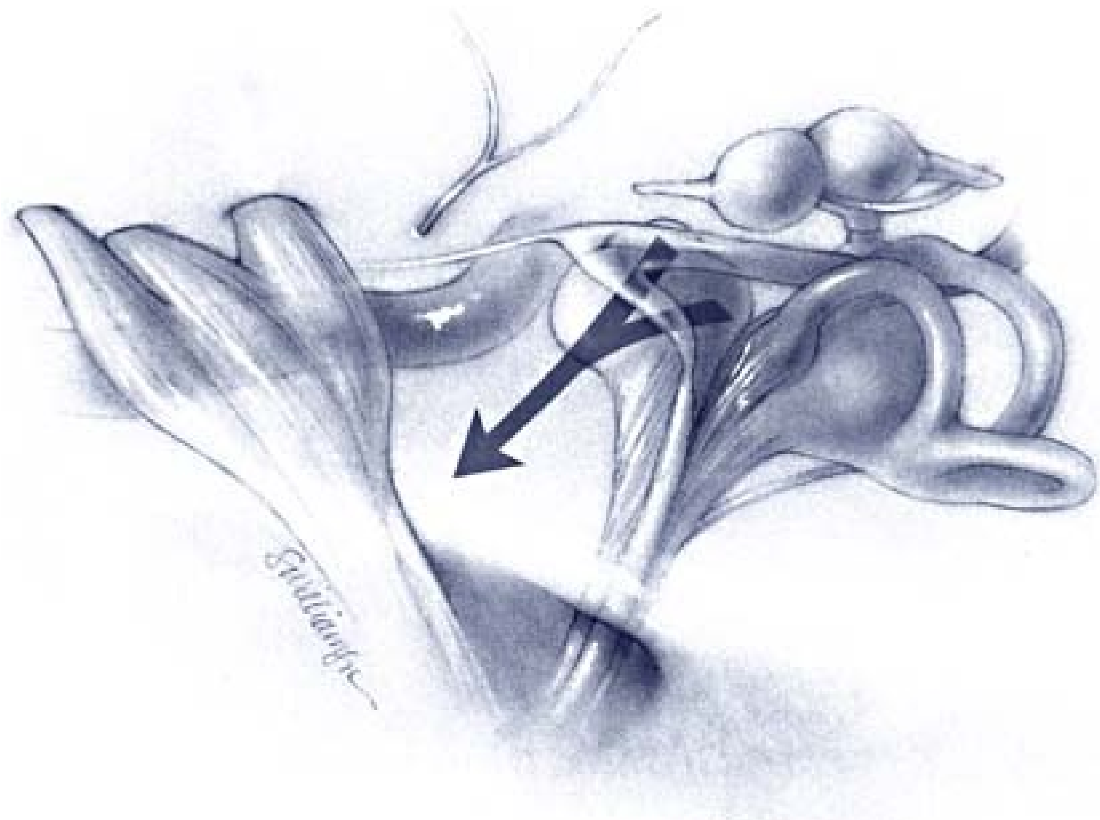

Figure 5

An overview schematic depicting the path of dissection of the transcochlear extension of the translabyrithine approach within the right temporal bone

PROCEDURE

A wide mastoidectomy is carried out, beginning the dissection at the root of the zygomatic arch, extending the cortical cuts to the sinodural angle and mastoid tip, decompressing the sigmoid sinus and retrosigmoid areas, while preserving the bony external auditory canal wall. The bony labyrinth is then drilled out to expose the internal auditory canal, as described in the translabyrinthine approach in Chapter 11.

The facial nerve is completely skeletonized within the temporal bone from the labyrinthine segment of the Fallopian canal, to the stylomastoid foramen distally, opening an extended facial recess (posterior tympanotomy) in the process. The ossicular chain is disarticulated and removed to facilitate visualization of the labyrinth through the middle ear.

The geniculate ganglion and greater superficial petrosal nerve are identified superomedial to the tensor tympani attachment. The greater superficial petrosal nerve is transected at its origin from the geniculate ganglion. The facial nerve can now be mobilized, translocated, and positioned posteriorly to enable exposure of the petrous apex (Figure 5).

The cochlea is drilled out between the jugular bulb and inferior petrosal sinus below and the genu of the internal carotid artery anteriorly. Bone removal inferiorly extends to the inferior petrosal sinus and jugular bulb. Superiorly the superior petrosal sinus is skeletonized to view the undersurface of the trigeminal gangion within Meckel's cave.

The dissection is extended into the anteromedial aspect of the petrous apex, and may be extended to the clivus (Figure 5). This dissection is bounded by the bony eustachian tube and internal carotid artery laterally and the dura medially. Lesions localized to the petrous apex can be removed directly through this exposure, with the facial nerve often lying on the posterior aspect of the tumor.

Intradural tumors are removed with techniques previously described elsewhere in this text (e.g. Chapters 11 and 13). The dura is opened on the surface of the tumor. Intracapsular debulking to achieve a slack capsule facilitates dissection from adjacent nerves, vessels and the underlying brain stem. The location of the anterior inferior cerebellar artery and the basilar artery should be determined. It is typically situated on the superior aspect of the tumor. The vertebral artery is most often positioned in the posterior mid-line, inferior to the tumor.

Following tumor removal, the facial nerve is reflected back to its anatomic position. The eustachian tube opening and middle ear are packed with pieces of fascia. A sheet of temporalis fascia is placed over the dural defect and an abdominal free fat graft is packed within the mastoid defect. The fat pack is further stabilized with temporalis muscle sutured over the mastoid defect. The wound is closed in layers.

COMPLICATIONS

One complication of special mention is temporary facial nerve paresis from facial nerve translocation. The best effort is made to preserve the blood supply to the facial nerve, especially that originating from the stylomastoid foramen and from the internal auditory canal from the anterior inferior cerebellar artery. This is accomplished by maintaining a cuff of (fascial) soft tissue surrounding the nerve trunk at the stylomastoid foramen. Dissection and retraction of the nerve should be performed with minimal longitudinal traction applied to the nerve. Facial weakness in the immediate postoperative period may be encountered, as in other procedures requiring facial nerve translocation. Institution of eye care for corneal protection and prevention of long-term sequelae must be diligently initiated. These measures include application of topical moisturizing drops, lubricating ointment, and a moisture chamber. Improvement in facial nerve function is expected where the integrity of the facial nerve is maintained. Systemic steroids have been used at our institution to address neural edema from surgical nerve manipulation.

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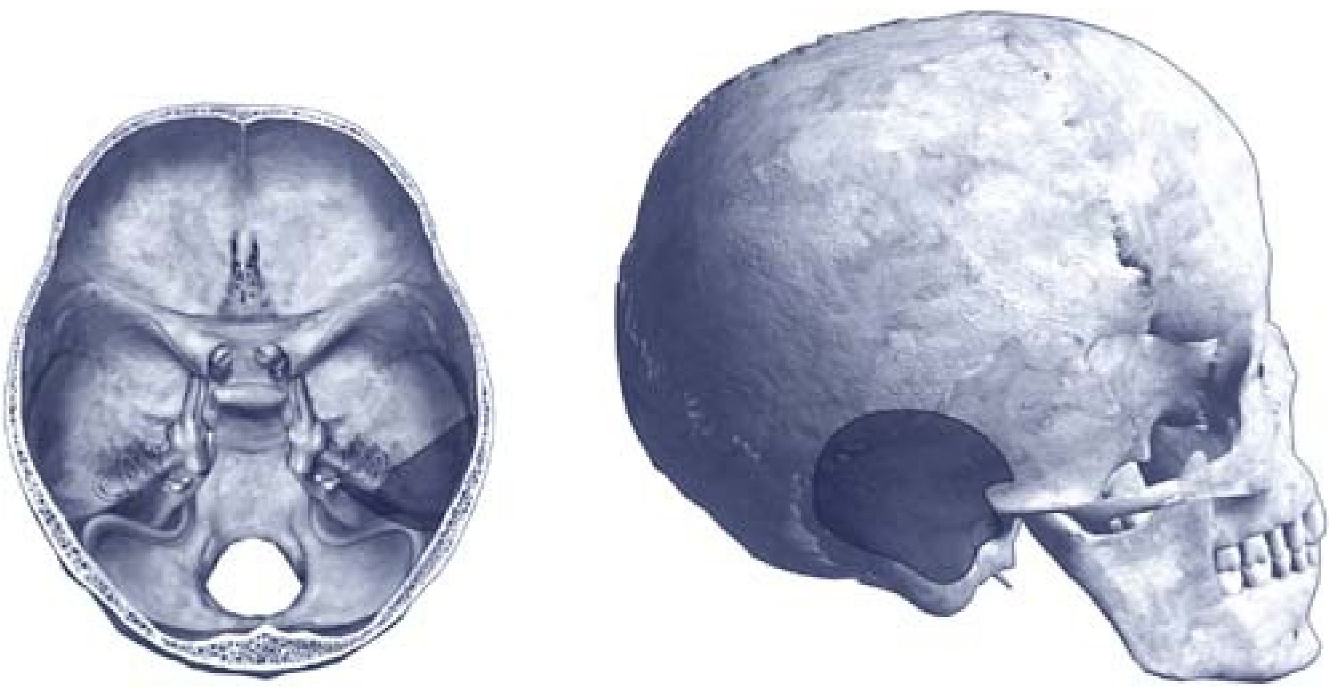
13
Retrolabyrinthine approach

John K.Niparko



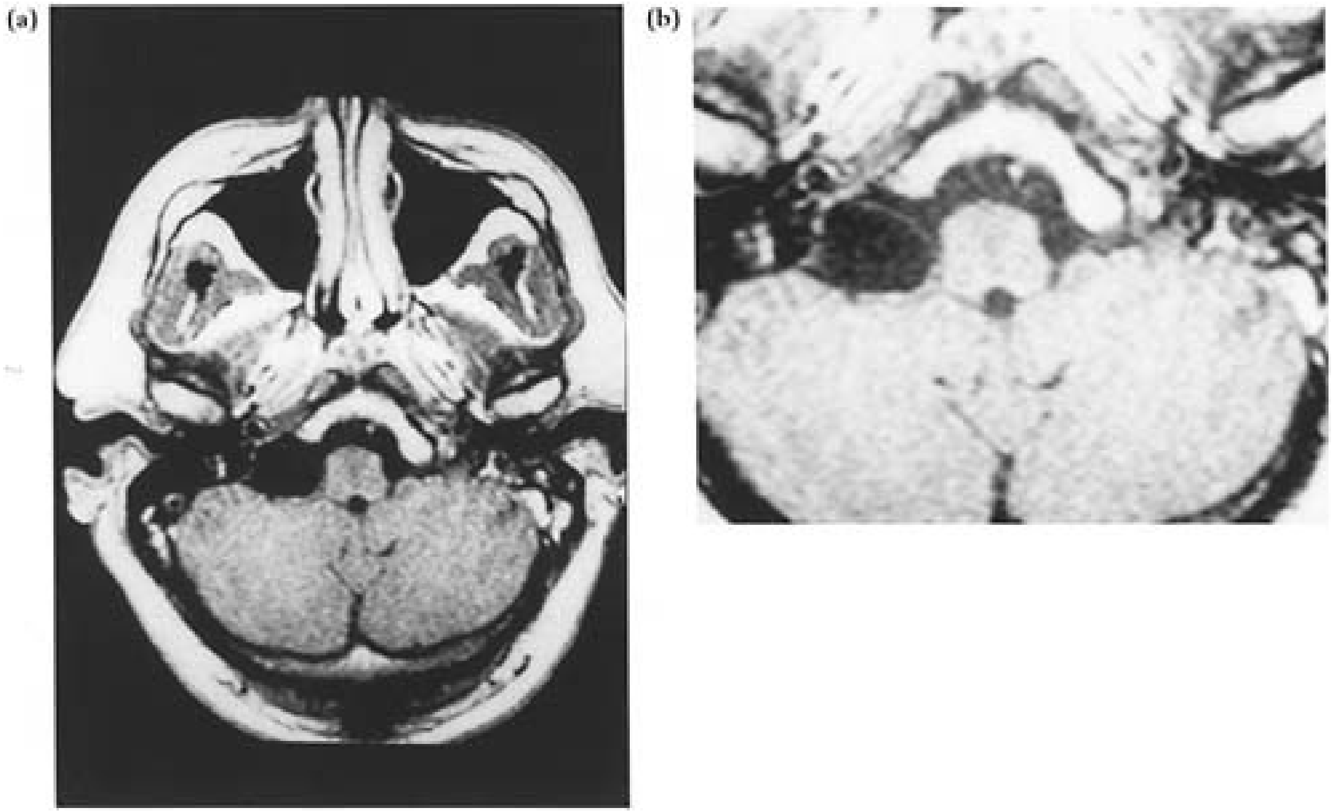


Figure 1

(a) T1-weighted axial MRI demonstrating an arachnoid cyst of the right cerebellopontine angle in a patient with intractable vertigo and right-sided vestibular hypofunction demonstrated on ENG testing; (b) high-power view of the same lesion

INDICATIONS

The retrolabyrinthine approach to the posterior fossa provides direct access to the cerebellopontine cistern and the intracranial segments of the VIIth and VIIIth cranial nerves within the posterior fossa. Prior descriptions suggest that this approach can also be extended anteriorly to access the trigeminal ganglion to address disorders such as tic doloreaux. Retrolabyrinthine procedures are indicated for neurovascular abnormalities in which resection and risk of associated bleeding are minimal—principally vestibular nerve section for intractable vertigo and vascular decompression procedures. Cholesteatomas of the skull base and rare cystic lesions of the cerebellopontine angle may be addressed with the retrolabyrinthine approach as well (Figures 1 and 2).

PATIENT EVALUATION

The retrolabyrinthine approach is characterized by relatively narrow exposure of the posterior fossa midway between the root entry zone and porus acousticus of the internal auditory canal (Figures 3 and 4). However, such exposure produces a correspondingly low morbidity, provided that the surgical team is well aware of the anatomic constraints. Thus, preoperative CT imaging should confirm surgical accessibility through the perilabyrinthine and retrofacial air cells of the temporal bone. A small, contracted mastoid can severely hamper such access. MRI and MRA imaging can provide diagnostic information regarding the distribution of the basilar and anterior inferior cerebellar arteries, and help to determine if vascular compression underlies asymmetric VII or VIIIth nerve

Figure 2

Right-sided cholesteatoma with intracranial involvement extending from the mastoid into the upper cervical region removed via the extended retrolabyrinthine approach

function. MRI imaging may also provide information on anomalies of the trigeminal ganglion.

The retrolabyrinthine approach is used most often to accomplish sectioning of the vestibular nerve. This approach is one of several available that are used to section the vestibular nerve for the control of disabling vertigo experienced by patients with Meniere's disease or uncompensated vestibular neuronitis. The nerve section procedure should be considered only in those patients who fail medical management. The middle fossa and suboccipital approaches (Chapters 9 and 14) provide alternative surgical exposures for vestibular nerve section. All approaches permit selective denervation of the vestibular portion of the offending inner ear, while sparing the cochlear portion of the VIIIth nerve. The retrolabyrinthine approach is preferred as the least invasive of these three approaches, requiring a relatively small dural incision and minimal retraction of central nervous system structures.

Candidates for any surgical approach to managing vertigo should undergo the proper audiologic (audiogram, electrocochleography), vestibular (clinical assessment of compensation, electronystagography), and radiographic imaging (high-resolution CT scanning of the temporal bones, MRI with gadolinium scanning of the posterior fossa). More conservative options involving medical and rehabilitative management should be explored prior to embarking on an ablative approach to intractable vertigo.

Retrolabyrinthine approaches to abnormalities involving cranial nerves VII and VIII mandate a thorough evaluation of vascularity provided by the anterior inferior cerebellar artery. Vascular impingement of the VIIth and VIIIth cranial nerves may be diagnosed with MRA in cases of overt vessel impingement. However, clinical suspicion of vascular compression is based most often on symptomatology and test results (audiometric or vestibular) that indicate asymmetric neural function.

ANATOMICAL CONSIDERATIONS

Patterns of pneumatization are key to effective retrolabyrinthine exposure of the posterior fossa. The posteromedial cell tracts are the principal tracts that extend

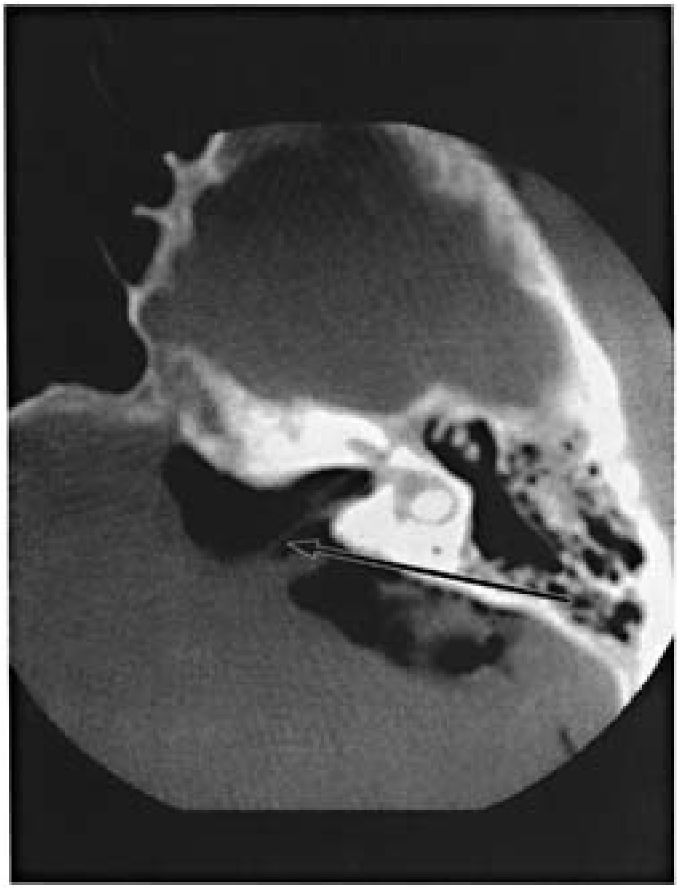


Figure 3

Axial air-contrast CT demonstrating the surgical trajectory of the retrolabyrintine approach to the cerebrospinal fluid VII-VIII complex within the cerebellopontine angle

along the posterior surface of the petrous bone, bounded by the endolymphatic duct and sac and the bony wall of the posterior cranial fossa. Although this labyrinth-sparing, transmastoid approach to the posterior fossa is designated as retrolabyrinthine, in fact, much of the access is gained through retrofacial, infralabyrinthine exposure. Thus, preoperative CT scans of the temporal bone can help to predict whether there is adequate development of the perilabyrithine and retrofacial air cell tracts to enable retrolabyrithine exposure (Figures 3 and 4). Such exposure can address the VII and VIIIth nerves in their intracranial course, bearing in mind that these nerves pursue a cephalad orientation from the root entry zone medially, to enter the porous of the internal auditory canal laterally

Exposure to permit adequate visualization and surgical dissection usually requires retraction of the sigmoid sinus and skeletonization of the jugular bulb. Removal of at least 1.5 cm of retrosigmoid bone, from the transverse sinus above, to the digastric ridge below, facilitates adequate retraction.

PROCEDURE

Following administration of general anesthesia, with the patient in the supine position, subdermal electrodes are placed for monitoring facial electromyographic activity Earphone inserts can be used to generate far-field auditory brain stem responses for monitoring the status of the auditory periphery, and near-field VIIIth nerve potentials to facilitate identification of the transition between the auditory and vestibular portions of the VIIIth nerve.

Figure 4

Temporal bone CT obtained after a retrolabyrinthine approach to the cerebellopontine angle. Arrows depict the exposure obtained with retrolabyrinthine dissection. Inspection of the contralateral side reveals retrolabyrinthine air cell tracts that facilitate this exposure

The surgical field should provide access to the entire mastoid and retrosigmoid area. This facilitates a complete mastoidectomy and decompression of the sigmoid sinus and the posterior fossa dura that lies both medial and posterior to the sigmoid sinus. This requires that a wide area of the postauricular scalp is shaved, surgically prepared, and then draped.

A curvilinear incision, extending from above the temporal line just above the attachment of the auricle, is directed posteriorly to the retrosigmoid area (Figure 5). The incision is extended inferiorly posterior to the mastoid tip, remaining within the confines of hair-bearing skin. An anteriorly based scalp flap is elevated lateral to the temporalis fascia superiorly incorporating the mastoid periosteum inferiorly. Care is taken not to injure the skin of the external ear canal, as this can lead to cerebrospinal fluid otorrhea and contamination of the cerebrospinal fluid space. A 3×3 cm piece of temporalis fascia is harvested for coverage of the dural defect at closure.

A complete mastoidectomy is performed (Figure 6). The mastoidectomy is extended to expose the sigmoid sinus and approximately 2 cm of dura posterior to the sigmoid sinus. The entire sigmoid sinus is retracted posteriorly by a self-retaining retractor to expose the posterior fossa dura from the sinodural angle superiorly, to the retrofacial air cells inferiorly Retrofacial air cells *must* be removed in the proximity of the jugular bulb to ensure adequate exposure of the cerebellopontine angle cistern, and the intracranial course of cranial nerves VII and VIII.

Several measures are used to facilitate exposure of the cerebellopontine angle prior to dural entry. When the mastoid drilling commences, mannitol (50 g intravenous dose) is administered intravenously to induce diuresis. Hyperventilation is performed to reduce the end-tidal *p*CO2 to approximately 25 mmHg. Intravenous high-dose steroid-dosing postoperatively is routinely used. These techniques reduce intracranial pressure and facilitate retraction of the cerebellum without applying excessive brain stem traction.

A posterior fossa dural incision is made parallel to the sigmoid sinus, approximately 1 cm anteromedial to the wall of the sigmoid sinus (Figure 7). The dural flap is held anteriorly with a retention suture and the dural incision is

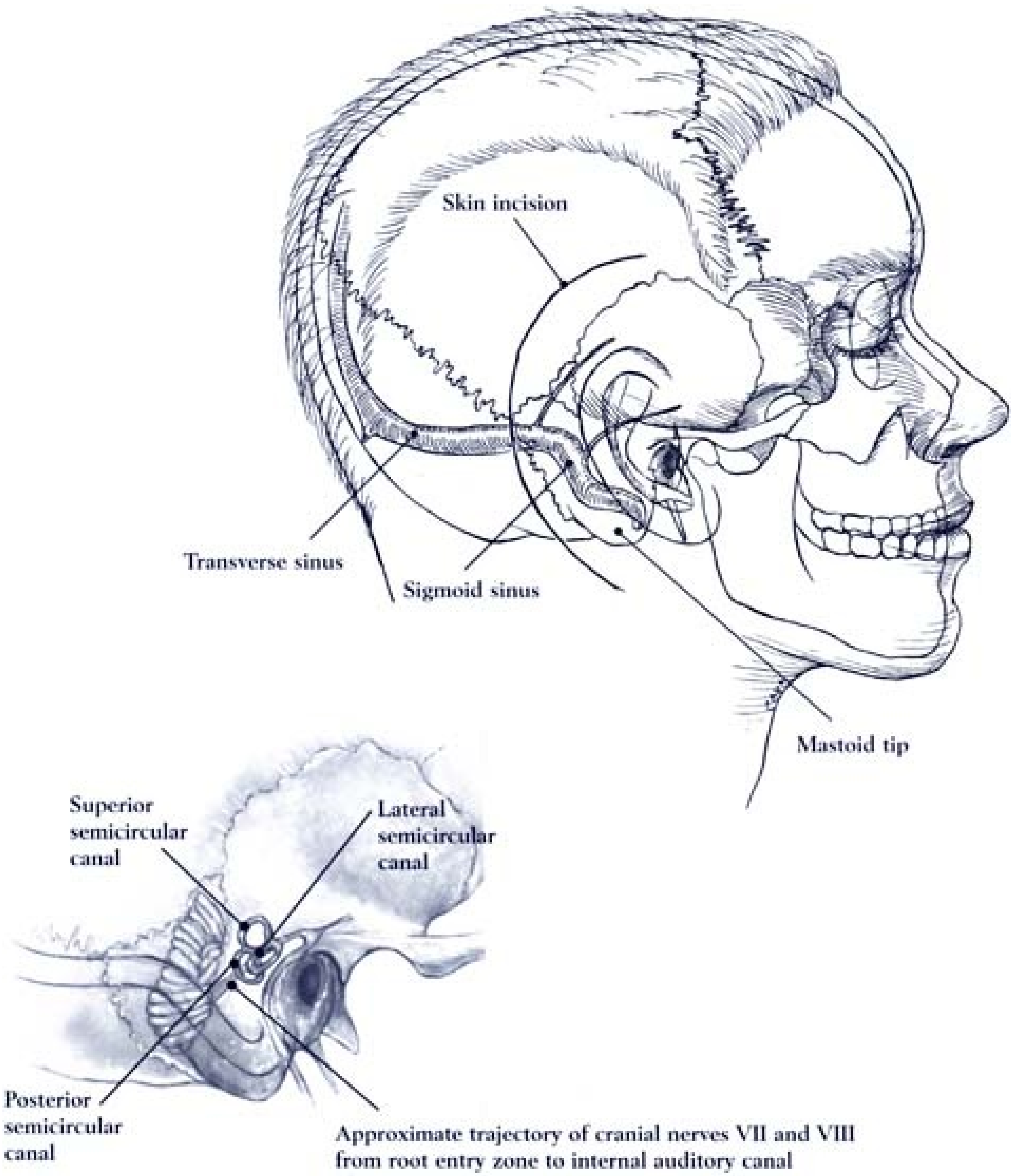


Figure 5

Incision used for the retrolabyrinthine approach. The incision extends from just above the superior temporal line to the retrosigmoid area. The inset shows the relationship between the labyrinth, facial nerve, and sigmoid sinus within the mastoid cavity

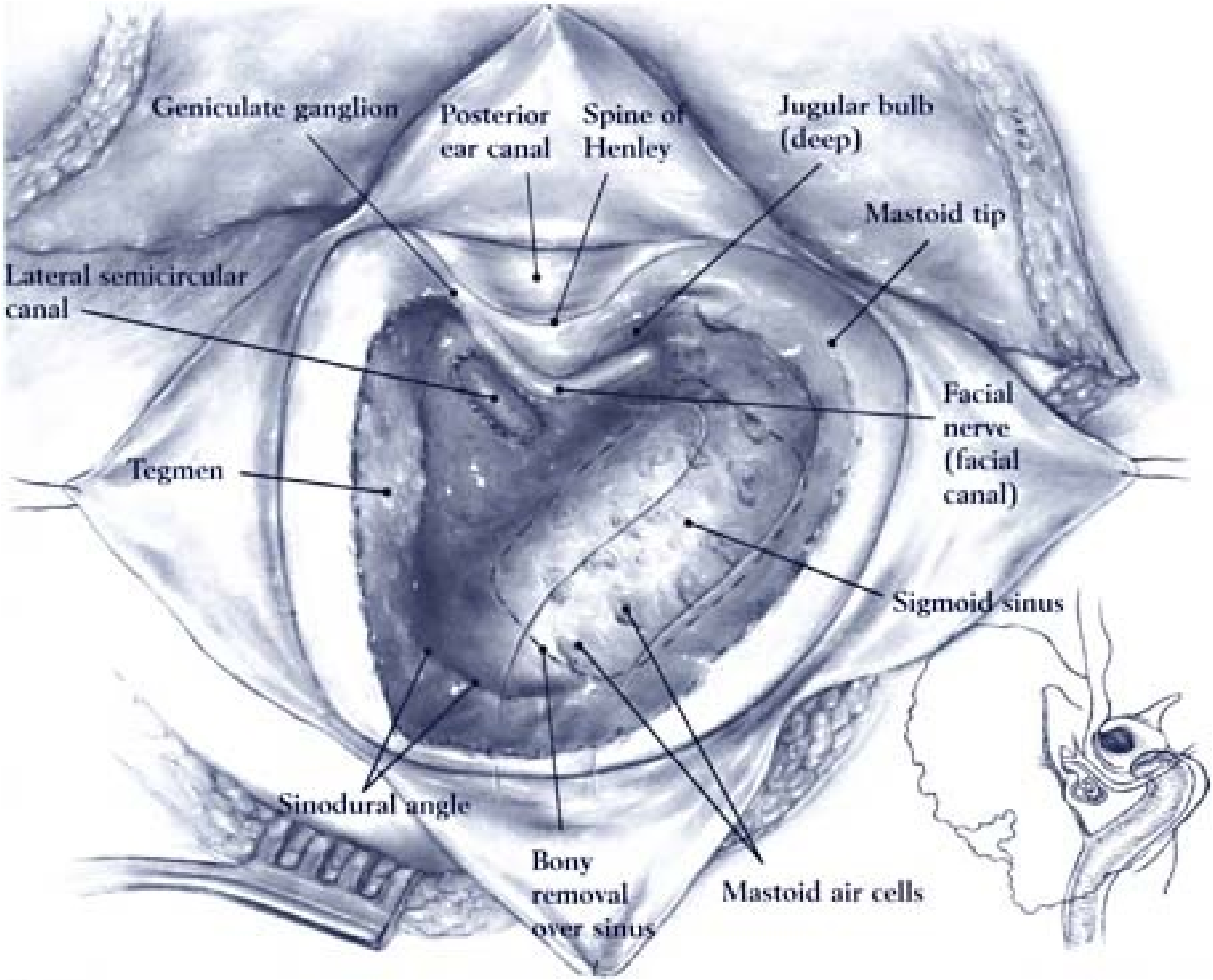


Figure 6

Complete mastoidectomy performed. Bone is removed to skeletonize the middle fossa dura, sigmoid sinus, posterior bony external auditory canal wall, and posterior fossa dura. Note the relationship of the facial nerve inferior to the lateral semicircular canal

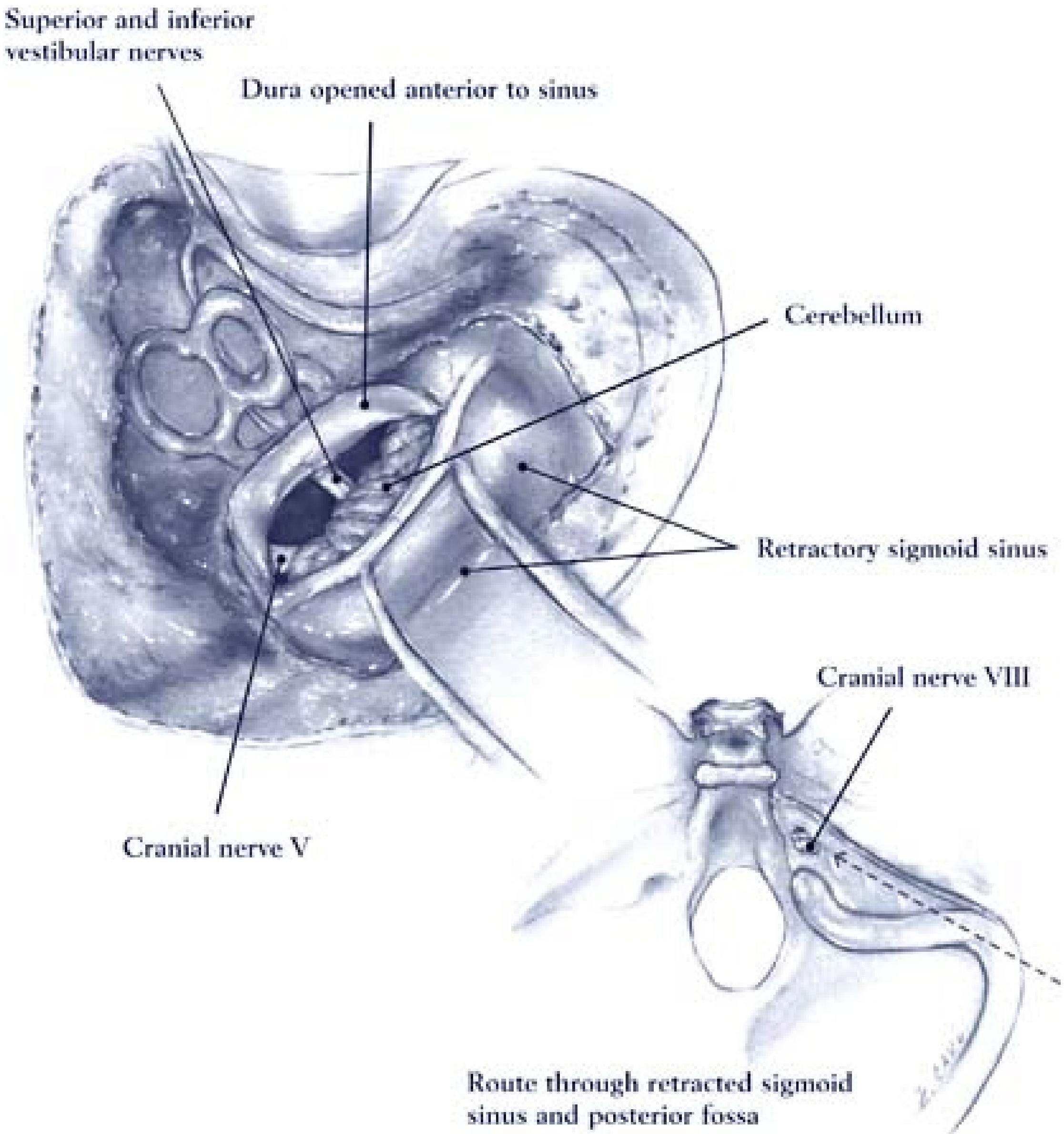


Figure 7

The dural incision is made anterior to the sigmoid sinus. The inset demonstrates the trajectory taken during the retrolabyrinthine approach to the vestibulocochlear nerve bundle and facial nerve in the cerebellopontine angle

continued parallel to the superior petrosal sinus if there is need for additional exposure.

A self-retaining retractor is then inserted to retract the cerebellum. The authors prefer the use of an Apfelbaum adjustable-armed retractor with a malleable extension. This self-retaining retractor provides sufficient strength of retraction without bulky connectors that can interfere with the surgeon’s line of vision.

After noting the position of the tentorium and the trigeminal nerve, the VIIth/VIIIth cranial nerve complex is identified in the cerebellopontine angle. Frequently, opening the arachnoid of the cisterna magna and retracting the cerebellar

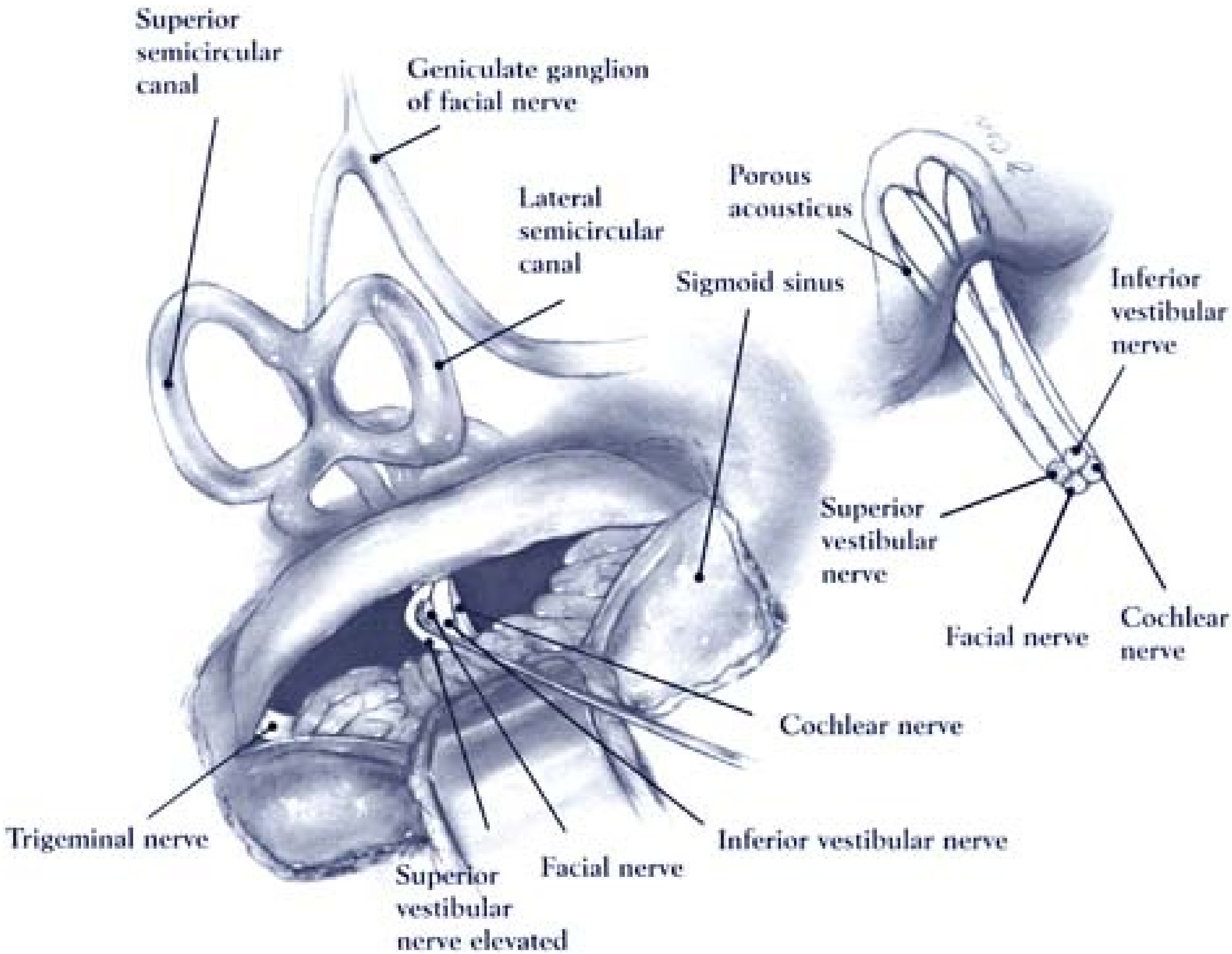


Figure 8

Establishing the surgical plane between the superior and inferior vestibular nerves in the cerebellopontine angle with the cerebellum retracted. The inset demonstrates the relationship of the vestibulocochlear nerve bundle and facial nerve as it traverses through the cerebellopontine angle into the internal auditory canal

flocculus posteriorly improves exposure of this cranial nerve complex.

The VIIth cranial nerve is identified by gentle inferior retraction of the VIIIth cranial nerve. A bony septum divides the cochlear and vestibular divisions of the VIIIth cranial nerve and is often delineated by a visible arteriole on the posterior aspect of the nerve. A difference in the color of these two divisions can be noted, with the vestibular nerve often appearing somewhat more opaque. A Rosen needle is used to establish the plane between the two divisions (Figure 8). The vestibular nerve is sectioned with fine neurosurgical scissors.

Reconstruction of the dural and mastoid defects requires a fat pack in addition to dural closure and a fascial graft positioned over the dural incision. The dural incision is closed with 4–0 interrupted silk sutures. This closure is usually not watertight and is therefore reinforced with a portion of the temporalis fascia. A previously removed bone fragment is used to block the aditus ad antrum, although care is taken not to allow the bone chip to touch the ossicular chain. This method prevents movement of the fat graft into the middle ear with attendant conductive hearing loss. The remainder of the temporalis fascia is placed superficial to the bone fragment to seal the aditus ad antrum from the mastoid cavity which is then obliterated with an abdominal free fat graft.

To reduce the likelihood of fat-graft infection, meningitis and postoperative wound infection, Bacitracin irrigation (50 000 U in 250 ml of 5% dextrose in water) is also used before the mastoid cavity obliteration and incision closure. The skin incision is closed in multiple layers. The periosteal and subcutaneous layers are closed with interrupted 2–0 chromic catgut and the skin is closed with a continuous locked 2–0 polypropylene suture.

POSTOPERATIVE CARE

A mastoid dressing is applied and kept in place for 5 days postoperatively. This dressing is then changed and a new dressing maintained for an additional 3–5 days. Postoperative vertigo is expected for several days after vestibular nerve section. The vertigo will improve in time with central compensation. Vestibular suppressants may be used in the immediate postoperative period; but should not be used for longer periods.

COMPLICATIONS

The common complications after the retrolabyrinthine approach include cerebrospinal fluid leak, either through the wound or eustachian tube, and meningitis and wound infection. Prevention is best accomplished during dural closure. The surgeon should pay strict attention paid to meticulous closure, with use of fascia to help to create a watertight dural closure. Slips of temporalis fascia may be oversewn in the dural suture line if there are small gaps between the dural edges. The suture line may be reinforced with fibrin glue. Before application of the fibrin glue, thorough irrigation of the wound will help to clear the surgical field of bone dust and old blood, while allowing the surgeon to assess the dural suture line more closely for small cerebrospinal fluid leaks under magnification. This thorough irrigation will also help to prevent infection at the surgical site and identify small leaks.

Persistent vertigo occurs in a minority of patients, usually approximately 5%. In these cases, incomplete nerve section is usually suspected. Evaluation for a residual functioning vestibular labyrinth is performed. If this is the case, the patient is counseled regarding either chemo-labyrinthectomy or complete eighth nerve section if the vertigo continues to be disabling.

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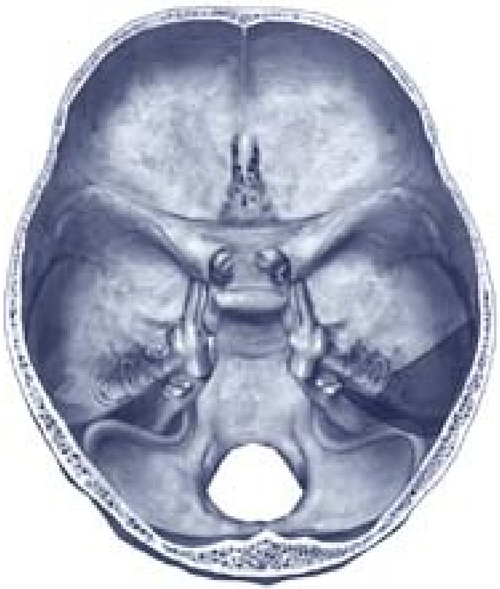
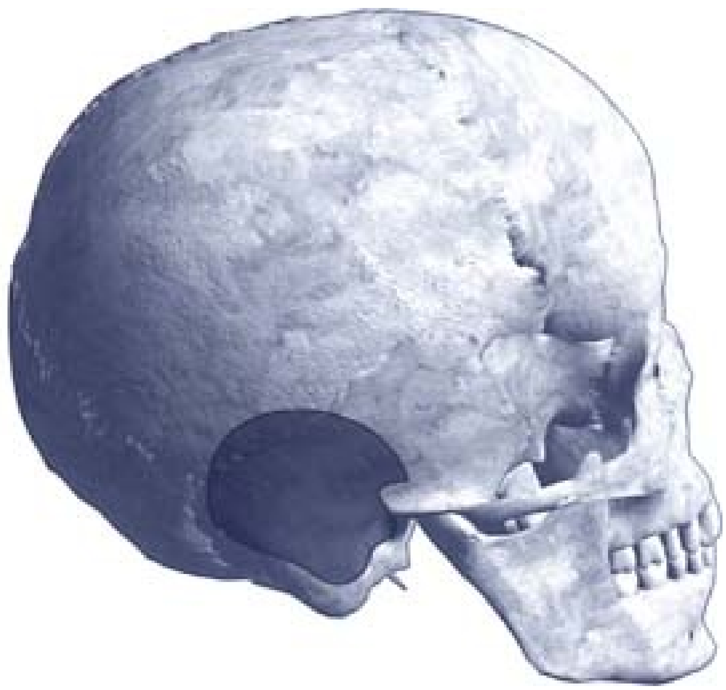
14
Suboccipital (retrosigmoid) approach

Donlin M.Long, John K.Niparko and Michael J.Holliday





INDICATIONS

Suboccipital exposure offers a time-tested approach to the entire posterior fossa, enabling visualization of the brain stem and cranial nerves II through XII (Table 1). The suboccipital approach facilitates cranial nerve decompression and section, complete excision of small-to medium-sized acoustic tumors when hearing preservation is a goal, and the necessary viewing angles required for safe excision of larger tumors that efface the brain stem and incorporate major vessels of the posterior circulation. Review of cumulative data from the Johns Hopkins' experience indicates that cranial nerve preservation with suboccipital approaches to acoustic neuroma removal matches or exceeds that of other approaches. Moreover, morbidity is low despite our use of this approach with a disproportionately high number of large tumors. Outcomes with the suboccipital approach are far better when cerebellar retraction is minimized and when the surgeon adopts an efficient strategy of microdissection. The suboccipital craniotomy and posterior fossa exposure provided by it may be modified for the management of tumors that involve the infratemporal fossa (Appendix I) and the petrous apex (Appendix II).

PATIENT EVALUATION

The preoperative evaluation of disorders should provide the surgeon with a complete understanding of the anatomy of the posterior fossa, temporal bones, and basiocciput, including the foramen magnum. Evaluation of the posterior fossa should include assessment of the brain stem, root entry zone, and cerebellum, with attention paid to ventricular size as well as effacement of neural structures.

Magnetic resonance imaging (MRI) provides the best definition of soft tissue anatomy and is the preferred means for assessing cerebellopontine angle masses (Figure 1). Schwannomas, meningiomas (Figures 2 and 3), cholesteatomas, and vascular masses are often discernible, based upon their enhancement patterns on T1-and T2-weighted images. Tumors exhibit characteristic patterns of contrast enhancement with administration of Gd-DTPA (gadolinium-diethylenetriamine pentacetic acid).

Computerized tomography (CT) readily demonstrates the erosive effects of neoplasms or inflammatory lesions on temporal and basioccipital bone. Preoperative CT informs the surgeon as to the pattern of air cell tracts within the temporal bone, and the proximity of the vestibular and cochlear labyrinths relative to the pathology to be addressed. Such information is helpful when bony decompression of the internal auditory canal is necessary to access the intracanalicular component of an acoustic tumor without violation into the bony labyrinth. It may also help to indicate the position of the jugular bulb so that inadvertent injury to a high-riding jugular bulb may be avoided during bone removal at the porus acousticus.

Table 1 Regions and structures accessible by the suboccipital/retrosigmoid approach

Cerebellopontine angle
Medial internal auditory canal
Brain stem
Cerebellum
Cranial nerves IV, V, VI, VII, VIII, IX, X and XI

Vertebral-basilar circulation

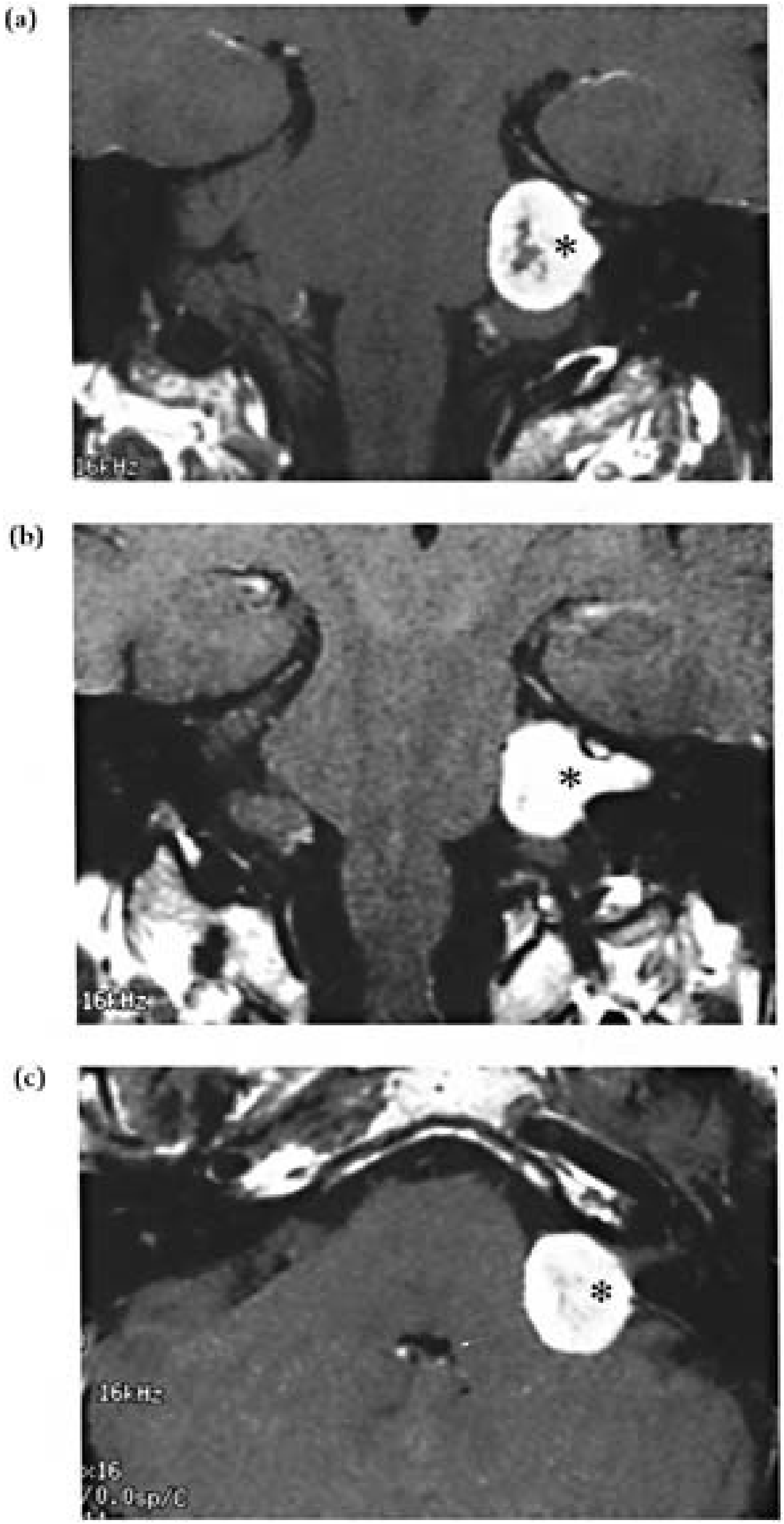


Figure 1

Vestibular schwannoma. (a) Coronal MRI with gadolinium enhancement of acoustic neuroma; (b) canalicular component of the same tumor shown on a different section; (c) medial component of acoustic tumor abutting the brain stem and cerebellum. Access to the tumor is best taken via the suboccipital approach to address both the canalicular component and the cisternal extension to the root entry zone

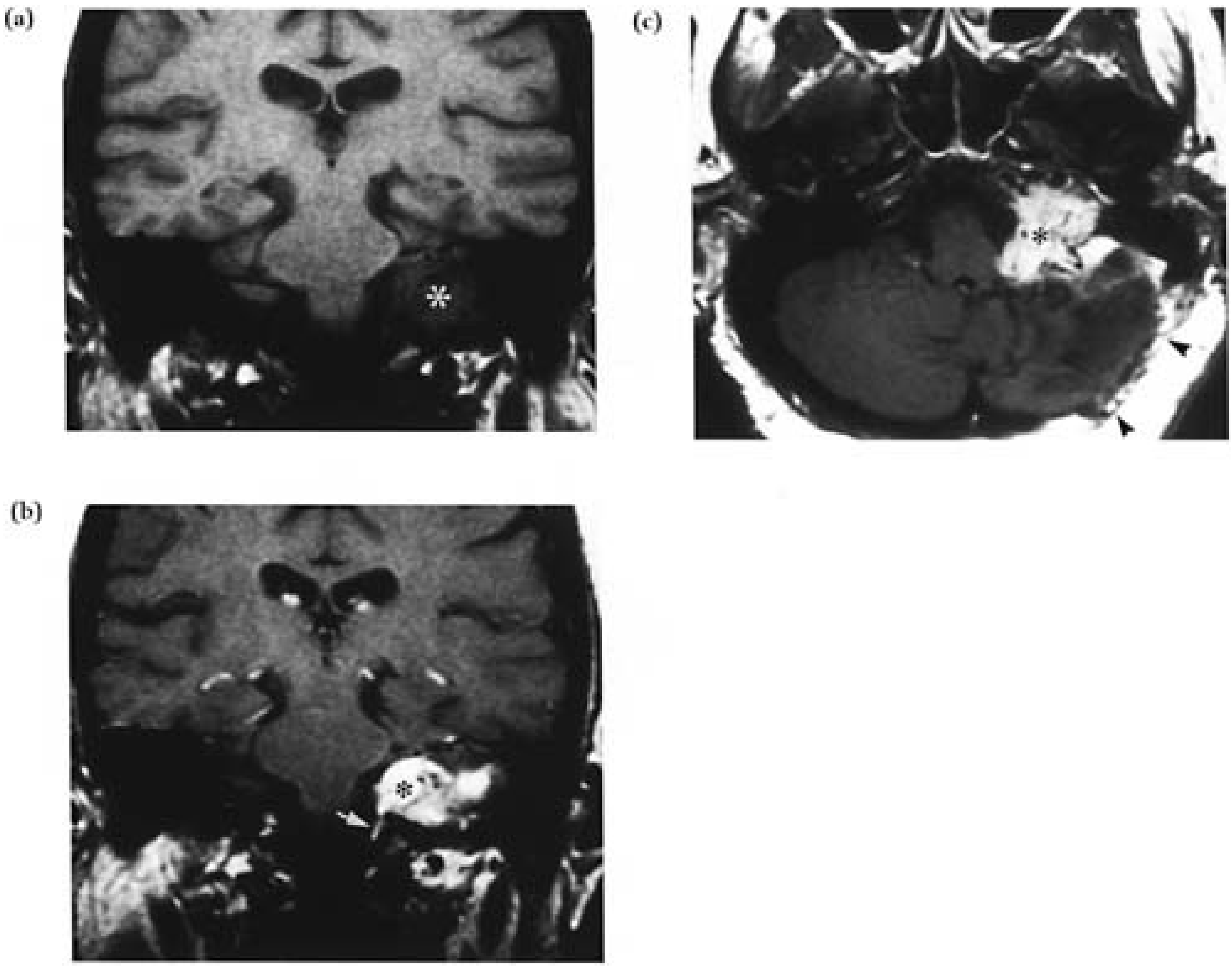


Figure 2

Cerebellopontine angle meningioma. (a) The asterisk demarcates the meningioma on T1-weighted coronal MRI scan; (b) T1-weighted MRI coronal scan with gadolinium enhancement of meningioma and dural tail (arrow); (c) axial T1-weighted MRI of the meningioma. Note the involvement of the bone of the petrous apex Preoperative angiography is indicated when MRI or CT suggests a highly vascular lesion, and when involvement of the vertebral, basilar, or internal carotid artery or major venous sinuses is likely. For large glomus jugulare tumors with intracranial extension into the posterior fossa, preoperative embolization may help to reduce blood loss during tumor removal.

ANATOMICAL CONSIDERATIONS

Proper placement of the posterior craniectormy relies on familiarity with the external landmarks of the posterior skull. From medial to lateral, the mid-line occipital protuberance (inion), junction of the occiput and temporal squamosa (asterion), and mastoid process are helpful landmarks in planning the incision and subsequent craniectomy. The craniectomy, centered on the asterion, is

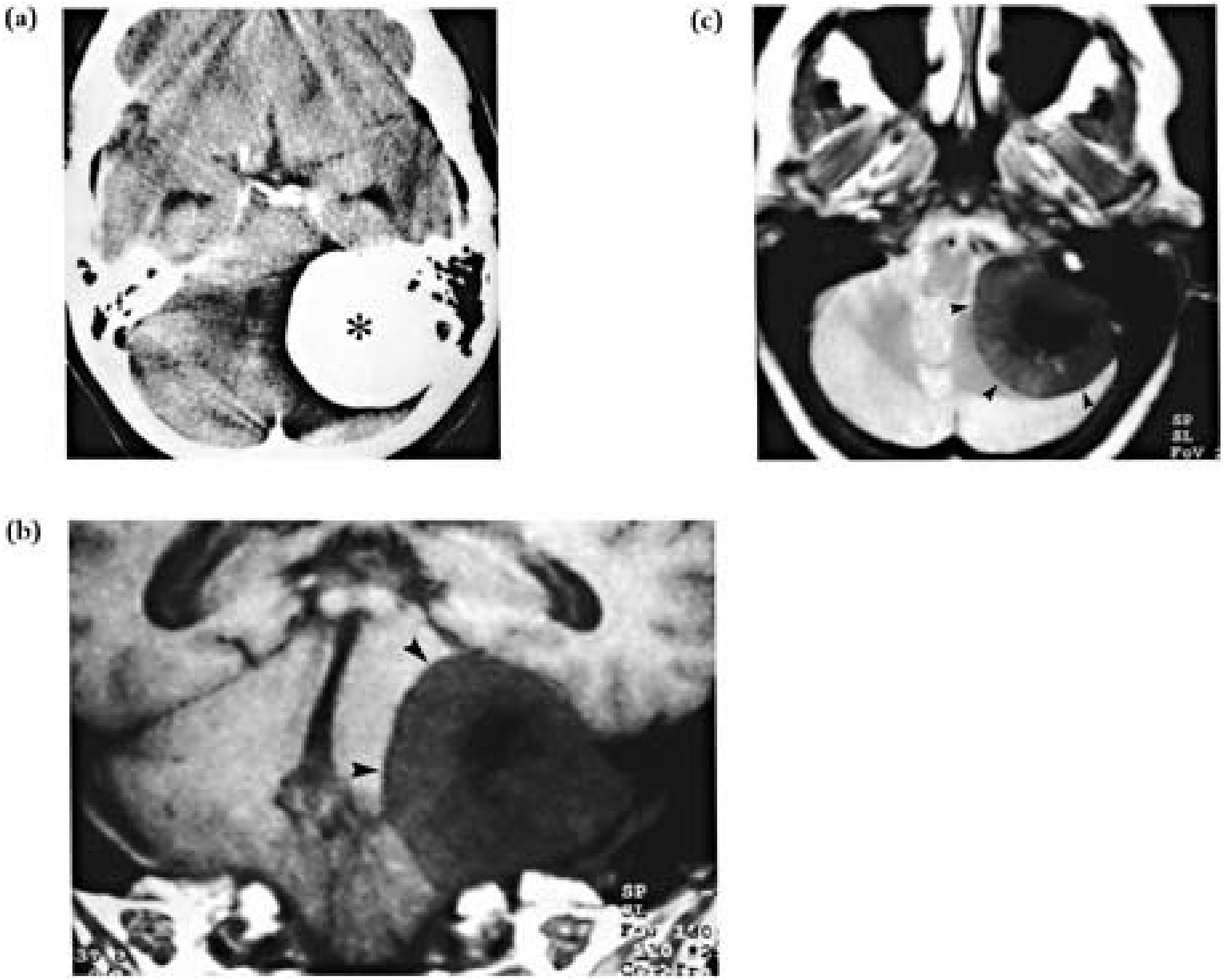


Figure 3

Large cerebellopontine angle meningioma. (a) The asterisk demarcates a large cerebellopontine angle meningioma on axial CT scan; (b) T1-weighted axial MRI scan with gadolinium of the meningioma. Note the cystic component; (c) coronal T2-weighted MRI scan of the same lesion. Note brain stem compression medially

extended anteriorly until the sigmoid sinus is visualized, and superiorly until the lateral third of the transverse sinus is visualized (Figure 4). Extension of the craniectomy in this manner provides the necessary exposure for optimal exploration of the cerebellopontine angle and tumor resection.

The suboccipital approach is most commonly employed to address lesions that involve the cerebellopontine angle. Some of these lesions include acoustic neuromas, large glomus jugulare tumors, or fifth nerve schwannomas with posterior fossa extension (see Appendix II). This area is best conceptualized as a potential space that lies between the clivus of the basiocciput anteriorly, the petrous tip anterolaterally, and the paired cisterns surrounding the cerebellum posterolaterally. Critical neurovascular structures that lie within the cerebellopontine angle include the vessels of the posterior circulation and the caudal cranial nerves.

The devastating consequences of iatrogenic injury to the posterior circulation mandate detailed understanding of the anatomy of the vertebrobasilar arterial system. The cerebellar arteries (posterior inferior cerebellar artery (PICA), anterior inferior cerebellar artery (AICA), and superior cerebellar artery (SupCA) branch from the

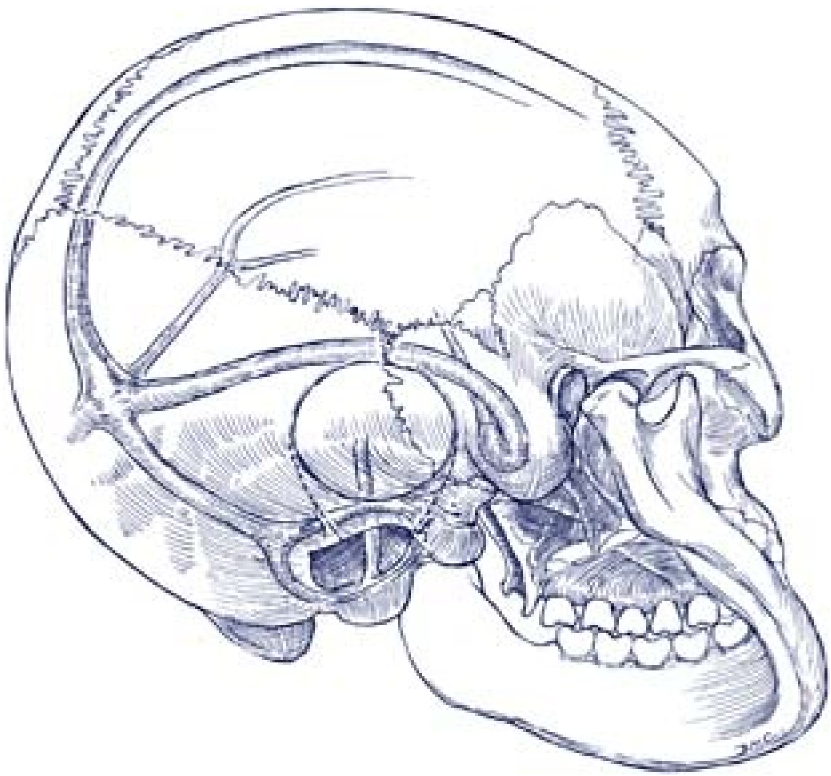


Figure 4

The borders of the craniotomy for the suboccipital approach are shown. Note its relationship under the transverse sinus, behind the sigmoid sinus, and its relation to the asterion (junction of the occipital and posterior temporal sutures) junction of the vertebral and basilar arteries. The AICA, in particular, because of its tortuous course, resides adjacent to the VII/VIIIth nerve complex, and is frequently incorporated in the capsule of acoustic tumors. AICA injuries can produce significant morbidity due to brain stem and cranial nerve ischemia, as well as bleeding into the cerebrospinal spaces and a consequent loss of vasomotor regulation.

The internal auditory (labyrinthine) artery must be preserved to achieve hearing preservation. This artery branches from the basilar artery just cephalad to the AICA, and is most easily preserved when the artery courses between the auditory and vestibular divisions of the VIIIth nerve. When elevated from this plane and adherent to the tumor capsule, the artery may not be easily recognized nor easy to separate from the tumor and preserve.

Familiarity with the root entry zone of the caudal cranial nerves is key to optimizing surgical results. At the point where the choroid plexus leaves the lateral aperture of the fourth ventricle directly inferior to the flocculus, cranial nerves V, VI, VII and VIII diverge and pursue an inferomedial to superolateral course. More caudally, cranial nerves IX and X pursue a course from inferomedial to superolateral to enter the jugular foramen.

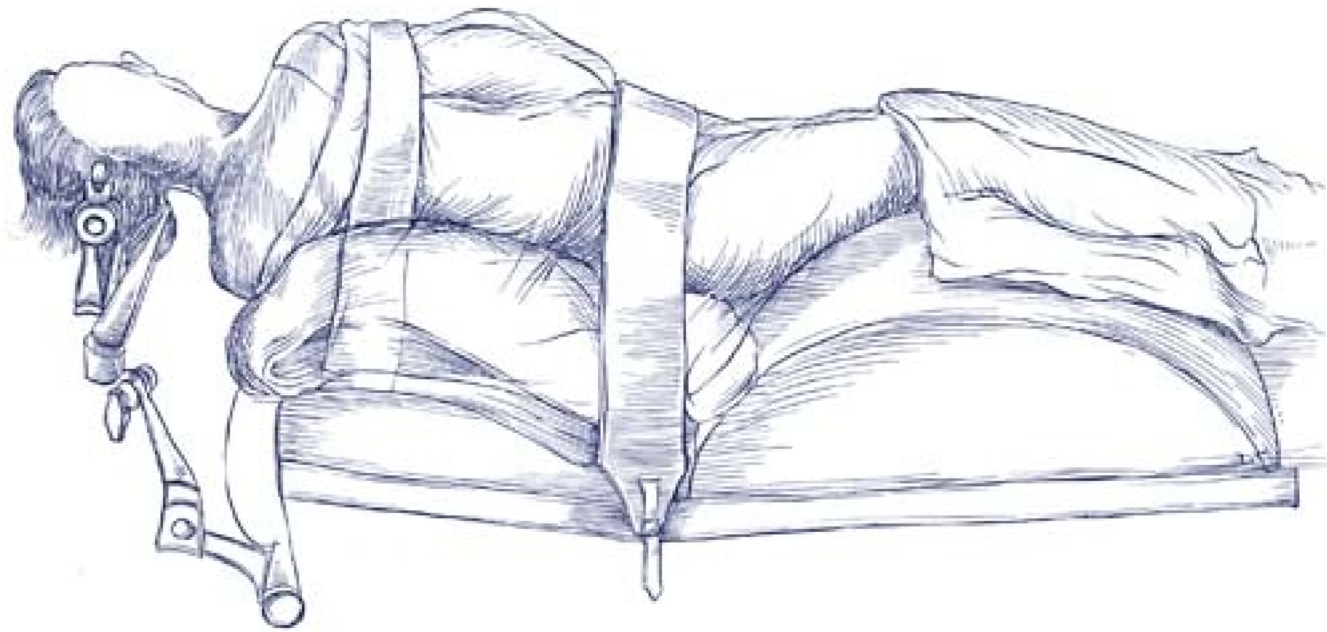


Figure 5

Patient positioning (park-bench position) for suboccipital craniotomy

PROCEDURE

Anesthesia and positioning

Suboccipital procedures are carried out under general anesthesia. Since neurophysiologic monitoring is an important adjunct of the operation, the anesthetic technique must allow for spinal and brain stem evoked potentials, cranial nerve electromyography, and cochlear functional testing (auditory evoked potentials or direct VIIIth nerve potential) to be monitored accurately as soon as manipulation of the nervous system begins. With large tumors that compress the brain stem, it is important to begin monitoring even during patient positioning.

The operation can be performed with the patient supine and head turned to expose the occipital bone. However, we prefer the park-bench position (three-quarters lateral position) with the patient reclining on the side, head held by pin fixation, and an axillary roll to protect the dependent brachial plexus from compression (Figures 5 and 6).

Figure 6

Patient head positioning with Mayfield pin stabilization. The surgeon's line of vision and surgical trajectory into the posterior fossa will approximate that of the petrous ridge

Skin incision and craniectomy

A 6–8-cm curvilinear skin incision is made in the posterior scalp from the asterion to the cervical-occipital junction (Figure 6). The mid-point of the incision should be about 3 cm posterior to the mastoid bone. The incision is made directly through all soft tissue layers to bone. Hemostasis is critical, for any bleeding into the highly magnified field will later be a serious distraction. The tendinous insertions of the trapezius and splenius capitis muscles are detached from the occipital bone and mastoid with periosteal elevators or electrocautery. Angled cerebellar retractors are placed and the occipital bone exposed.

We prefer to perform an occipital craniotomy with a drill, but traditional techniques of perforator and rongeurs work

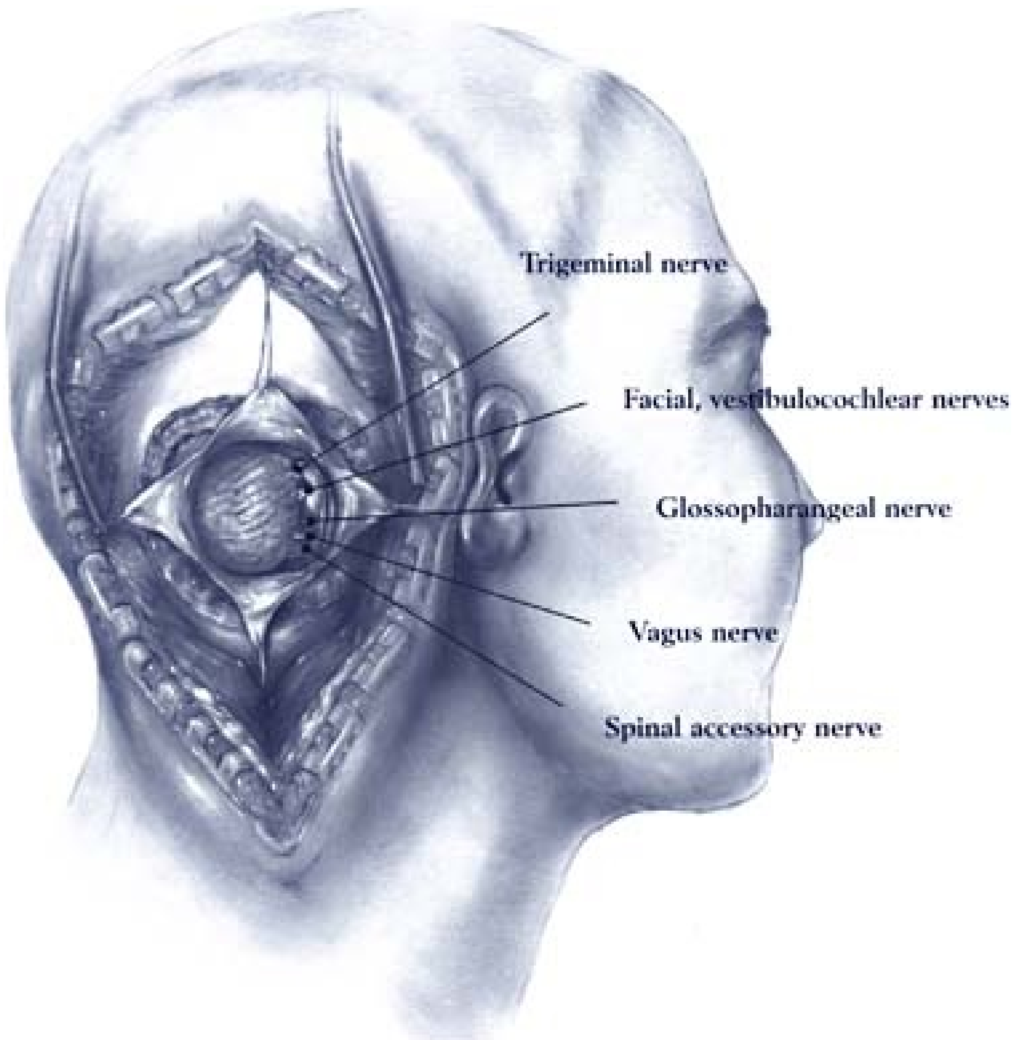


Figure 7

Skin incision, craniotomy, and dural incision, exposing the cerebellar hemisphere and caudal cranial nerves

as well. Drilling the craniectomy offers better control of bleeding from the emissary vein when it is entered. Bone is removed superiorly to the transverse sinus and lateral to the sigmoid sinus. The size of the craniectomy depends upon the size of the tumor. There is no reason to make the exposure larger than 3–5 cm in diameter with small and medium tumors. Larger tumors may require a larger craniectomy, extended toward the mid-line to provide unimpeded cerebellar retraction. Exposed air cells are waxed thoroughly as they are encoutered to prevent postoperative cerebrospinal fluid leak.

The dura is opened in a cruciate fashion, suture retracted, and covered with moist cottonoids to prevent dessication and provide protection (Figure 7). The cerebellum is elevated and the inferiorly located cisterna magna opened.

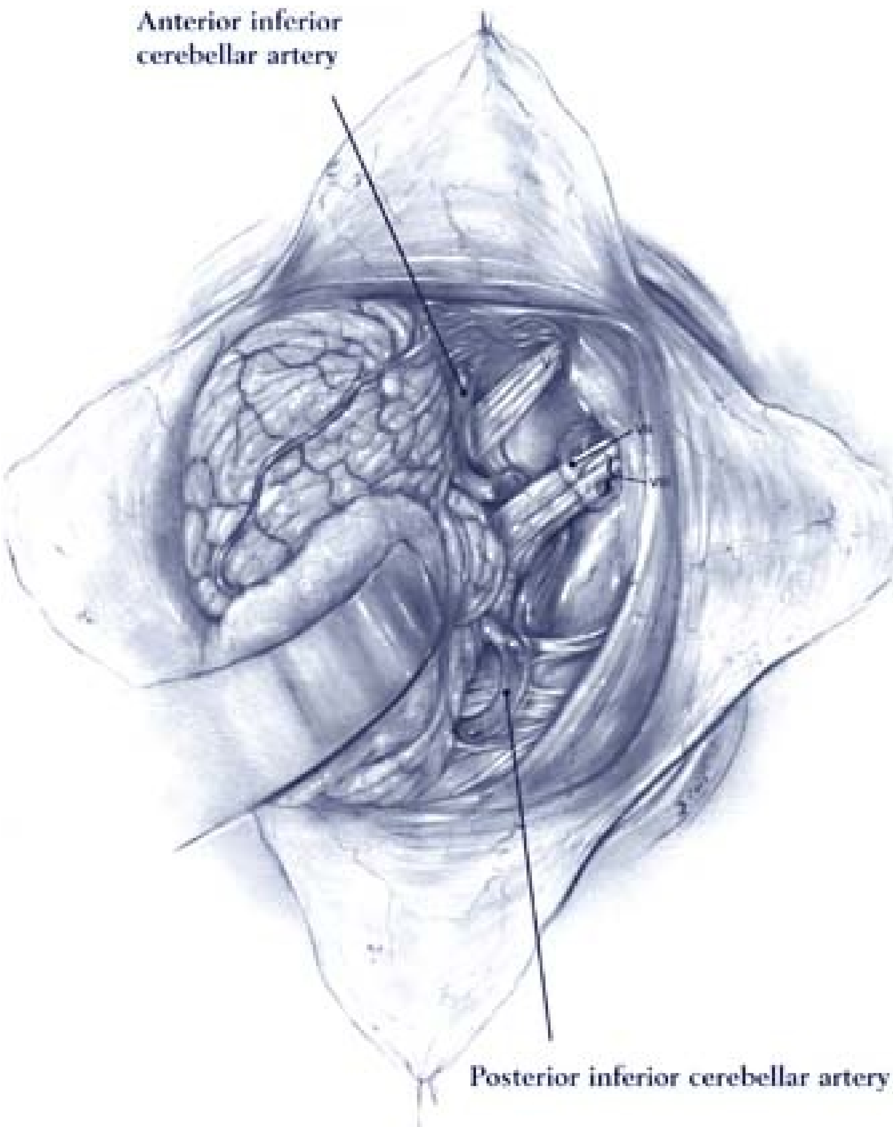


Figure 8

Exposed cerebellopontine angle and caudal cranial nerves. The typical appearance of the tumor extending from the porus region of the internal auditory canal is depicted

Cerebrospinal fluid is drained until the flow attenuates. This usually provides adequate relaxation so that retraction may be unnecessary in exposing the cerebellopontine angle. If necessary, the cerebellum is retracted in a superomedial direction until the cerebellopontine angle and the medial extent of the tumor are exposed. Tension on the retractors can be reduced and little retraction is required from this point forward (Figure 8).

Removal of small to medium tumors
When hearing preservation is a goal, the first step after exposure of the tumor is placement of a recording electrode directly on the acoustic nerve or the brain stem at the root entry zone. Given the real-time monitoring capabilities afforded by this recording strategy any manipulation which alters the electric potential can be immediately recognized.

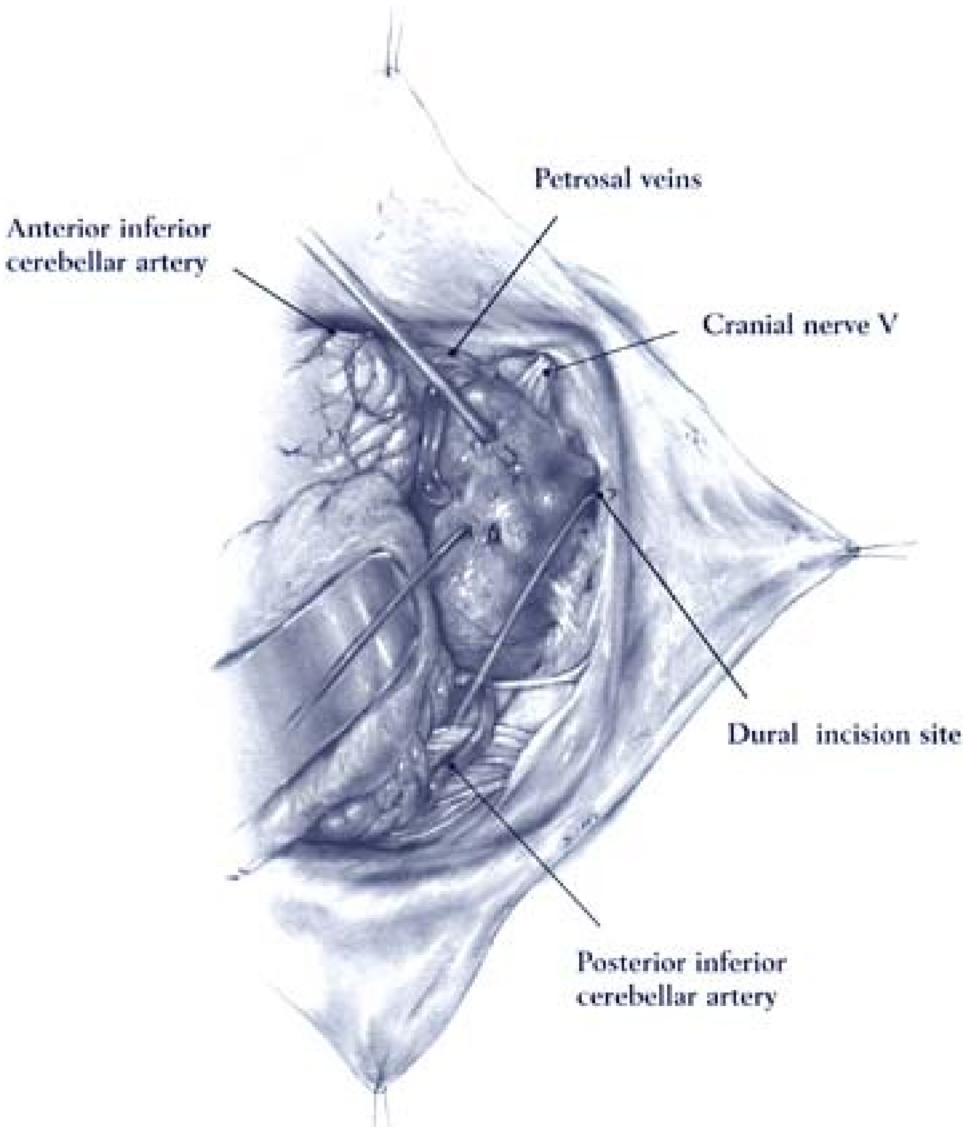


Figure 9

Extracapsular dissection of the nerves and the vessels from the tumor. Shown in this illustration are the various techniques used to free the tumor from the surrounding arachnoid

Continuous monitoring of the auditory evoked potential directly from the nerve allows even minor changes to be recognized immediately so that the dissection technique can be modified.

The next step is to remove the arachnoid and establish the appropriate plane of dissection around the tumor (Figure 9). The plane developed should separate the tumor capsule and surrounding layers of filamentous arachnoid. Regional cranial nerves and major arteries typically course beneath the arachnoid, and can be shielded from the dissection by maintaining the arachnoid plane.

Once this plane is established circumferentially sharp dissection is used to divide the vestibular nerve remnant exiting the tumor, enabling separation of the VIIth nerve and the acoustic portion of the VIIIth nerve at the medial margin of the tumor. Positive identification of the anterior inferior cerebellar artery is critical if it is suspected that the subarachnoid plane of the brain stem has been violated and the artery is unprotected. If the anterior inferior cerebellar artery or any of its major branches are adherent to the capsule, this is the appropriate time to dissect them free. Pontine branches from the anterior inferior cerebellar artery are identified and preserved, whereas branches to the tumor surface can be safely coagulated. If the tumor is large enough to contact the Vth, IXth, Xth or XIth nerves, those adhesions should be dissected now, and the AICA is displaced medially over the caudal cranial nerves. The tumor is then dissected to the porus acousticus.

Once the nerves are identified, there are two possible courses of action. With small tumors, the tumor mass is left intact and the tumor simply dissected from the nerves to the porus. With medium tumors, it is better to coagulate the posterior margin and debulk the tumor to reduce tension on the VIIth and VIIIth cranial nerves at the junctional zone, preferably with an ultrasonic dissector/aspirator.

Removal of large tumors

The technique for tumors measuring 3 cm and larger differs in the method used to manage the surrounding neurovascular structures. The procedure begins with cerebellar retraction to expose the lateral half of the tumor and both poles. The appropriate subarachnoid extracapsular plane is identified. The use of high magnification begins as soon as the tumor is exposed. The tumor is inspected to be certain that the VIIth nerve is not on the posterior surface which occurs only rarely. Any important blood vessel or branch on the posterior surface should be dissected free. The poles are explored to separate the Vth nerve superiorly and the IXth, Xth, and XIth cranial nerves inferiorly. With large tumors, always be cognizant that the IVth, VIth, and even the XIIth cranial nerves can be involved.

As soon as the tumor is well defined, the posterior capsule is opened and intracapsular dissection performed, preferably with an ultrasonic dissector/aspirator (Figure 10). The more tumor is removed, the easier the subsequent dissection will be; with less risk of traction applied to the VIIth and VIIIth nerves (Figure 11). The goal should be to thin the remaining capsule to a few millimeters. The technique is to gradually retract cerebellum and deliver the tumor into the field. Redundant tumor capsule is excised and any remaining tumor bulk gradually removed. It is key not to go through the capsule to avoid injury to the brain stem or adherent cranial nerves. As the tumor is delivered, all cranial nerves are dissected from the capsule. Sometimes, it is straightforward to identify the VIIth nerve at the brain stem and separate the capsule from the facial nerve to the level of the porus. However, tumor bulk, adherence of the tumor to the facial nerve and attenuation of the facial nerve make separation of the tumor from the nerve difficult without applying medial-to-lateral traction.

It is sometimes helpful to determine the level of the root entry zone by first following the IXth and Xth nerves to their medial insertions to the brain stem, thus identifying the level of the root entry zone. The zone of entry of the VIIth and VIIIth nerves can be determined by tracing this line superiorly. In our experience, most often the VIIth nerve traverses the equator or superior pole of the tumor. It is less common for it to be displaced inferiorly or posteriorly However, it can be displaced forward adjacent to the Vth nerve and loop back to the porus. Therefore, we dissect adherent tumor in the region of the porus acousticus as the last step, since this is where the nerve will be thinnest. As the VIIth and VIIIth nerves are often splayed over the ventral aspect of the tumor, stripping the nerves of tumor produces substantial traction, and a risk of avulsing the nerve from the brain stem. Instead, adhesions to the epineurium should be sharply divided.

The transitional or junctional zone at the level of the porus presents a particular challenge in dissecting the VIIth nerve and the cochlear VIII nerve from the anterolateral aspect of the tumor. We prefer to use sharp rather than blunt dissection after adequate tumor debulking, and to remove the tumor piecemeal in small fragments to mobilize the superior and caudal poles of the tumor, rather than manipulating large portions of the tumor and thus traumatizing the nerves. These strategies minimize traction on the nerve while dissecting and removing the tumor, and are particularly useful for nerve preservation at the junctional zone. The nerve may appear to be easily dissected in this region, but is often quite adherent to the tumor as a result of tumor invasion of the arachnoid at this level. Moreover, the nerve often assumes an acute angulation at.

When the porus is reached or when it is apparent that the adherence will make separation of the tumor from the brain stem difficult, the tumor load is reduced by removing the tumor from the porus acousticus and internal auditory canal after bony decompression of the internal auditory canal, as

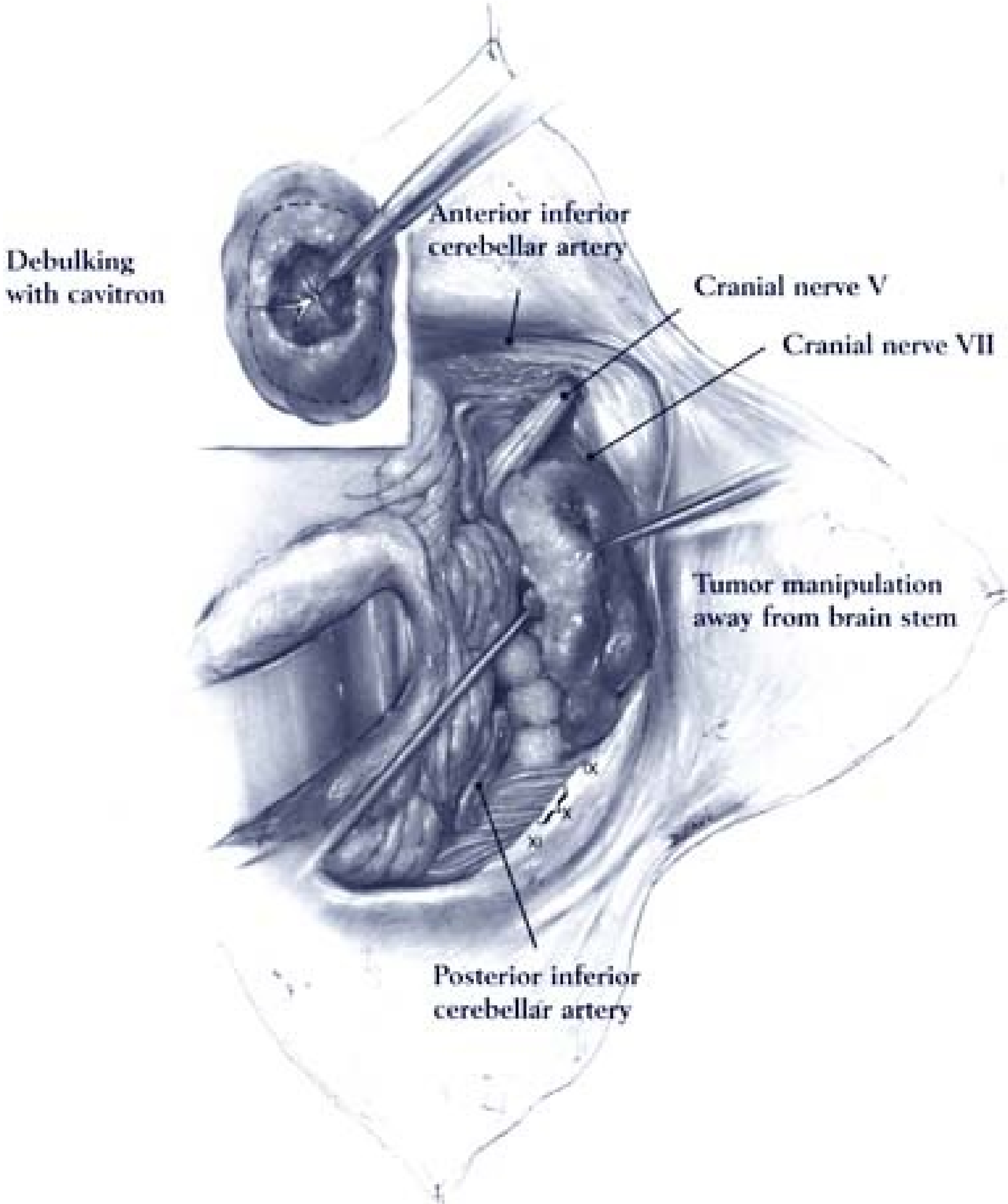


Figure 10

Plane of dissection to separate the tumor capsule from the nerves, vessels, and brain Posterior inferior stem. Intracapsular tumor removal may be cerebellar performed with ultrasonic aspirator (inset)

described below. The now decorticated tumor can be entered near the lateral margin of the canal, the VIIth nerve identified visually and confirmed with stimulation. The vestibular nerve is sectioned. In most large tumors, preservation of hearing is not a goal, but we prefer to leave the VIIIth nerve intact since it can provide a ballast in limiting movement about the VIIth nerve, and may reduce the risk of ischemia of the VIIth nerve.

The tumor is then resected from the internal auditory canal and the VIIth nerve identified to the porus acousticus. It is then possible to coagulate and cut the adhesions between the tumor and dura at the walls of the porus without concern for VIIth nerve injury. This allows the residual tumor to be mobilized and removed piecemeal with the VIIth nerve continually visualized on both sides.

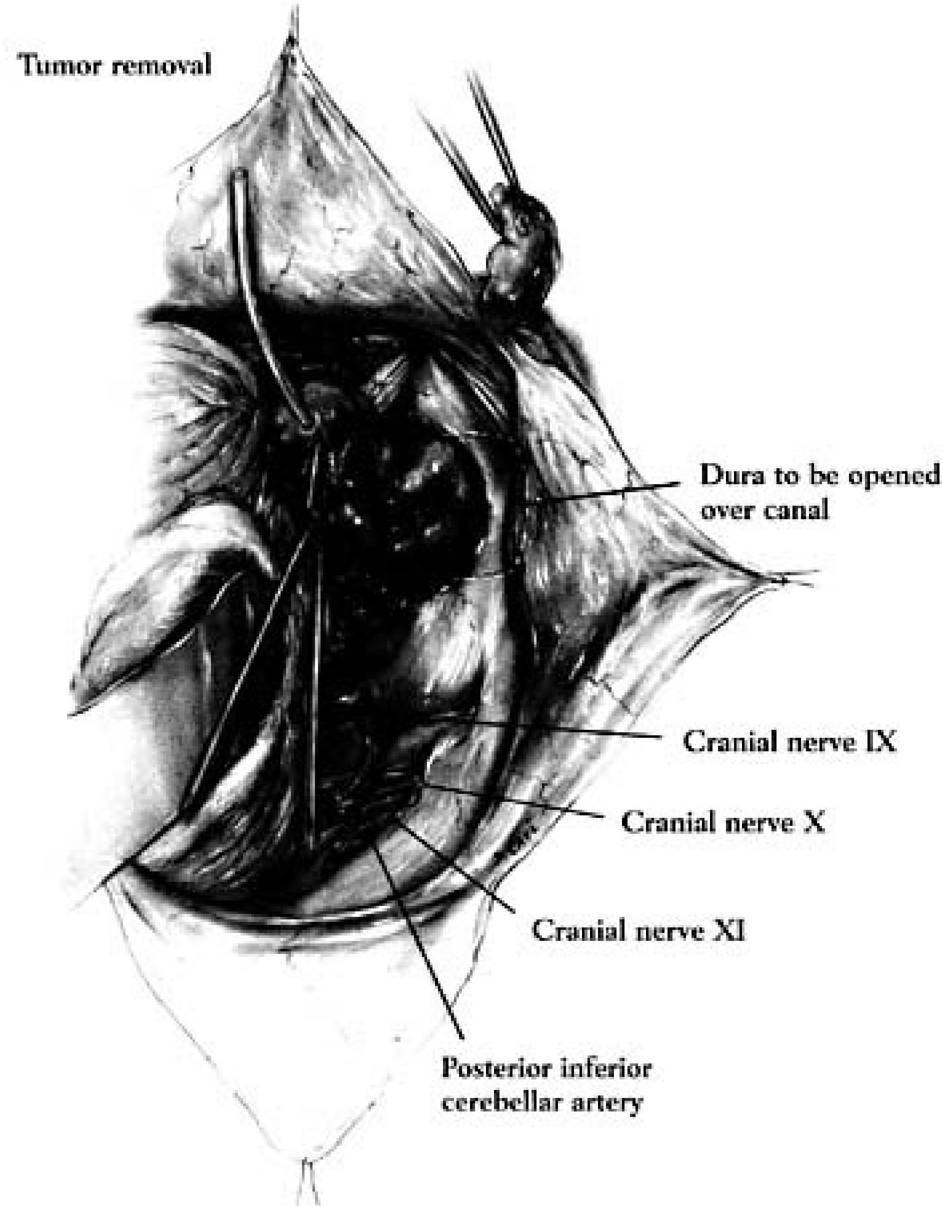


Figure 11

Piecemeal removal of the separated tumor from vessels and nerves. The dashed lines indicate the area of dural removal to access the posterior aspect of the porus acousticus for internal auditory canal bony decompression/exteriorization

Internal auditory canal decompression: exteriorizing the intracanalicular aspect of the tumor

A blunt nerve hook is used to palpate and define the upper and lower limits of the porus of the internal auditory canal. Because thickened dura at the porus typically constricts the tumor as it extends laterally the contours of the tumor in the posterior fossa often give an inaccurate impression as to the true caliber of the porus and the amount of bone to be removed. Landmarks on the posterior surface of the temporal bone provide orientation to the labyrinth. The subarcuate artery corresponds to the level of the center of the superior semicircular canal, although the artery is

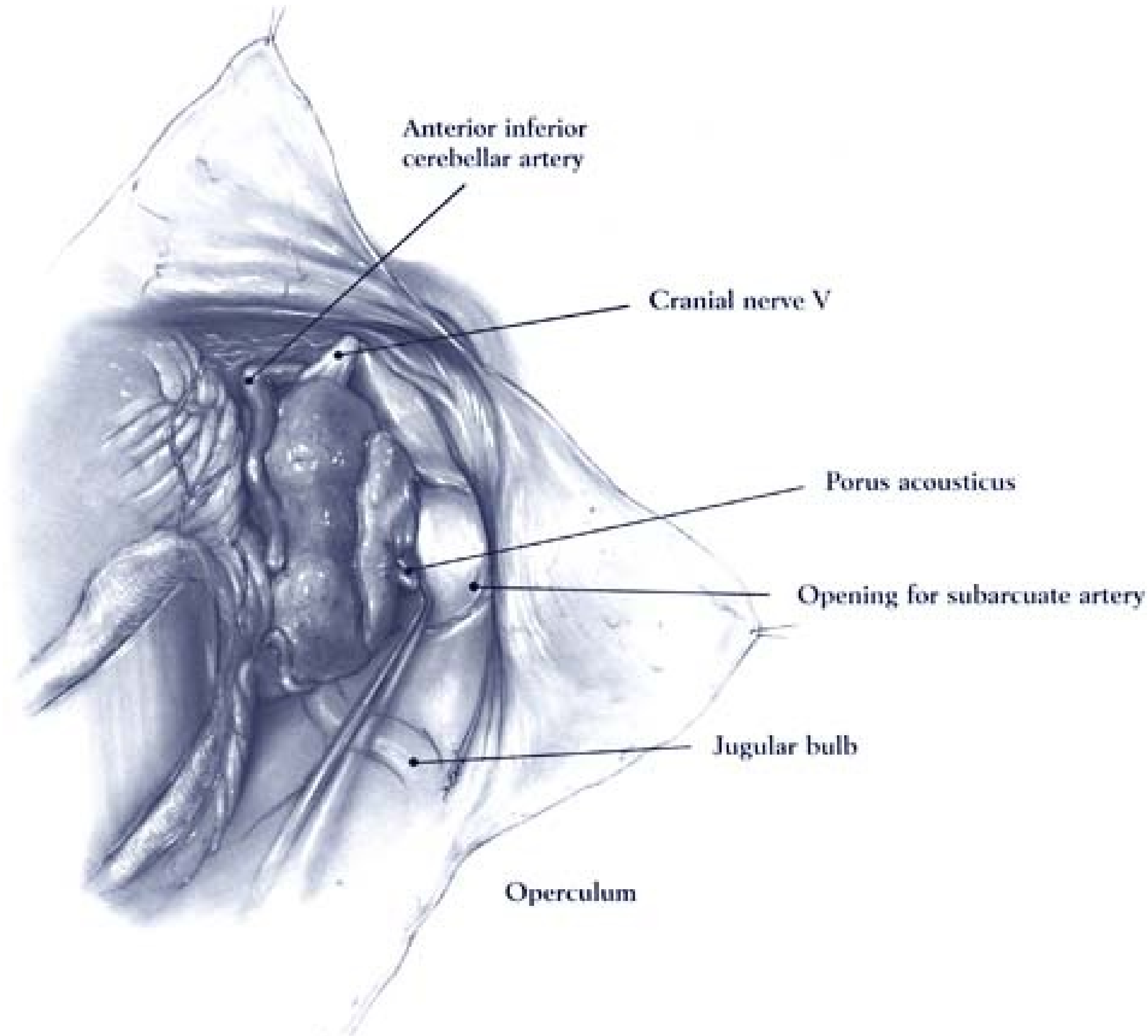


Figure 12

Dural incisions are made and the dural apron created to expose the petrous bone and meatal porus acousticus

frequently obscured by adhesions over the posterior aspect of the tumor. The bony operculum is a bony cusp that overlies the aperture of the vestibular aqueduct, housing the endolymphatic sac. Although somewhat variable in its location, it lies at a level that typically corresponds with the floor of the internal auditory canal. The endolymphatic sac and duct can be used as a lateral boundary to avoid the common crus and ampullated end of the superior semicircular canal. Drilling should be limited to bone that is medial and anterior to the duct.

Dura applied to the posterior surface of the temporal bone is incised in a 2-cm arc from the posterior lip of the porus acousticus of the internal auditory canal (Figure 12). The dura is elevated to the level of the porus and draped over the posterior aspect of the tumor. An intact dural reflection

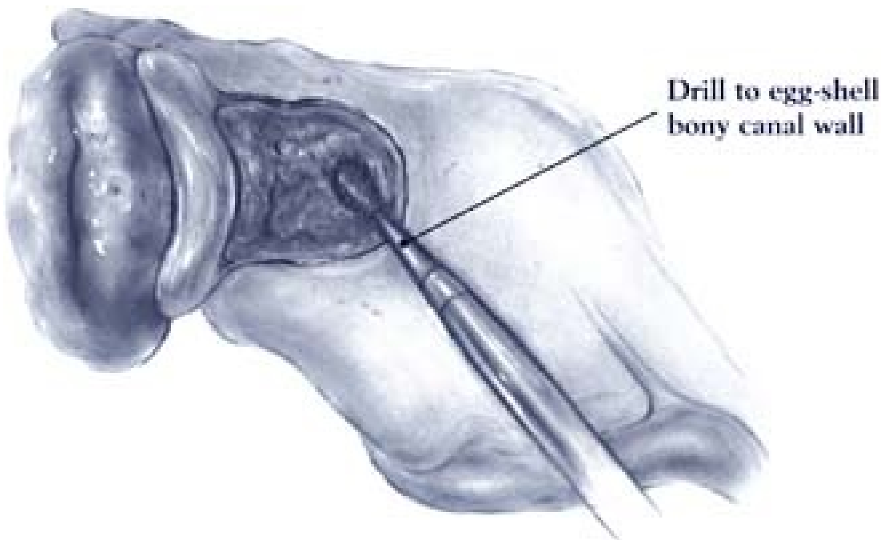


Figure 13

Drilling is performed to leave an egg-shell thickness of bone delineating the confines of the internal auditory canal

provides a flap that can later be used to cover exposed (perilabyrinthine) air cells surrounding the internal auditory canal, which have been opened during bone removal.

Decortication of the internal auditory canal
To achieve full exposure of the tumor within the internal auditory canal and a comfortable working space, a widely beveled bony trough is necessary Adequate exposure of the most lateral aspect of the canal is necessary for complete tumor excision from a site that is highly likely to harbor residual tumor—the lateral aspect of the canal adjacent to the neural foramina. The challenge, of course, is to provide such exposure while maintaining the integrity of the labyrinth. A large cutting burr and continuous suction/irrigation are used to create a saucerized bony defect rather than a gutter-like defect that hampers dissection of the canalicular portion of the tumor. Because exteriorization of the internal auditory canal requires drilling within the relatively narrow confines of the posterior fossa, a ‘pine cone’ burr facilitates efficient bone removal with the expanded side of the burr (Figure 13).

The dura of the internal auditory canal is exposed from medial to lateral (Figure 14). Initial drilling of the porus region may be extensive as dense bone and occasionally an osteoma are encountered. The dura is then skeletonized along its long axis, using progressively smaller cutting and then diamond burrs. The dura of the internal auditory canal is exposed over at least 180°, with an emphasis placed on uncapping the roof of the canal. Drilling the bone that overlies the canal avoids the creation of a bony ledge. This bony overhang can obscure visualizaton of the plane of dissection of the facial nerve and may prevent adequate room for the microinstrumentation used for tumor dissection. Moreover, extensive decortication of the superior aspect of the porus facilitates later dissection of the tumor from the facial nerve at the critical transition zone.

Drilling is performed with care taken to avoid injury to the dura and underlying facial nerve. With diamond burr (extradural) drilling, the dura typically shields the nerve and facial nerve injury is unlikely with reasonable precaution. However, in the unusual case of a posteriorly displaced facial nerve, drill-related injury may occur. After sufficient

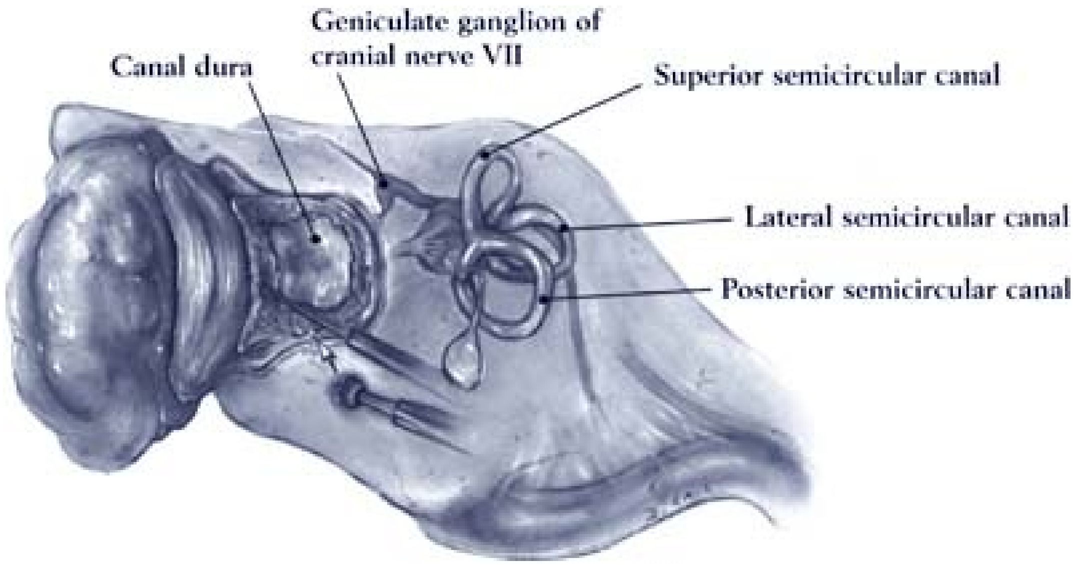


Figure 14

The internal auditory canal dura is exposed. Note the relationship of the fundus of the internal auditory canal to the labyrinth of the inner ear and surrounding structures

thinning of the bone to achieve ‘egg-shell’ thickness of the bone, the canal is completely decorticated. Exposure of the floor of the canal may be hampered by an abnormally positioned, high-riding jugular bulb. In this case, maximal exposure is achieved by cautiously decorticating the jugular bulb. Rarely, re-exploration is needed via the translabyrinthine or middle fossa approach.

Exposure of the internal auditory canal dura should be carried out as far laterally as the tumor extends. This can be recognized as a transition in the character of the dura (from blushed, tumor-involved dura to white, uninvolved dura). Ideally the lateral aspect of the tumor can be accessed without invading the common crus or ampullated end of the superior semicircular canal (Figure 15). Tumors that extend far laterally may require blue-lining of the common crus or ampullated end of the superior semicircular canal, and exposure of the horizontal transverse crest. Since residual tumor in the lateral aspect of the canal is likely to lead to clinically significant regrowth, exposure of the lateral extent of the tumor is necessary. Endoscopic visualization into this area may help in such situations.

The dura of the internal auditory canal is exposed and divided along the mid-portion of the canal (Figure 16). Attention is turned to the superolateral aspect of the canal where the superior vestibular nerve and tumor can be displaced inferiorly to expose the facial nerve.

Tumor dissection is continued from medial to lateral, gradually dissecting tumor remnant from both facial and acoustic nerves (Figure 17). At the lateral margin of the canal, the vestibular nerve is identified and divided. It is often possible to save either the superior or inferior vestibular nerve, although this may adversely affect vestibular compensation postoperatively if the nerve is severely attenuated. In such instances, we prefer to divide the attenuated nerve. At the lateral margin of the canal, any residual tumor is dissected in a plane outside the capsule and the last remnants are peeled off the nerves.

Preservation of facial function without a temporary palsy and preservation of hearing both require very specialized techniques. Facial EMG continuously monitored allows the

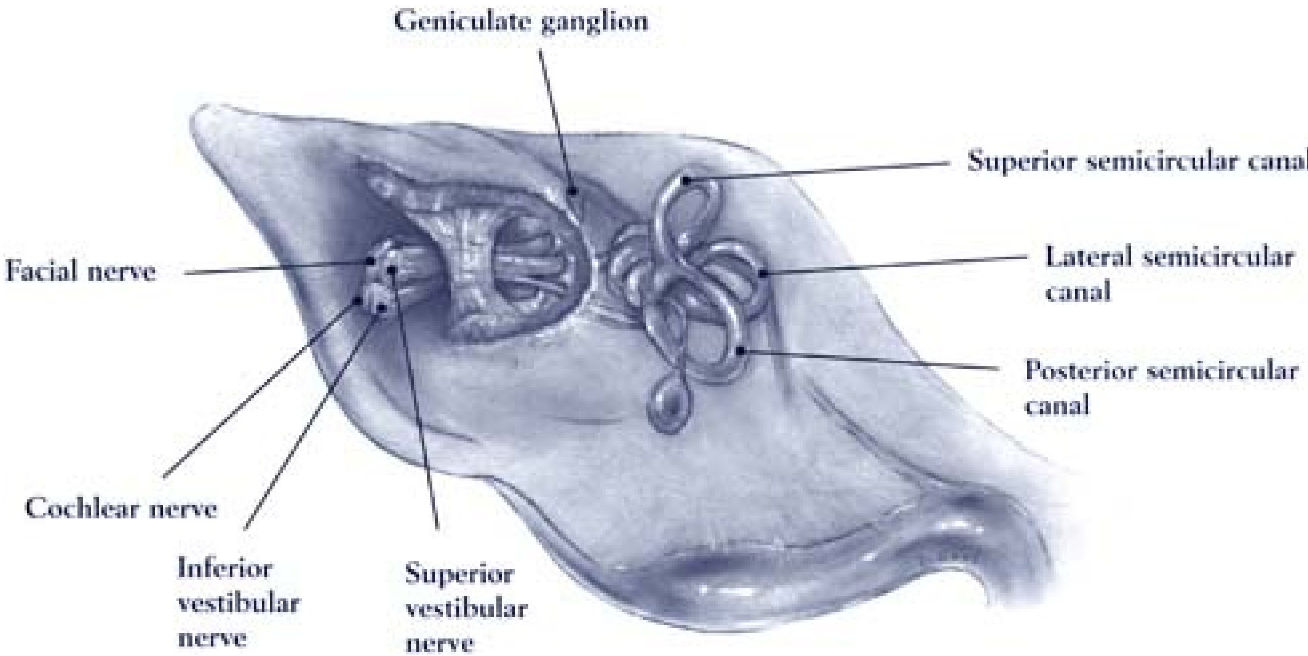


Figure 15

The surgical anatomy of the internal auditory canal, depicting the relationship of the fundus of the internal canal and the bony and membranous labyrinth

surgeon to determine which maneuvers may be detrimental to the facial nerve. It is common that the facial EMG is activated by maneuvers with the tumor remote from the nerve itself, suggesting that there are several stages of the operation where neuropraxic injury of cranial nerve[s] may occur. At the lateral margin of the canal, any residual tumor is dissected in a plane outside the capsule and the last remnants are dissected from the nerve.

Closure

Once tumor removal is complete, the porus and canal should be carefully investigated for defects which might communicate with the perilabyrinthine air cells. Fenestrated air cells may be waxed. Small plugs of muscle, dura, or fat are used to further occlude cerebrospinal fluid from any undetected defects. These are placed into any minute bony defects to seal them. A more recent addition is the use of fibrin glue Tisseel® to fill the newly created posterior aperture of the internal auditory canal, to ensure that the plugs of tissue into the air cells are secured. Techniques to contain the fibrin glue during the solidification process within the confines of the internal auditory canal include placing pressed Gelfoam® over the remaining canalicular VII–VIIIth nerve complex and at the medial end of the internal canal at the porus to function as a dam.

After application and solidification of the fibrin glue, the posterior fossa dura is then closed in a watertight fashion. We reconstitute the bony defect with thrombin-soaked Gelfoam® absorbable gelatin sponge and titanium mesh cranioplasty to restore the cosmetic appearance (Figure 18). The remainder of the wound soft tissue is closed in anatomical layers.

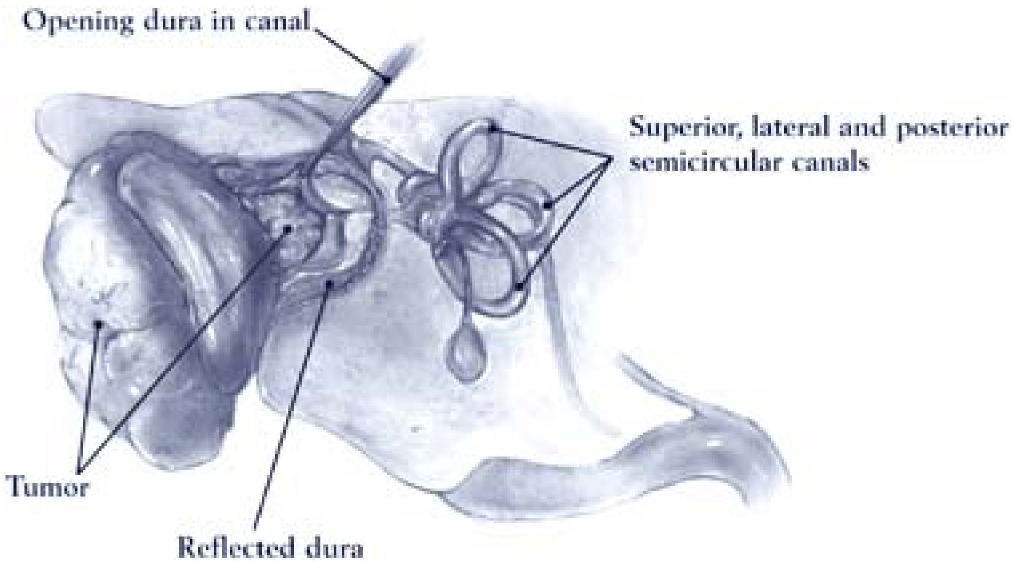


Figure 16

The dura of the internal auditory canal is incised to expose the intracanalicular aspect of the tumor

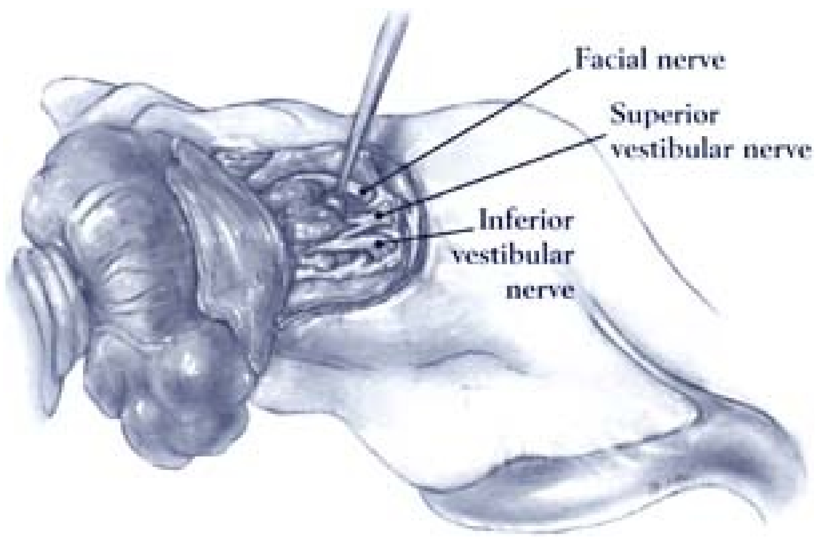


Figure 17

The intracanalicular portion of the tumor is dissected from medial to lateral. The most lateral aspect of the tumor is freed from the facial nerve epineurium near the meatal foramen

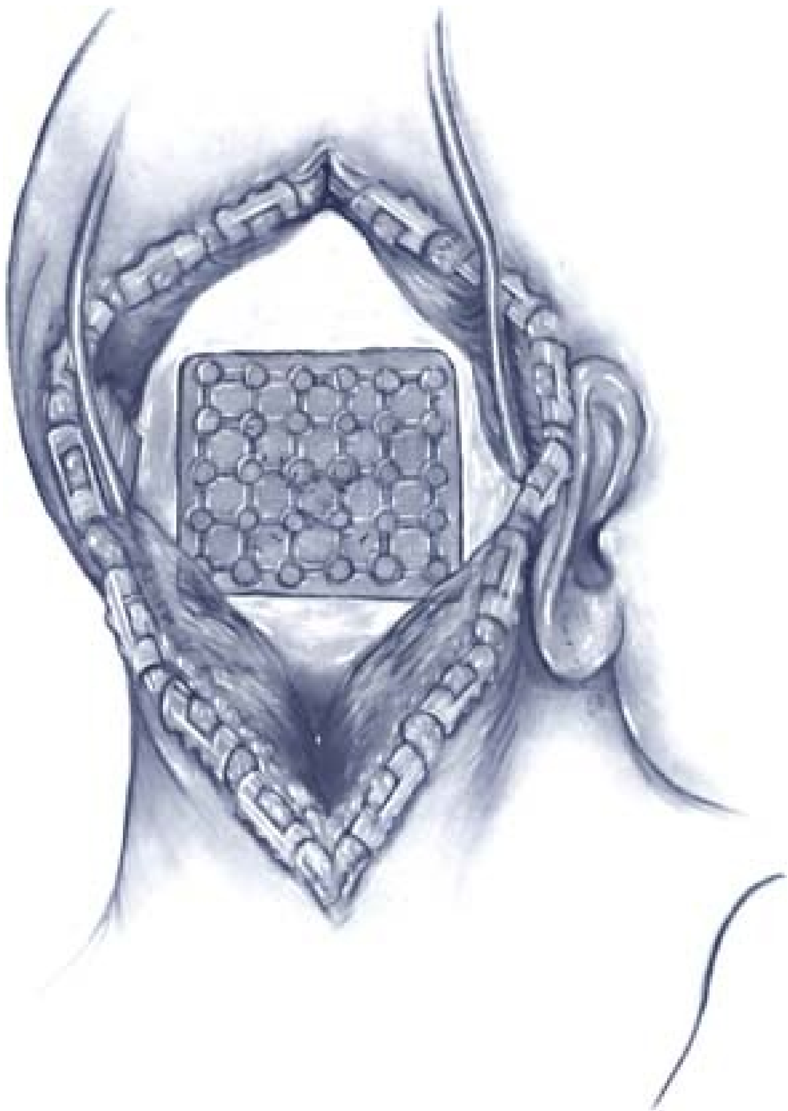


Figure 18

Closure of the skull defect with titanium mesh to reconstruct the bony craniotomy defect. Substantial overlays of the margins of the craniotomy should be avoided

Preservation of hearing

It has become increasingly obvious that preservation of hearing is a valid goal for many patients. In our experience, the techniques required for hearing preservation are quite different than those used when VIIth nerve preservation is the only goal. The VIIth nerve can be stripped from the tumor capsule using sharp dissection to free adhesions and redundant nerve weighted down with small cotton pledgets without increased risk. The VIIIth nerve does not tolerate even these minor manipulations. Continuous recording of VIIIth nerve potentials has provided insight into those surgical strategies that can best preserve auditory function.

Injury to the internal auditory artery or its branches must be avoided. Adhesions to the nerve must be performed with sharp dissection using scissors or a very sharp arachnoid knife. Blunt dissection, no matter how gentle, often results in loss of auditory potentials. Another issue which is often not appreciated is the loss of auditory signal or activation of VIIth nerve function during manipulations of portions of the tumor remote from those nerves. For that reason, we remove the tumor piecemeal with the least manipulation possible. The most hazardous part of the dissection with regard to hearing appears to be removal of the final remnants of the tumor that lie far lateral in the internal auditory canal. When the tumor does not reach the end of the canal, this maneuver is not difficult. However, when the tumor extends to the lateral reaches of the canal, it is common to suddenly lose the auditory signal during the dissection of the last fragments of the tumor. This must be done with minimal traction applied to the cochlear nerve at what appears to be a particularly vulnerable point—where the nerve exits the cochlear modiolous.

COMPLICATIONS

Complications related to the suboccipital approach are not unique to other craniotomies. These include cerebrospinal fluid leak through the wound or circuitously through the perilabyrinthine air cells to the middle ear cleft and eustachian tube. In these cases, patients will present with cerebrospinal fluid rhinorrhea. There are also the potentials for postoperative hemorrhage, meningitis, and lower cranial neuropathy.

Intraoperative complications include excessive cerebellar retraction, leading to cerebellar edema, and potential stroke from vascular injury to the posterior circulation, such as the AICA, which may also lead to ischemia to the remnant vestibulocochlear bundle and inner ear. Adequate measures, therefore, must be made to reduce cerebellar swelling (intraoperative corticosteroids, mannitol, hyperventilation, periodic release of gentle cerebellar retraction, adequate release of spinal fluid from the cerebellopontine cistern). Breach into the bony and membranous labyrinth of the inner ear during exteriorization of the internal auditory canal may lead to hearing loss. Disruption of the cochlear nerve fibers at the lateral end of the internal auditory canal may result in hearing loss if tumor dissection is not carried from a medial to lateral direction. Facial nerve injury may occur at either the cerebellopontine or canalicular segments from either inadvertent transection or traction.

Delayed postoperative cephalgia has been implicated as a potential sequela of the suboccipital approach. Some have speculated that the etiology stems from the presence of bone dust left in the operative field, deep cervical muscular-dural adhesions from the healing process, or persistent arachnoiditis.

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Appendix I Large glomus tumor removal via the suboccipital approach

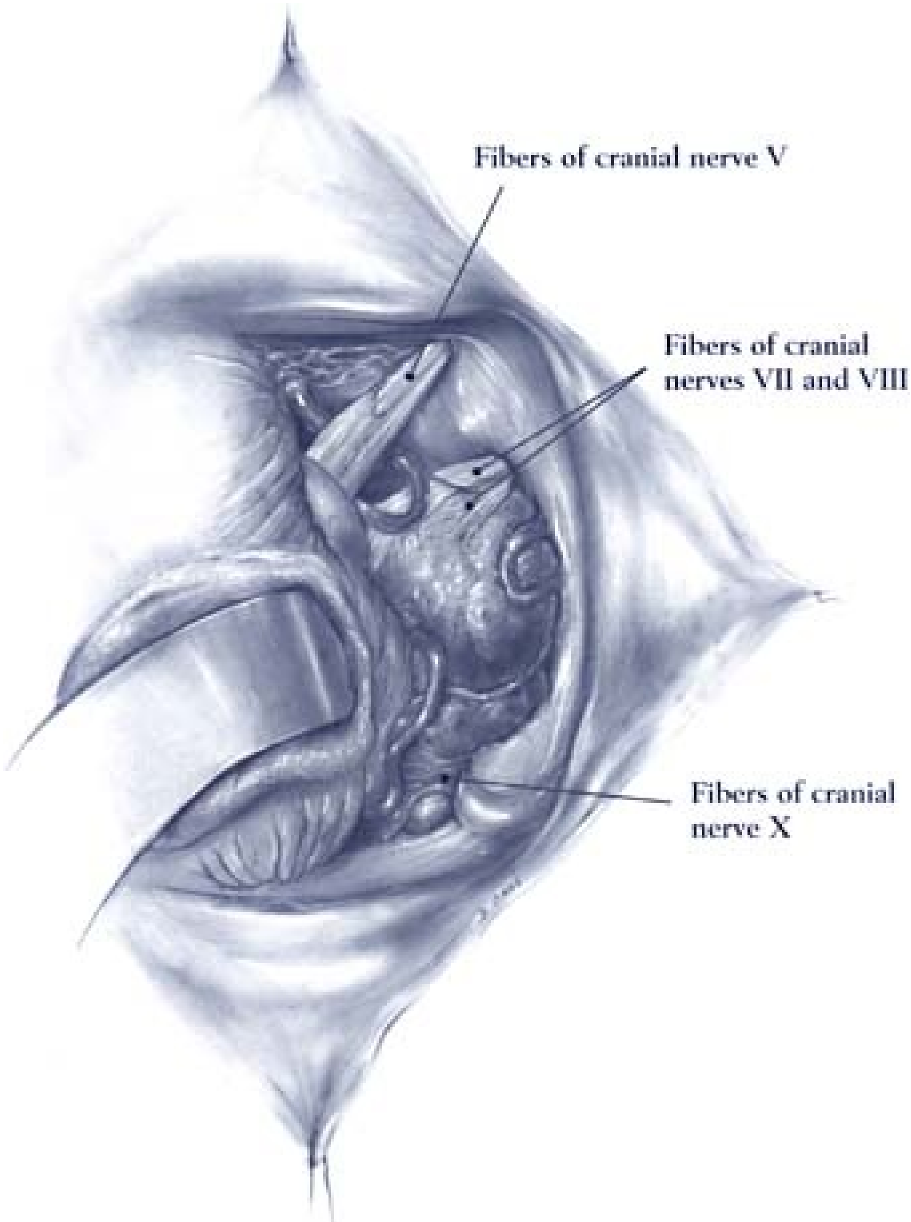


Plate 1

Debulking of a large glomus jugulare tumor extending into the right posterior cranial fossa. Note the involvement and displacement of the caudal cranial nerves by the tumor

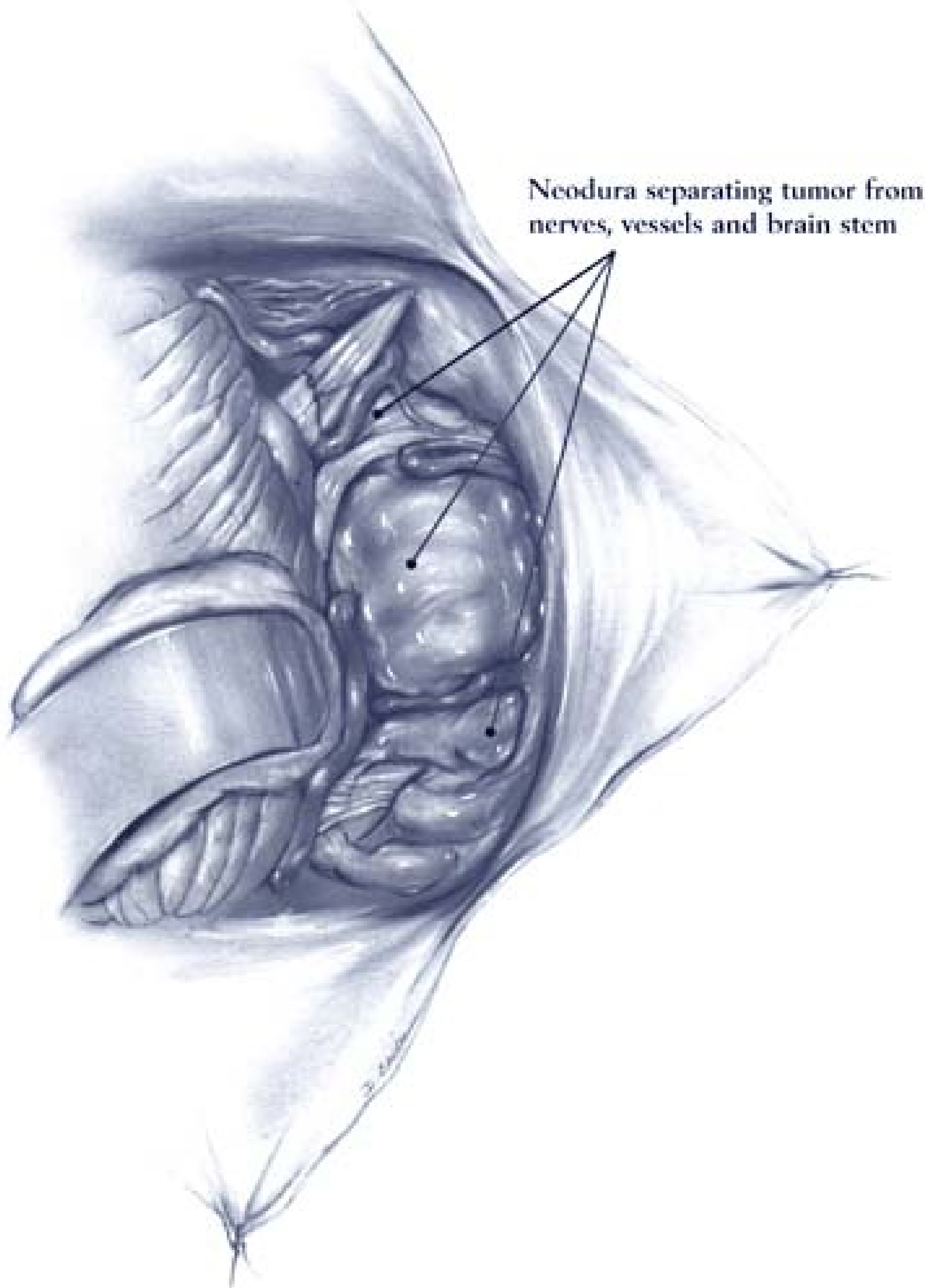


Plate 2

Removal of the intracranial portion of the glomus tumor has been completed. Dural reconstruction (creation of ‘neodura’) with fascia lata graft with apertures made into the graft to allow passage of the adjacent cranial nerves and vessels

Appendix II Fifth nerve schwannoma extending to the posterior fossa via the suboccipital approach

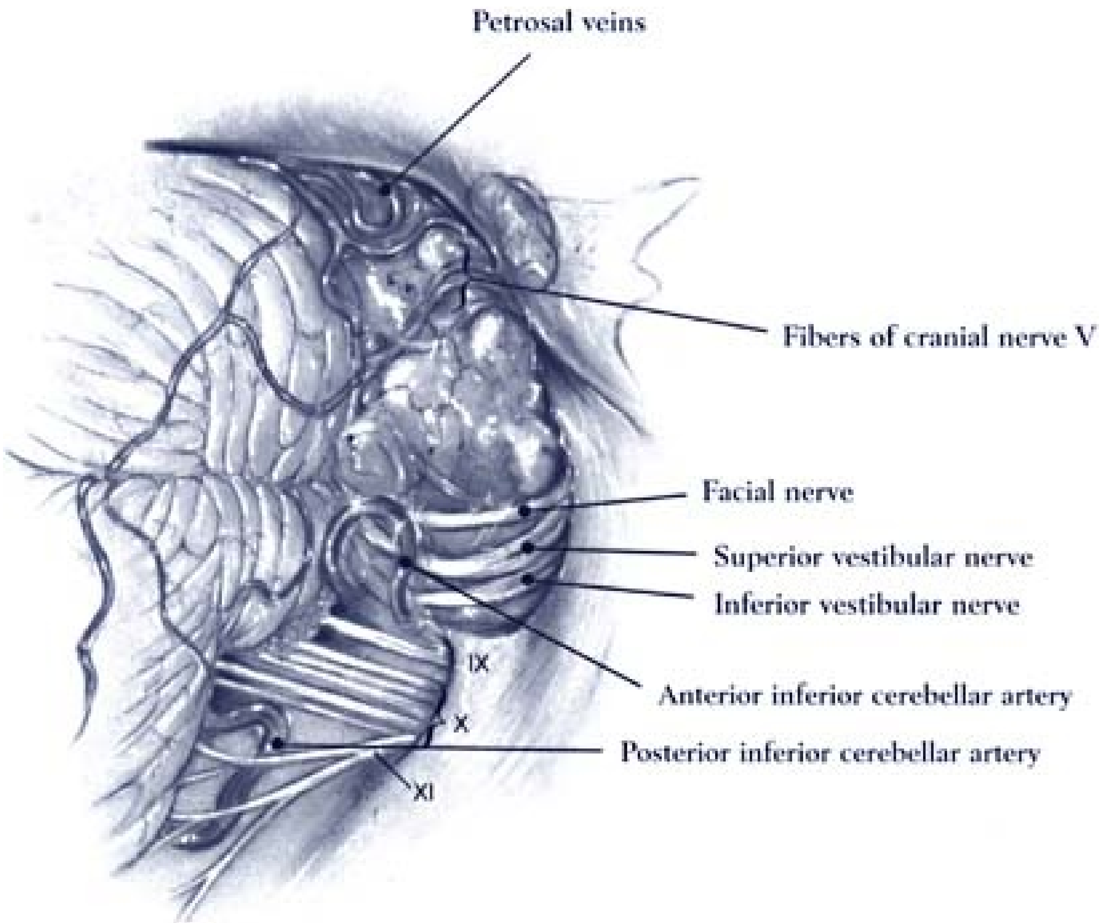


Plate 1

The posterior fossa component of a right fifth nerve schwannoma depicted with intimate involvement of the vestibulocochlear bundle

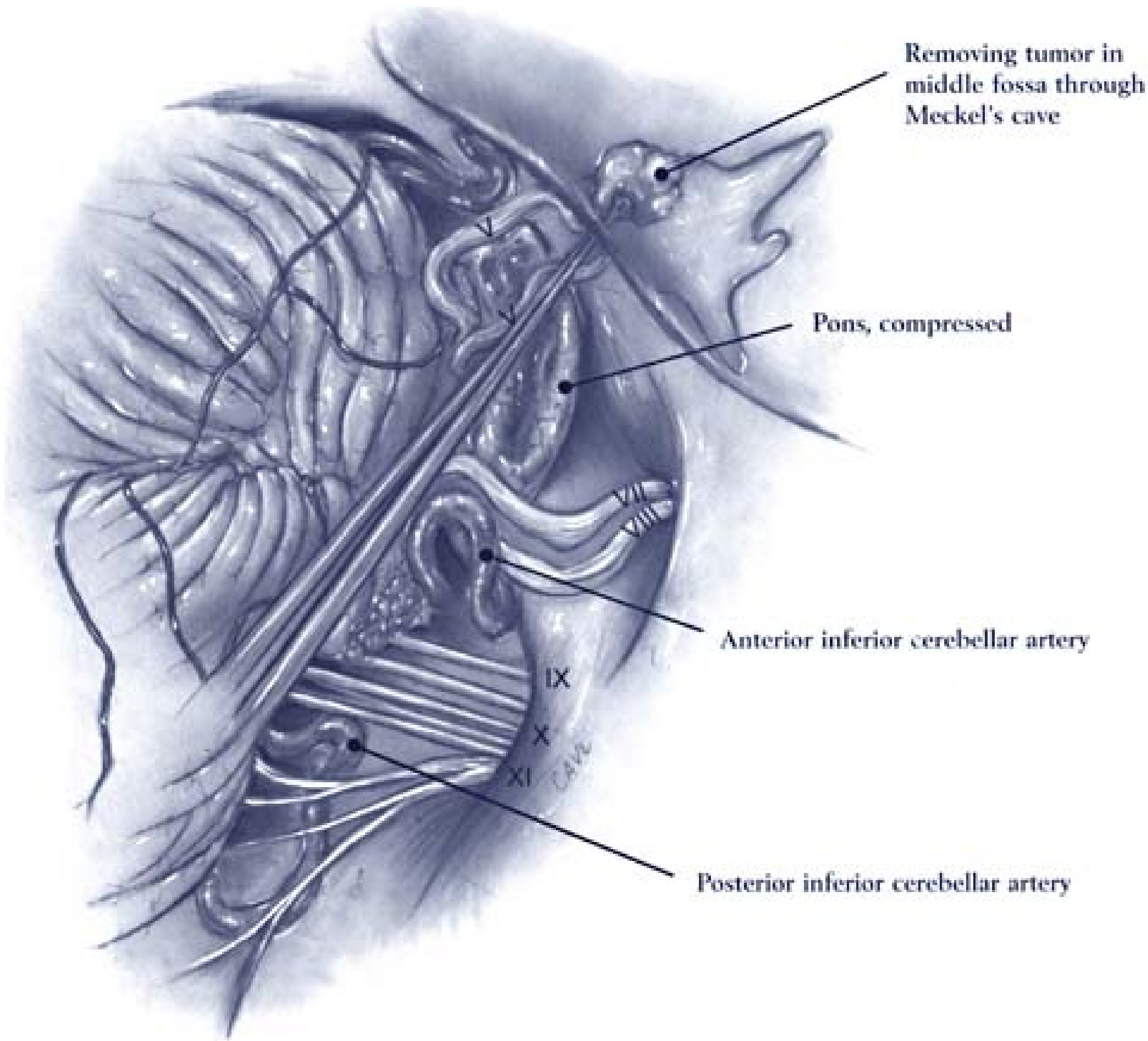
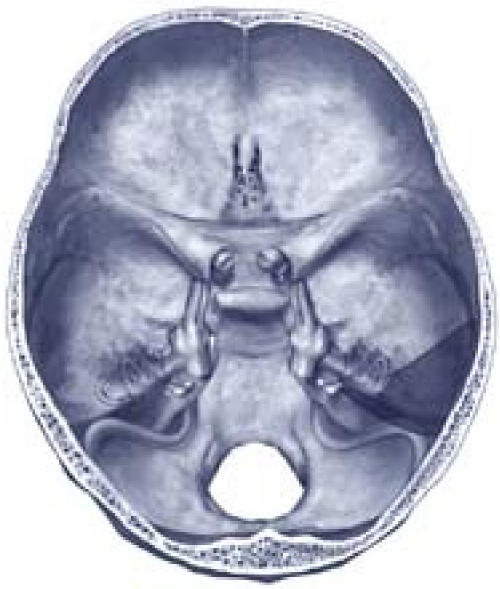


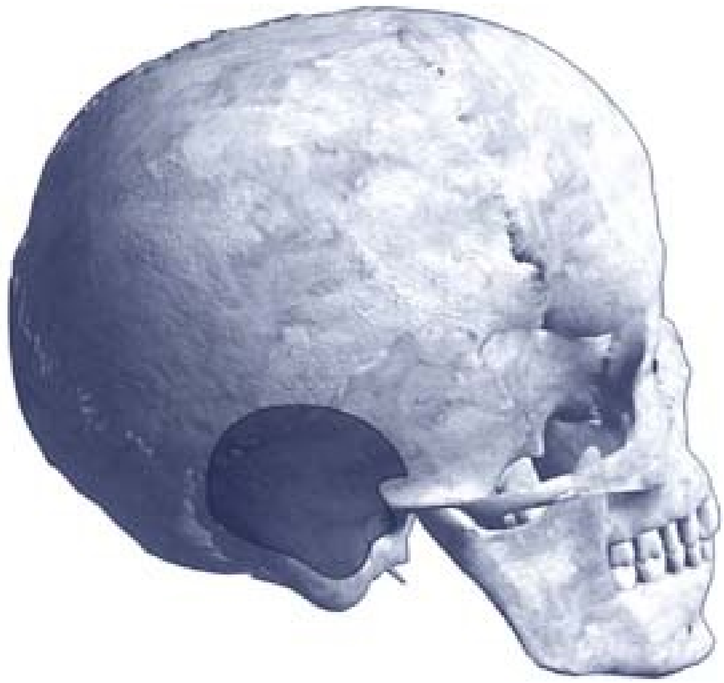
Plate 2

The middle fossa component of the tumor may be removed via Meckel's cave from the posterior fossa

15
Far lateral approach to the lower clivus and foramen magnum region

Donlin M.Long and Matthew Ng





INDICATIONS

Lesions of the foramen magnum may require an approach that provides wide exposure of the entire craniocervical junction. Meningiomas that involve the foramen magnum spread anteriorly up the clivus and down toward the cervical spine. These occasionally require a radical lateral approach for total tumor removal. The need for this surgery, however, is rare. Nearly all such tumors may be managed by an extensive posterior approach without undue risk to the brain stem. The usual indication for the far lateral approach, also known as the extreme lateral transcondylar approach, is the tumor situated in the mid-line and directly in front of the lower brain stem and spinal cord (Figure 1). As a result, control of the proximal vertebral artery gained with such an exposure may be a virtue, as the vertebral artery is identified, mobilized and transposed. Typically, these tumors are asymmetrical and the tumor mass may have already retracted the brain stem for the surgeon so that a radical posterior approach is satisfactory.

Other lesions accessible by this surgical approach include both intradural and extradural neurogenic lesions (chordomas, large glomus tumors), vascular lesions of the brain stem posterior circulation (arteriovenous malformations and aneurysms of the vertebrobasilar system), chondro-osseous lesions in the proximity of the craniocervical junction (chondromas, chondrosarcomas), and access to the atlanto-occipital and atlanto-axial junctions (Table 1).

The addition of a suboccipital approach, including mastoidectomy and removal of the posterior fossa dural plate with skeletonization of the sigmoid sinus, allows extension for access to the cerebellopontine angle. A combination of the infratemporal and subtemporal approaches may help to gain extended access to the middle and lower clival regions.

Table 1 Regions accessible by the far lateral approach

- Foramen magnum
- Lower clivus
- Hypoglossal canal
- Ventrolateral brain stem
- Spinomedullary junction
- Upper cervical spine and cervical nerve roots
- Vertebral artery and vertebrobasilar brain stem circulation
- Bony craniocervical junction: atlanto-occipital joint, atlanto-axial joint

Figure 1

Petroclival tumor displacing surrounding the caudal cranial nerves, brain stem and cerebellum

PATIENT EVALUATION

Preoperative clinical evaluation of the patient with lesions in the proximity of the craniocervical junction may reveal lower cranial nerve deficits that are important to note. The clinical examination, as well as the radiologic information, will often help to determine from which direction to approach the ventral mid-line lesion in this lateral approach, usually on the side with the pre-existing neurologic deficits. Particular attention should be given to protecting and preserving the contralateral lower cranial nerves during tumor removal to prevent devastating functional deficits with the airway speech, and oromotor functioning, usually associated with bilateral lower cranial neuropathy

Valuable information can be gained from both magnetic resonance imaging (MRI) and computed tomography (CT). CT imaging allows assessment of the bony craniocervical junction, particularly the occipital condylar-atlas-axis joint interfaces, and a view through the bony aperture of the foramen magnum. MRI indicates the extent of the tumor in relation to the brain stem and the upper spinal cord within the narrow bony confines of the posterior cranial fossa, foramen magnum and spinal canal (Figure 2). An additional feature of MRI is angiography (MRA) which will help to determine vertebral artery patency. Conventional vertebral artery angiography, however, can provide even more detailed

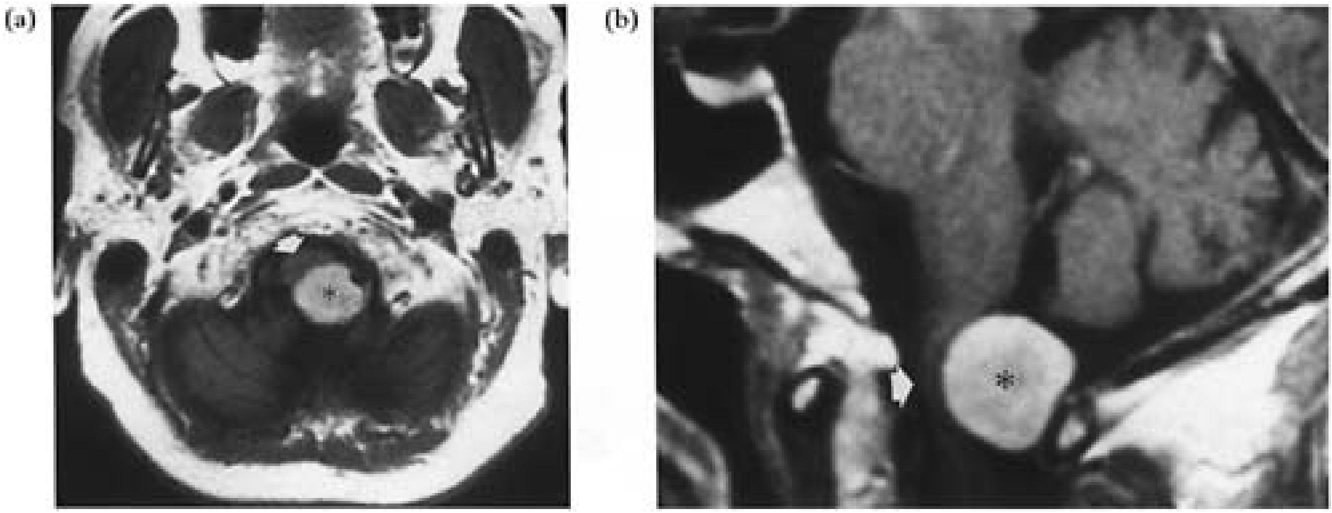


Figure 2

Foramen magnum meningioma. (a) T1-weighted axial MRI scan of meningioma (*) abutting the posterior margin of the foramen magnum. The white arrow shows the compressed brain stem; (b) sagittal T1-weighted image using gadolinium of the same tumor

anatomic information, as well as the functional status of the contralateral vertebral artery, in case the surgeon is faced with the decision to sacrifice or repair the injured vertebral artery. Arteriography may help to address lesions amenable to preoperative embolization, if necessary Vascular lesions, such as aneurysms, can be equally imaged quite well, demonstrating their relationship to surrounding vital structures (Figure 3)

ANATOMICAL CONSIDERATIONS

The strategy of the far lateral approach is to access lesions of the craniocervical junction, with the benefits of proximal control and mobilization of the vertebral artery, minimal rotation and retraction of the neural axis, and the opportunity to combine other approaches, such as the subtemporal-infratemporal and suboccipital approaches, to expand the field of exposure. Key steps involve identification and mobilization of the vertebral artery from the vertebral level of the C2 transverse foramen to its intradural entry, bony removal of the lateral occipital bone and occipital condyle, partial or hemilaminectomy of the atlas and axis, tumor removal, and stabilization of the craniocervical junction, if necessary (Figure 4). Familiarity with the neurovascular structures in and around the foramen magnum, hypoglossal canal, and jugular foramen is essential for the best functional results.

One of the main areas of focus during the operation is the vertebral artery. The vertebral artery is responsible for the blood supply to the upper spinal cord, brain stem, cerebellum and the postero-inferior portion of the cerebral cortex. It originates from the subclavian artery and courses through the transverse foramina of the cervical vertebrae prior to penetrating the posterior atlanto-occipital membrane to enter intradurally into the intracranial cavity. Its entry into the cervical vertebral transverse foramina usually begins at C6, but may begin variably as low as C7 or as high as C4. The two vertebral arteries ascend through the foramen magnum to join and form the basilar artery at the caudal end of the pons (pontomedullary junction). The best location to identify the vertebral artery in the far lateral approach is between the atlas and axis, found at the caudal border of the obliquus inferior muscle. As the vertebral artery exits the transverse foramen of the atlas, it courses posteromedially in the arterial sulcus of the atlas (posterior atlas arch), prior to piercing the posterior atlanto-occipital

(a) (b)

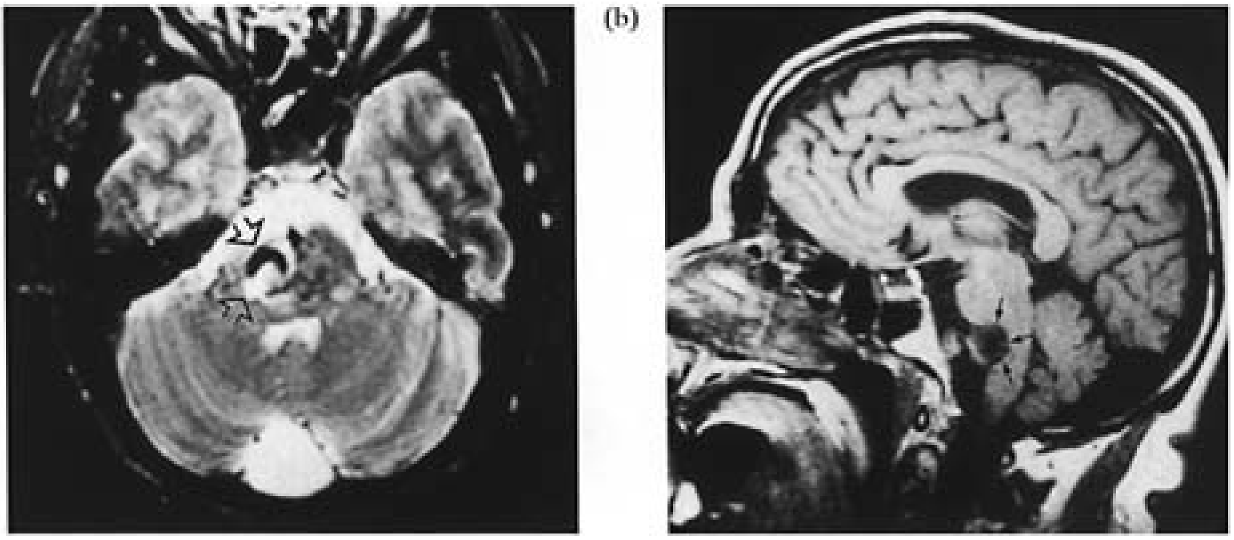


Figure 3

Vertebro-basilar aneurysm approachable by the far lateral approach. The advantage of this approach is the direct vascular control of the vertebral artery. (a) Arrows show aneurysm on this axial MRI; (b) sagittal T1-weighted MRI of same aneurysm at the pontomedullary junction

membrane. As the artery courses over this sulcus after its exit-from the C1 transverse foramen, the suboccipital nerve (dorsal ramus of C1) may be found interposed between the artery and C1. The vertebral artery is located ventral to the facet joints of the cervical vertebrae and ventral to the cervical nerve rootlets.

PROCEDURE

The operation can be carried out with the patient in the prone or sitting position. Because of the potential necessity for exposure of the sigmoid sinus and jugular bulb, the prone (park bench) position is preferred. Stabilization of the head using a Mayfield head-holder is performed with the head in a lateral, slightly flexed position. Provisions for electrophysiologic monitoring of the lower cranial nerves and somatosensory evoked potentials are made.

The typical suboccipital craniotomy incision is made and extended down the neck parallel to the transverse processes of the cervical vertebra, with the inferior extent as low as the C3 vertebral spinal level.

The occipital bone is exposed along with the vertebral transverse processes, laminae, and bases of the spinous processes of C2 and C3 after division and retraction of the posterior nuchal musculature. C1 is exposed medially from the transverse process toward the mid-line. Remember to palpate and identify the vertebral artery between the occiput and C1 laterally. At this point, the vertebral artery should not be fully exposed, as it occasionally loops far medially and injury must be avoided.

Remove the muscle from the transverse processes of C2 and C3, avoiding injury to the corresponding cervical nerve rootlets. At the top of the C2 transverse process, the vertebral artery will be encountered where it exits from its transverse foramen. The vertebral artery should then be dissected free from the surrounding soft tissues and mobilized. There is an extensive venous plexus around the artery and its mobilization may be time-consuming if excessive bleeding is encountered. Remove the bone over the vertebral artery at C2 and C3. Remember the vertebral artery may be very adherent to the periosteum, and vascular injury is possible if the bony removal is not carefully performed (Figure 5).

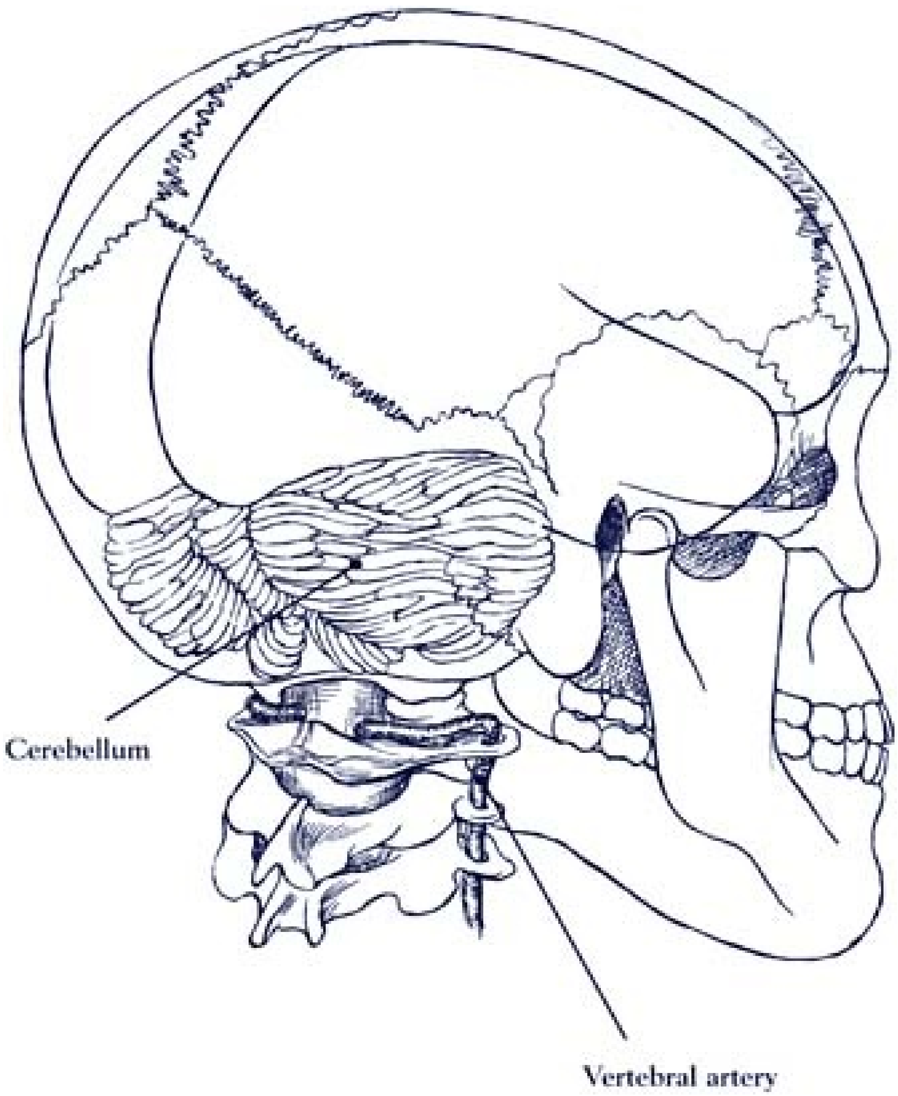


Figure 4

extradural course of the artery with its relationship the cervical vertebrae

Follow the loop of the vertebral artery over C1 up to the base of the skull. The lateral half of the C1 vertebra is removed, and the bony removal of C2 and C3 extended to include their laminae. This will expose the spinal canal up to the foramen magnum. Next, remove the bone overlying the posterior fossa, exposing the dura to the jugular bulb and transverse sinus. The medial exposure should be to the mid-line and the exposure superiorly depends upon the size of the tumor and the distance up the clivus one must go.

The dura is opened parallel to the transverse sinus and to the position of the spinal cord behind the root entry zone. This will allow the exposure of the lower brain stem, cervicomedullary junction, and upper spinal cord. The advantage of the prone position for the surgery is that the table can now be rotated away from the surgeon, providing substantial retraction from gravity

Many of these tumors require division of the C2 and C3 nerve rootlets. If possible, work between the roots. If not.

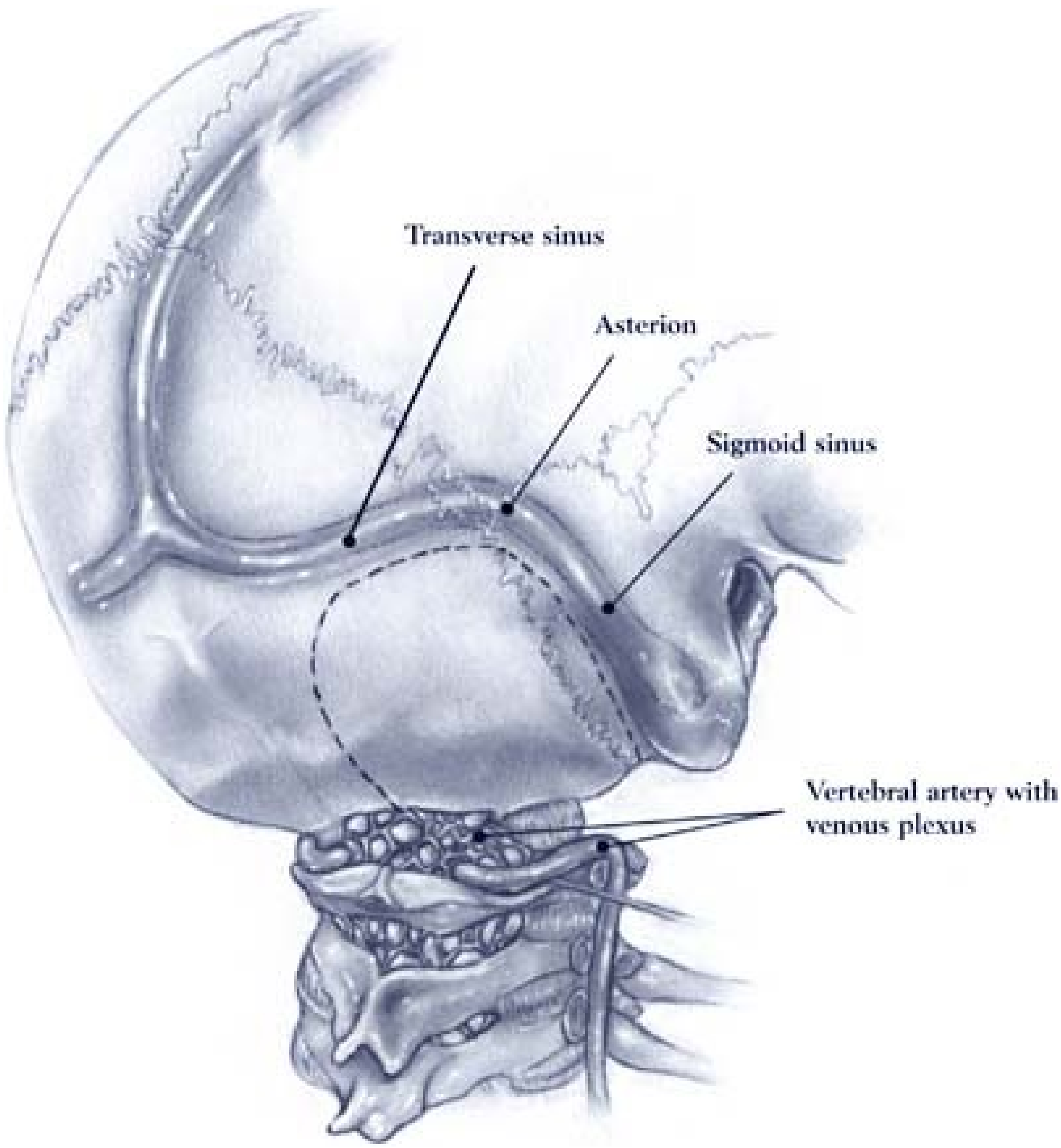


Figure 5

Isolation and dissection of the vertebral artery and cervical vertebrae C1, C2, C3. Note the extensive venous plexus within this region

the rootlets can be clamped and cut, with bleeding vessels coagulated by fine bipolar coagulation. Self-retaining adjustable retractors can be placed upon the brain stem and spinal cord, but retraction must be gentle: the less, the better. All manipulations should be performed under neurophysiological monitoring, and the retractors should be released and moved on a timed schedule. Use no more retraction than is necessary for the area where the surgeon is working.

The anatomical considerations are extremely important. All of the following structures may be involved in or obscured by the tumor (Figure 6). First, locate cranial nerves IX, X, and XI. Then visualize the location of the XIIth nerve. A unilateral XIIth nerve palsy is not a serious problem, but a bilateral paralysis is a catastrophe. Since many of these tumors are mid-line, the XIIth nerves are often bilaterally involved. Visualize the vertebral artery and its relationships to the tumor. Tumors often surround the vertebral artery

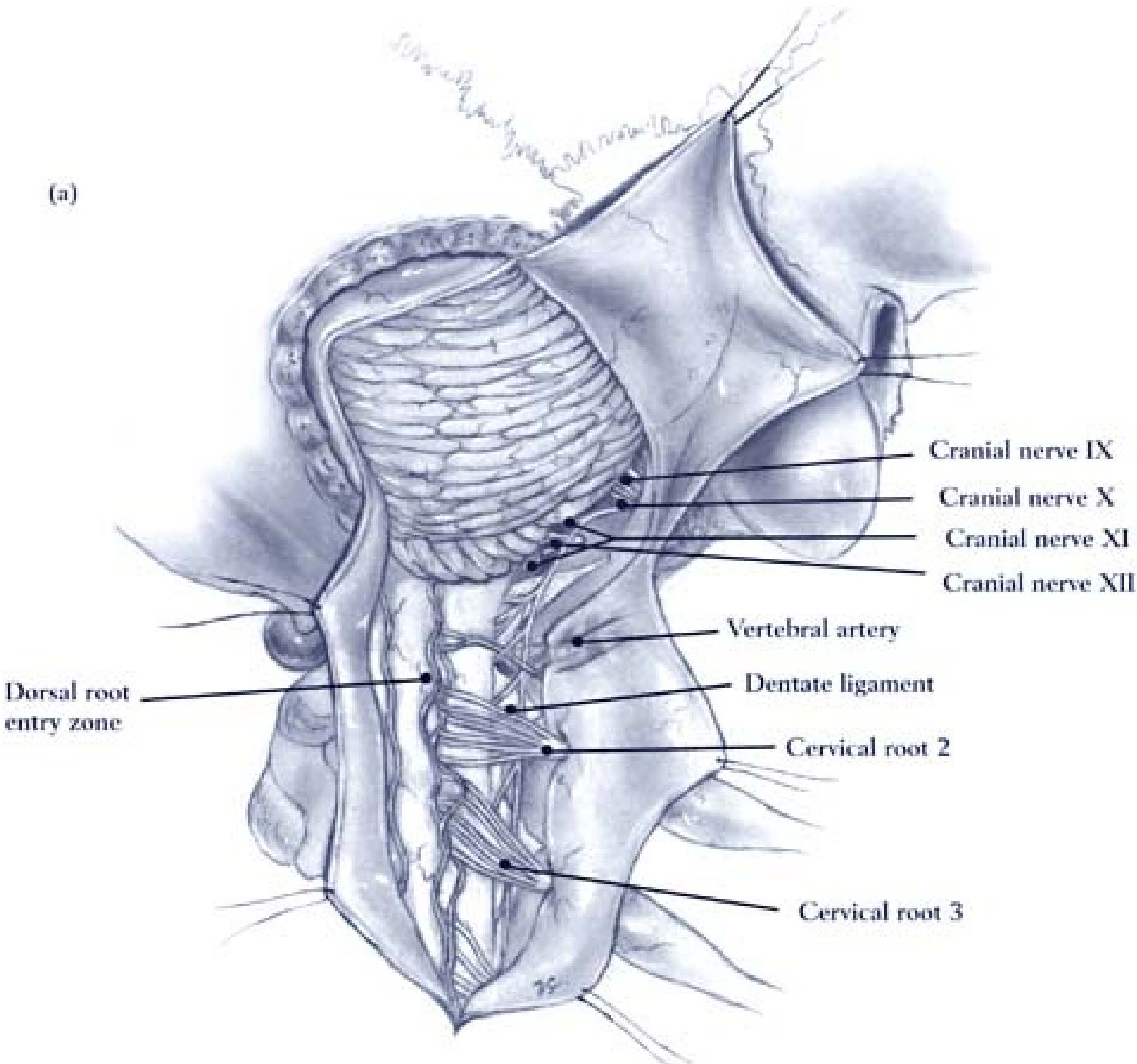
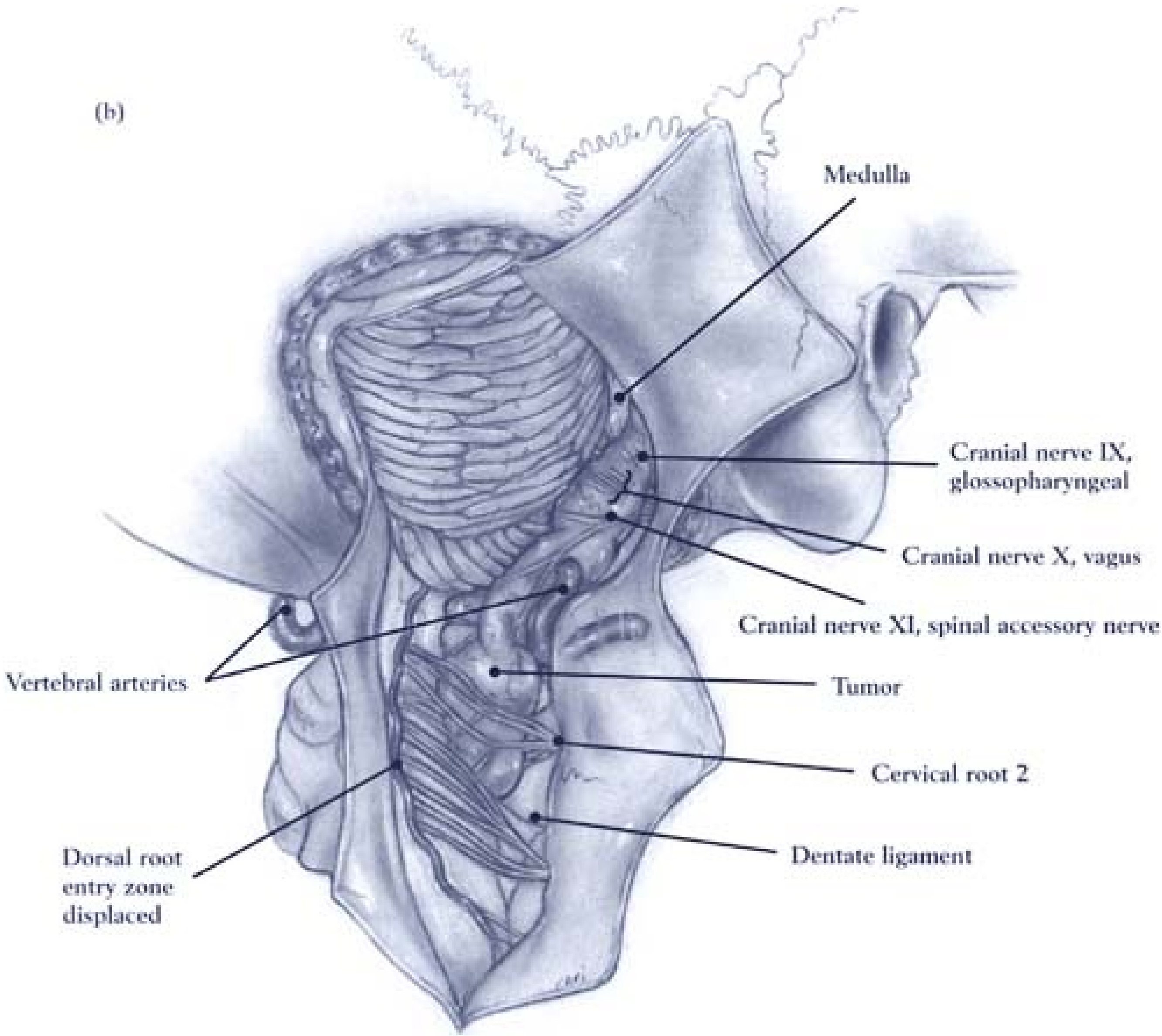


Figure 6

(a) Dural opening to expose the cerebellum, pontomedullary junction, caudal cranial nerves; intradural vertebrobasilar artery system; and cervical nerve rootlets; (b) dural opening with tumor exposed. The surrounding structures are displaced by the tumor *(see opposite page)*

(b)


Medulla
Cranial nerve IX, glossopharyngeal
Cranial nerve X, vagus
Cranial nerve XI, spinal accessory nerve
Vertebral arteries
Tumor
Cervical root 2
Dentate ligament
Dorsal root entry zone displaced

and the vessel must be dissected throughout most of its intracranial course. If the upper cervical roots can be salvaged, they should be, but dividing them for exposure and good tumor removal is acceptable. Most meningiomas are firm and vascular. The ultrasonic dissector is an excellent way to remove them. The laser is also a helpful adjunct.

Begin by debulking the tumor throughout its length and begin to dissect the vertebral artery and its vascular branches out of the tumor. Then free the lower cranial nerves from the collapsing capsule. If the tumor is very vascular, it may be useful now to separate the base of the tumor from the dura, since this will effectively destroy the blood supply. If the tumor is not so vascular, the brain stem dissection can now follow. In the event of a serious problem, the base could be left, whereas, without the brain stem dissection, it is unlikely that surgery will have accomplished the desired goal of brain stem decompression. Occasionally one of these tumors is very soft and is easily removed with suction or the ultrasonic dissector. Then the tumor is gradually debulked and teased away from surrounding structures, while keeping it under tension for delivery with suction. Once the tumor is completely removed, the laser is used to vaporize the dura of the base. Areas of particular attachment are usually around the vertebral artery and the jugular bulb. Make sure the XIIth nerve is not injured during the laser coagulation.

The dura is then closed in a watertight fashion, unless there is an extradural component of the tumor as well. In that case, the remainder of the tumor is removed and the intervening dura should be taken with it. A dural patch would then be required. An alternative is to perform the operation in two stages. For this alternative, once the intracranial tumor is removed, the next step is simply to place a fascia lata graft, as described in Chapter 8. The extracranial tumor and involved dura will be removed at a second stage.

Removal of the occipitocervical condyle

The far lateral approach offers lateral access, but offers little real advantage over a posterior approach unless the articulating condyle is removed. To do this, once the exposure is completed as described, a high-speed drill is used to remove the bone of the occipital condyle. Rongeurs may be employed to perform this task, but drilling is much more precise and expeditious.

All or part of the condyle can be removed, giving access to the mid-line and beyond at the foramen magnum (Figure 7). To date, we have never found this approach necessary with an intradural foramen magnum tumor and have employed it exclusively for bony tumors of the craniocervical junction. Extradural masses that are directly mid-line are best approached by a transoral route (Chapter 5).

Removal of the condyle unilaterally necessitates posterior cervical fusion. When this is contemplated, the original exposure is modified by leaving transverse processes and laminae intact and leaving more occipital bone, so that rigid fixation plates may be secured to these areas. A cervical fusion is required. The fusion may be unilateral or bilateral, but, with an intact condylar articulation on the opposite side, unilateral fusion is all that is required.

The fusion

There are many techniques available, but the posterior cervical titanium rigid-fixation plates provide the simplest way to carry out fusion while achieving immediate stability (Figure 8). Improvements in fixators will change these cervical-occipital fusion techniques continuously. In order to use these plates effectively it is necessary to expose the laminae and transverse processes of the C2 and C3 vertebrae and have intact occipital bone to accept the plates and screws. For tumors whose removal necessitates upper cervical laminectomy and extensive removal of occipital bone, the far lateral approach is not a good choice.

Once the bone is exposed, it is roughened with a high-speed cutting burr and the cortical surfaces punctured in many places. Intact cervical vertebral joints should be opened and their cartilaginous surfaces drilled away. The bone obtained during skull and spine removal can be collected, morselized, and used for the fusion. Harvesting a bone graft from the posterior iliac crest will provide more reliable fusion. Once the free bone graft is harvested, a posterior cervical plate should be fashioned to fit the exposed area. Be certain that the head and neck are appropriately aligned in the neutral position prior to securing the plates and bone graft. Screws are engaged in the occiput and lateral masses of C2 and C3. The far lateral exposure makes the direct visualization of the vertebral artery possible during the placement of the screws, so that the safety of the vertebral artery is ensured.

Once the fusion is complete, inspect the dural closure line for leaks. Cerebrospinal fluid fistula in this situation is

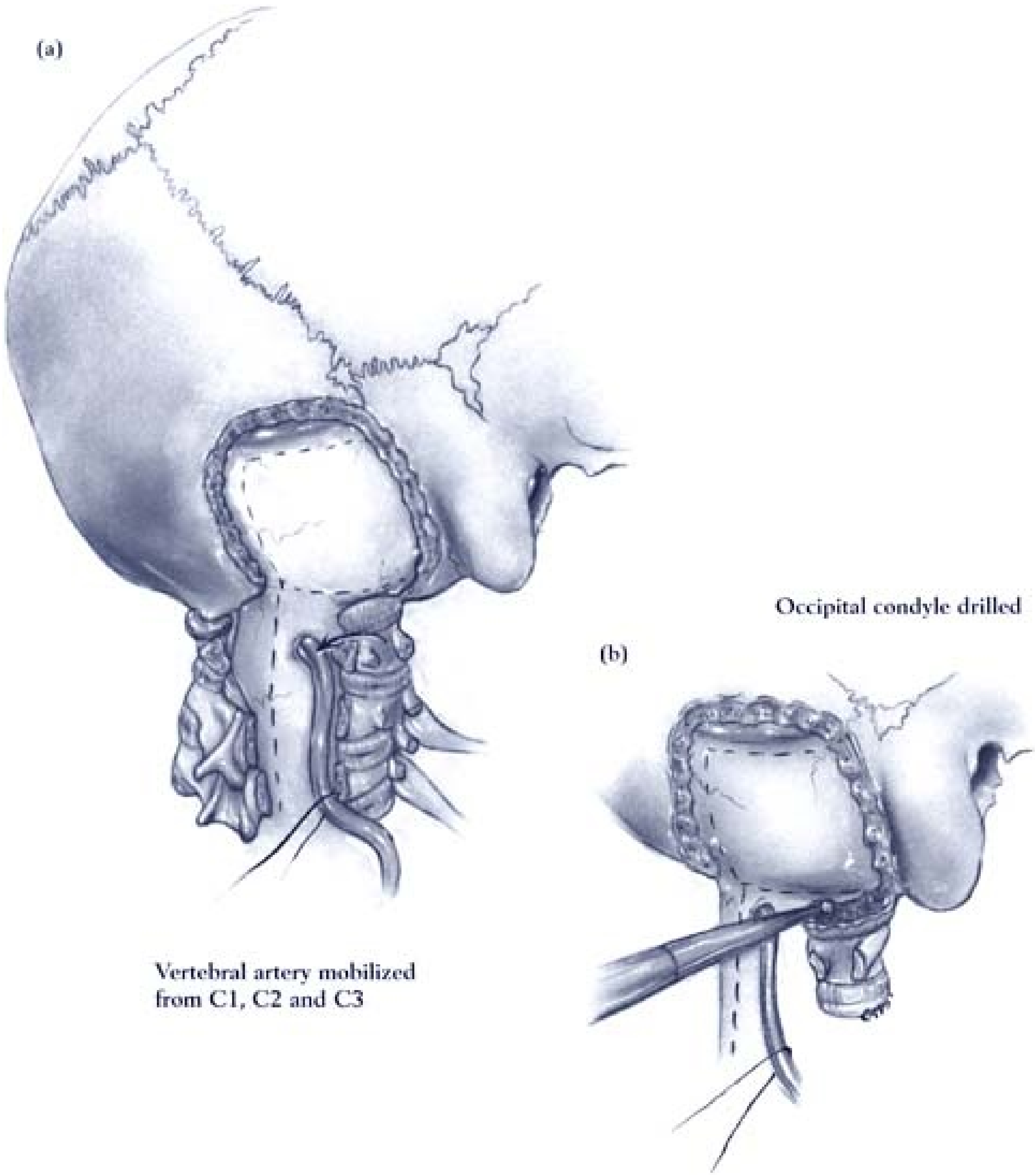


Figure 7

(a) Mobilization of the vertebral artery; (b) removal of the occipital condyle with the drill

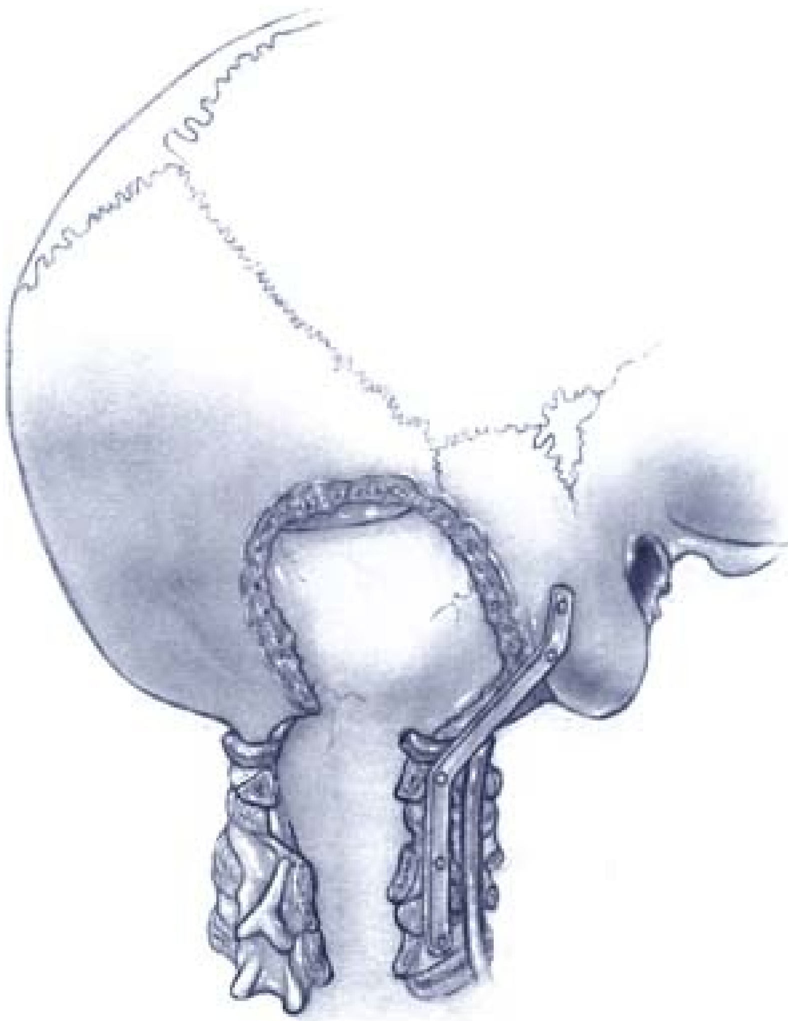


Figure 8

Cervical fusion performed with rigid fixation plates particularly dangerous. The wound is closed by careful and meticulous anatomic reconstruction.

Anatomy of the cervical musculature

It is worthwhile to review the anatomy of the origins and insertions of posterior nuchal musculature, as they are encountered during the exposure of the occiput and cervical vertebrae. There are several layers of musculature which must be traversed. The occipitofrontalis muscle is found superior to the line of attachment at the superior nuchal line. The trapezius and sternocleidomastoid muscles are usually detached from the superior nuchal line and reflected inferiorly. The sternocleidomastoid muscle has an additional attachment to the posterolateral mastoid process. The next layer of deeper musculature includes the semispinalis capitis, splenius capitis, and longissimus capitis muscles. The semispinalis capitis and splenius capitis muscles attach either on or below the superior nuchal line under cover of the trapezius muscle. The longissimus capitis muscle, located most laterally of the three muscles, attaches to the mastoid process. The deepest layer of musculature closest to the cervical vertebrae includes the obliquus capitis superior, obliquus capitis inferior, rectus capitis posterior minor and rectus capitis posterior major muscles. Their attachments to the occipital bone, spinous processes of C1 and C2, and to the transverse process of C1 must be removed to gain access to the occipitocervical junction and vertebral artery. Three of the muscles form the suboccipital muscular triangle within which the vertebral artery and suboccipital nerve may be found. These three muscles include the obliquus capitis major and minor muscles and the rectus capitis posterior major muscles.

COMPLICATIONS

There are several potential complications relevant to this surgical approach. Due to the requirement to identify and mobilize the vertebral artery, it naturally places the artery at risk for injury during the dissection. An idea of the contralateral vertebral artery patency and function (medullary contribution) is helpful in reaching a decision for either vertebral artery repair or sacrifice, in the case of vascular injury. This information is obtained on preoperative angiography or MRA of the vertebral arteries.

Craniocervical junction instability is a distinct possibility if extensive bony removal of the occipital condyle (greater than two-thirds of the posterior occipital condyle), atlas lateral mass, or axis facet joint is performed and no stabilization is attempted.

Finally, due to the proximity of the surgical field to the lower cranial nerves, they are also at risk for injury. One serious complication to the lower cranial nerves is related to the exposure. Particularly, the XIth cranial nerve may be injured in its extracranial portion if the skin incision is carried too far anteriorly Extubation and institution of an oral diet can only take place after thorough assurance of normal lower cranial nerve function postoperatively. Preparations for tracheostomy or enteral feedings must be initiated if there is lower cranial nerve dysfunction.

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Comptications in skull base, surgery: avoidance and management

Matthew Ng, Daniel J.Lee, Lawrence R.Lustig and John K.Niparko

INTRODUCTION

The success of skull base surgery hinges on obtaining adequate surgical exposure in one of the most anatomically complex areas of the head and neck, followed by surgical treatment of the pathology at hand, and anatomic reconstruction/physiologic restoration of the region that has been altered. Both soft tissue and bone around the central nervous system and neurovascular structures, such as cranial nerves, internal carotid artery and cavernous sinus, may be removed, transposed, retracted, or even sacrificed to gain the necessary exposure. Consequently, the anatomical barriers between the central nervous system and the extracranium are disrupted. The intracranial biochemical mileau and cerebrospinal fluiddynamics must be restored. Functional disability must be kept to a minimum. All this is attempted while trying to reduce morbidity and mortality.

Complications occur during and after skull base surgery. They are potentially devastating and life-threatening. As a result, the surgeon’s attention should be directed on *complication prevention,* holding continuous vigilance for impending complications, and aggressive treatment of the complications that occur as soon as they are manifest.

Since this chapter on complications in skull base surgery is written in the context of a surgical atlas, there is a focus on the preoperative planning, surgical technical issues, and postoperative management to help to prevent and treat complications. This chapter is organized according to region-specific complications. While similar complications can occur anywhere along the anterior, middle, and posterior skull base, the principles of management will be similar. However, there are complications that develop by virtue of the proximity of the operative field to a particular region of the skull base and these will require special consideration and treatment. Specific complications related to individual surgical approaches are discussed separately in each chapter of this Atlas.

ANTERIOR CRANIAL BASE SURGERY

Surgery in the anterior cranial base is commonly performed for parenchymal, neural and nerve sheath-based tumors in the frontal region (meningiomas, schwannomas, esthesioneuroblastomas and gliomas), primary bone, cartilage or soft tissue tumors (fibrous dysplasia, ossifying fibroma, osteosarcoma, chondrosarcoma, rhabdomyosarcoma), sinonasal malignancies with intracranial extension, and orbital tumors. Surgical access to this region is usually through a coronal incision and frontal craniotomy or some form of a transfacial approach, traversing the nasal cavity and paranasal sinuses. The temporary removal of the bony facial skeletal units facilitates the exposure for the surgical extirpation phase. During the reconstruction phase of the operation, these facial segments are returned to their appropriate skeletal relationships and stabilized with miniplate fixation techniques. Such are the cases in the transfacial and anterior craniofacial resection approaches described in this book.

Intuitively most of the complications arise from violation of the boundaries which separate the anterior cranial fossa from the extracranium. Communication with the nasal cavity and paranasal sinuses increases the chances of infectious complications, cerebrospinal fluidfistulae, and pneumocephalus. Proximity of the operative field to the orbit may also potentially compromise vision, orbital muscle movement and tear drainage.

Finally, since the transfacial approaches involve facial incisions and removal of the bony facial segments, there are cosmetic concerns as well. The reader is referred to a number of references pertaining to complications in anterior skull base surgery for detailed information1–6. These references reflect the evolution of the practices and surgical techniques in this region of the skull base.

Cerebrospinal fluid leak

Cerebrospinal fluid leak following anterior cranial base surgery is particularly worrisome due to the proximity of the fistulous site to the bacteria-laden intranasal cavity. Cerebrospinal fluid leaks of this type occur when there is a breach in the integrity of the dura and a consequential communication between the subarachnoid space and sinonasal cavity. Clinical presentation includes watery rhinorrhea, which is induced on leaning the head forward in the ‘sniffing position’, or drainage posteriorly into the nasopharynx and the back of the throat when lying supine.

It may be either spontaneous or precipitated with maneuvers that temporarily increase intracranial pressure, such as a Valsalva maneuver. Cerebrospinal fluid leaks may be immediate or delayed.

The simplest means to identify the source of a postoperative cerebrospinal fluid leak is inspection of the intranasal cavity with particular attention to the fovea ethmoidalis and cribriform plate, as well as paranasal sinus ostia. Rigid endoscopes are particularly useful for visual localization of the cerebrospinal fluid leak. Such an examination should provide an idea of the size of the defect, the presence of an encephalocele, the amount of room available within the nose to operate if a transnasal approach for repair is to be used, and the viable tissue in the adjacent areas to be used for pedicled mucosal flaps and reconstruction.

Radiographic means of identification of a cerebrospinal fluid leak from the anterior cranial base include computed tomography with thin sections (usually 1–2 mm thickness, bone algorithm windows) for evaluation of the bony details of the floor of the anterior cranial fossa and related foramina. The CT scan may reveal bony defects created surgically or by the tumor. Bony defects should be serially traced in consecutive coronal sections to estimate the size of the defect. Air-fluid levels within the paranasal sinuses, while the patient is in a dependent position, may suggest cerebrospinal fluid within the sinus. However, this scenario may also represent a blood collection in the sinus after surgery. Careful inspection of the ethmoid roof and cribriform plate, frontal and sphenoid sinus ostia will often identify the source. The surgeon should always be cognizant of the possibility of cerebrospinal fluid leaking from *multiple* sources, especially if the surgery was extensive and more than one sinus violated. If this is the case, repair of the leak may require an approach that will allow wide and simultaneous exposure of these multiple sites for repair. In other words, it may be easier to repair multiple defects in the floor of the anterior cranial fossa via a frontal craniotomy and pericranial flap, rather than repairing multiple sites intranasally where there is a chance that other defects may be missed.

Other localization modalities include the use of radiocontrast material, such as metrizimide, placed intrathecally in conjunction with a CT scan7. The leak, however, must be an active one in order to demonstrate its precise location.

Radionuclide scanning may alternatively be performed. A radioactive tracer substance, such as iridium, is placed intrathecally via lumbar puncture. Cottonoid pledgets are positioned within the nasal cavity in the middle meatus/frontal recess area, sphenoethmoid recess, roof of the nasal cavity and eustachian tube orifice8. Pledgets with correspondingly high radionuclide counts suggest the most likely areas of leak, depending on their location.

Biochemical confirmation of cerebrospinal fluid leak may be performed with a β2-transferrin protein assay9. The test is more sensitive than specific. Sufficient quantities of fluid must be collected, and the laboratory turnover time is variable. Therefore, rapid identification of the collected fluid specimen is not possible.

Prevention of cerebrospinal fluid leaks during anterior cranial base surgery begins with meticulous elevation and closure of the dura. The dura is particularly adherent to the floor of the anterior cranial fossa and multiple foramina for a number of nerves and blood vessels. Small rents may occur during dural elevation. If small tears are present, they should be suture-repaired primarily. Repair of dural tears should be performed as they occur to reduce the time for potential bacterial entry and contamination of the intradural spaces. This is most important and relevant when the sinonasal cavity has been already opened into the operative field.

After the surgical resection, efforts should be concentrated on restoring a watertight barrier. When dura is missing or primary closure is not possible, fascia lata or temporalis fascia is harvested to help to bridge the edges for dural closure. Non-autogenous materials; commercially available dural substitutes, have been used in the same manner, as an alternative. However, the best choice is healthy vascularized autogenous tissue which is introduced to aid in wound closure for large dural defects. Vascularized tissue, either in the form of pedicled flaps or free tissue transfer, provides bulk and support for the repair while minimizing chances of infection typically associated with the use of foreign, non-autogenous materials.

Restoration and reconstruction of a barrier between the sinonasal cavity and the intracranial space are necessary in addition to watertight dural closure. Split-thickness calvarial free bone grafts may be positioned under the frontal lobes to provide rigid structural support and prevent an encephalocele or meningo-encephalocele. The use of a viable pericranial flap, consisting of the periosteal and loose layers of the scalp based on vascular supply from the supraorbital and supratrochlear arteries, helps to provide an additional layer of support10,11. If the bony support of the anterior cranial fossa floor is already present; this pericranial flap may also be alternatively positioned under the frontal lobes and bony floor to help to close any residual dural defects.

The pericranial flap has been extremely useful in these reconstructive circumstances. Therefore; from the inception of the operation, extreme care should be exercised to preserve the pericranial flap, ensure adequacy of its length, and integrity of the supraorbital and supratrochlear vessels. This begins as early as from when the facial and scalp incisions are made. If two teams of surgeons are to be involved at different stages of the operation, good communication, foresight and planning are required to prevent inadvertent disruption of the pericranial flap. There has been suggestion that the pericranial flap may be insufficient to close larger dural defects and provide an adequate barrier in anterior skull base resections, especially in cases of orbital exenteration with inherently larger defects3. Free tissue transfer may be performed instead to provide the necessary tissue bulk for repair. Radial forearm fasciocutaneous or rectus abdominis/latissimus dorsi muscular flaps have been used in these circumstances12–16.

Conservative non-operative measures to treat cerebrospinal fluid leak include a lumbar drain or serial lumbar punctures. If a cerebrospinal fluid leak is present, postoperative spinal fluid drainage via a lumbar drain at regular intervals and in amounts usually less than 150 ml per 24 h may be performed to prevent high cerebrospinal fluid pressures from developing a persistent fistula. Serial lumbar taps may also be performed. Precaution, however, must be taken not to remove excessive amounts of spinal fluid. If large amounts of cerebrospinal fluid are removed, the patient may develop pneumocephalus, especially if there is already dead space in the anterior cranial fossa. Head elevation, administration of anti-tussives and laxatives, avoidance of sneezing with the mouth closed, and other maneuvers to prevent increases in intracranial pressure are simple and empiric measures to institute. Treatment of persistent cerebrospinal fluid leaks emanating from the anterior cranial base that fail to stop with these conservative measures may eventuate to surgical treatment. This occurs after an adequate amount of time has elapsed to allow for spontaneous closure, approximately 1–2 weeks, depending on how brisk the leak is. The potential risk of meningitis or other infection exists for as long as there is a communication and leak.

When the decision to proceed to surgical management is made, the operative site is explored and the fistulous site identified. Often, introduction of vascularized tissue in the form of free tissue transfer or placement of a vascularized pericranial flap, if one was not used earlier, may be performed to seal the leak. Local pedicled rotation flaps, such as galeal-pericranial flaps and temporalis muscle flaps, may be used as well17–19.

If the fistulous defect is small and located in the ethmoid roof or cribriform plate region, transnasal endoscopic closure may be an option20,21. In this latter situation, pedicled or free intranasal mucosal grafts or free fascia may be used to patch the leak with the aid of fibrin glue (tissue adhesive) and absorbable gelatin sponge (Gelfoam®) to support the repair.

Infectious complications

Infectious complications comprise the major category of complications in anterior skull base surgery1,3,4,6. They are related to the violation of anatomic barriers that normally exist between the intracranial cavity and bacteria-laden sinonasal cavity.

Meningitis is an ever-present concern due to the proximity of the surgical site to the sinonasal cavity. Nasal secretions bathe the operative site. Nasal packing is frequently placed to prevent postoperative intranasal bleeding and to provide temporary support for skull base reconstructions. However, this packing may harbor bacteria after several days. Pooled blood serves as a medium in which bacteria proliferate. The paranasal sinuses are prone to purulent infection due to bacterial proliferation and altered drainage patterns from surgery.

Meningitis may occur anytime during the postoperative period, and may occur several months after the operation. Florid meningitis is usually heralded by symptoms of fever, fatigue, neck pain, headache and photophobia. There is usually a change in mental status as well. Early meningitis, on the other hand, usually presents with patient irritability, restlessness, desire to be withdrawn from others, and photophobia. When this occurs, the clinician should evaluate the patient, looking for clinical signs of meningismus: Kernig's sign, Brudzinski's sign, nuchal rigidity, photophobia, fever, prostration. White blood cell count is obtained to identify leukocytosis. Radiographic imaging, consisting of CT scan of the brain with intravenous contrast and/or MRI, is obtained to rule out the presence of an abscess or to determine the presence of any localizable meningeal enhancement. After an intracranial abscess has been ruled out, lumbar puncture may be performed to look for spinal fluid cytological and biochemical profiles consistent with meningitis: presence of polymorphonuclear neutrophils, decreased glucose, increased protein. Gram staining and microbiologic cultures of the spinal fluid are performed as well.

Prevention of meningitis, as well as other infectious complications, begins as early as the preoperative period and well into the operation. Prophylactic antibiotic administration intraoperatively and continuing into the postoperative period is recommended, especially for clean-contaminated cases22. Preservation or restoration of an anatomical barrier between the sinonasal cavity and cranial cavity is essential. The presence of a cerebrospinal fluid leak always leaves a potential for meningitis. Therefore, cerebrospinal fluid leaks must be addressed sooner than later. Thorough cleansing of the operative site with antibiotic irrigant, such as bacitracin or clindamycin, at the time of wound closure to decrease bacterial counts is beneficial, especially if there has been a prolonged open communication between the two cavities. If possible, portions of the surgical case in potentially contaminated fields should be performed separately, either before dural opening or after dural closure. If the paranasal sinuses are entered, the mucosa must be removed thoroughly and not allowed to be in direct contact with the dura. If a sinus is left open, an adequate gravity-dependent drainage portal out of the sinus must be created. If the frontal sinus is cranialized, the mucosa is removed and the bone surfaces are burred away. In this way, deep invaginations of mucosa into the bone are evacuated. This rids any potential nidus for infection. If any of the other paranasal sinuses are opened, they must be separated from the intracranial cavity.

Treatment of meningitis is aggressive and begins as soon as the clinician suspects its presence and after cultures are obtained. Initial antibiotic coverage should be broad spectrum, with the ability to penetrate the blood-brain barrier into the cerebrospinal fluid until microbiologic cultures isolate and identify the involved bacteria. Administration of intravenous antibiotics directed against the culture isolates is instituted. The endpoint of therapy is usually the resolution of symptoms, normalization of white blood cell count, and repeat lumbar punctures without bacteriologic evidence of persistent infection. Involvement with an Infectious Disease specialist may be helpful in this regard to help to guide medical therapy.

The common microorganisms isolated are related to the resident bacterial flora in the nasal cavity. These typically include Gram-positive cocci. It has been estimated that bacterial counts from this region can be as high as 1011 organisms per ml of oronasopharyngeal secretion23. These include a variety of Gram-positive and Gram-negative organisms, both aerobic and anaerobic. Meningitis in the presence of a cerebrospinal fluid leak involves *Pneumococcus, Staphylococcus aureus* and *Staphylococcus epidermidis*24.

Infectious complications may include frontal lobe abscesses. The mechanisms of contiguous bacterial spread or inoculation at the time of surgery are more common than the hematogenous route of infection. Abscesses, if sufficiently large, may produce a mass effect on the brain, causing frontal lobe dysfunction and a decreased level of consciousness. Patients with a frontal lobe abscess present with cephalgia, fever; seizures, nausea, vomiting and altered mental status. Treatment consists of surgical drainage via burr hole craniotomy or open craniotomy and evacuation of the abscess in conjunction with prolonged intravenous antibiosis.

Preoperative radiation, typically >60 Gy, for sinonasal malignancies predisposes to infectious sequelae6. This is due primarily to radiation effects on tissue vascularity and, consequentially, poor tissue healing. This may secondarily cause wound breakdown and infection. Frontal bone flap osteomyelitis may require removal of the bone flap with delayed reconstruction with split-thickness calvarial bone grafting or other forms of cranioplasty.

Frontal lobe complications

Frontal lobe parenchymal injury may result from excessive retraction to gain exposure of the posterior limits of the anterior cranial fossa floor. If retraction of the frontal lobe is too vigorous, this may result in cerebral edema or contusion. More long-term effects include encephalomalacia. Vascular compression and ischemia or direct traumatic injury to the cerebral vessels may result as well. If frontal edema is excessive, surgical exposure will become more difficult and primary dural closure at the termination of the procedure may not be possible.

There are several ways to help to reduce the problems associated with excessive frontal lobe retraction. The retraction provided must be gentle, but firm. Periodic release of the retractors is necessary to allow reperfusion of the retracted areas. Moist cottonoids or non-adherent gauze are placed between the retracting spatula and frontal lobe for protection and to avoid tissue dessication. Likewise, when the retractors are removed after a long period, physiologic saline should be used to irrigate the spatula retracting blades and retracted brain to facilitate the release of the retracted tissues which may have dried onto the retracting blade.

Perioperative intravenous administration of mannitol (1 g/kg) and corticosteroids, hyperventilation to maintain pCO2 less than 25 mmHg, and patient positioning will often facilitate brain relaxation to obtain more operative working room within the confines of the anterior cranial fossa, while obviating excessive retraction. If preoperative placement of a lumbar drain is planned, release of spinal fluid is performed to aid in the process as well. Injury to the frontal lobes from surgical trauma may result in personality changes, apathy, and alteration in judgment.

Neuropathies
Various cranial nerves may be encountered and are vulnerable to injury during surgery in the anterior cranial base, depending on the particular approach. Olfactory loss is an expected sequela from anterior skull base surgery, where the frontal lobe is elevated due to disruption of the olfactory fibers as they traverse through the multiple foramina of the cribriform plate. This necessarily occurs during dural elevation of the frontal lobes to gain access to the ethmoid roof, cribriform plate, crista galli, orbital process of the frontal bone; and planum sphenoidale. Preservation of olfaction has been possible with some intradural frontal approaches25–27.

When total olfactory loss is expected, special mention should be made in the preoperative counseling period. Discussion should also take place regarding the precautions to take after surgery in situations where anosmia could place one at significant risk, such as in natural gas leaks and fires, as well as alteration of taste.

The optic nerve and optic chiasm are not usually encountered in the anterior approaches; however, they are encountered in the anterolateral approaches. The surgeon should have complete understanding of the anatomy using the appropriate landmarks to identify the optic nerve, chiasm and tract. These include the wing of the sphenoid leading to the anterior clinoid process. The optic nerve will course anteroinferiorly under the anterior clinoid process, medial to the petrous and cavernous carotid artery.

If surgical manipulation of the optic nerve, chiasm and tracts is expected, visual evoked potential testing may be performed to test the integrity of the visual system intraoperatively.

Pneumocephalus
One region of the skull base prone to develop pneumocephalus is the anterior skull base due to its proximity to the nasal airway. Sizable defects along the floor of the anterior cranial fossa in communication with the sinonasal cavity may place the patient at risk to develop this. This is true especially in situations when large volumes of air under pressure are generated and

forcibly enter the intracranial cavity, such as when a person sneezes or when positive pressure ventilation is administered postoperatively via bag-mask ventilation. The end result is pneumatic compression on the brain. Some advocate that, if a large anterior cranial fossa floor defect is present, the patient may be left intubated for several days or a tracheostomy may be performed to circumvent this problem. Nasal packing may help temporarily to occlude air entry into large nasal roof defects. Alternatively, a nasal trumpet may be placed in both nostrils to direct air flow through the nose in a controlled manner. Pneumocephalus may also develop if there is excessive dead space already present in the anterior cranial fossa floor postoperatively. This, combined with large amounts of cerebrospinal fluid evacuation from a lumbar drain, may predispose to development of pneumocephalus.

An extremely dangerous predicament results when tension pneumocephalus occurs with rapid deterioration of the patient's condition. Tension pneumocephalus occurs when there is entry of air into the intracranial cavity and the air becomes trapped without the ability to escape (ball-valve effect), a situation similar to a tension pneumothorax. Immediate surgical management to open the unidirectional fistulous site is necessary to allow release and evacuation of the air collection, with subsequent surgical repair.

Small amounts of post-surgical pneumocephalus may be present and followed with serial CT scans or standard radiographs to ensure that the collection of air is resorbed and decreasing. One must be vigilant in this period for meningitis and abscess. If air can enter the intracranium, infections may also spread through these same pathways.

If a large amount of air is present within the cranial cavity, the air may be evacuated by needle aspiration via a frontal burr hole. Recurrence and recollection of air may necessitate an open procedure for repair.

One of the keys to prevention of pneumocephalus is the reduction of as much dead space as possible during the reconstruction phase of the operation. Introduction of bulky pedicled flaps or free tissue transfer into the floor of the anterior cranial fossa may help to reduce this complication. Dural tacking by sutures to the bony edges of the craniotomy may also help to limit postoperative epidural pneumocephalus. If a lumbar drain is placed perioperatively, the drain may be removed immediately after surgery to prevent inadvertent release of large volumes of cerebrospinal fluid.

Orbital complications

Due to the proximity of the orbit to the paranasal sinuses and its location in the anterior skull base, orbital function may be disturbed during anterior craniofacial resections or in procedures which require surgical manipulation around the orbit28. Excessive bone removal of the orbital walls, regardless of the approach, may result in enophthalmos. This will be evident in cases where the lamina papyracea is removed in ethmoidectomies, the orbital roof and lateral orbital wall removed in the anterolateral approaches, or the orbital floor removed in procedures featuring a maxillectomy. Sometimes, the amount of bone removal cannot be minimized due to the need to obtain additional exposure without having to retract on the frontal lobes or to achieve appropriate surgical margins. If sufficient bone is removed in the orbital plate of the frontal bone and the orbit becomes 'unroofed', cerebral pulsations may be transmitted directly to the orbit, creating an exophthalmos instead. These cases are best prevented by rigid reconstruction of the orbital walls if it appears that significant alteration of orbital volume will occur. Rigid miniplate fixation of split-thickness calvarial bone grafts is used for the reconstruction to restore orbital support, prevent dystopia, and to re-create a barrier between the frontal lobe and orbit.

The transfacial and anterior craniofacial resection approaches to the anterior skull base feature several surgical manipulations that may affect orbital function and cosmesis. The transconjunctival incision, if not properly performed, may result in entropion. If the integrity of the lacrimal drainage system becomes disrupted and epiphora results, stenting of the lacrimal ducts via dacryo-cystorhinostomy will be required. Epiphora is a problem that patients will not often relate to the physician in follow-up, so the physician should always keep this in mind. If the canthal ligaments are transected, resuspension is necessary to restore a symmetric appearance and prevent blunting of the medial canthus (pseudohypertelorism). Overcorrection of ligamentary suspension is recommended to account for tissue laxity over time.

Direct injury to the extraocular muscles or to cranial nerves III, IV and VI when operating around the orbit may result in disturbance of binocular vision and conjuguate eye movement. It may become necessary for the patient to tilt the head to compensate for the loss of conjugate eye movement function. Rehabilitation of these deficits may require use of prism glasses. Consultation with ophthalmological colleagues is essential.

When radiation to the anterior skull base is necessary and the radiation ports will incorporate the orbits, ocular shielding must be used.

MIDDLE CRANIAL BASE SURGERY

The middle cranial base is traversed to access areas such as the sella, parasella, upper clivus, cavernous sinus, petrous apex, cranial nerves II through VIII, internal auditory canal and petrous carotid artery. These approaches include any variety of the anterolateral, transtemporal, subtemporal and middle fossa approaches discussed in this surgical atlas. A combination of facial and temporal scalp incisions are created to expose the lateral orbit and zygoma portions of the facial skeleton, as well as the lateral frontal, parietal, pterional, and temporal regions of the skull. Entry into the intracranial cavity is usually performed by a bone flap craniotomy or removal of a facial skeletal segment. Access to the particular site is gained by either retraction of the frontal-temporal lobes or judicious bone removal adjacent to important neurovascular structures (cranial nerves, petrous carotid artery, bony orbit).

Cerebrospinal fluid leaks
Cerebrospinal fluid fistulae after transtemporal approaches across the middle fossa may occur through various routes into bony defects at the petrous apex or floor of the middle cranial fossa. They manifest as cerebrospinal fluid rhinorrhea, as the circuitous flow of spinal fluid enters the temporal bone air cell system and exits the middle ear space via the eustachian tube. Occasionally, if there is a perforation of the tympanic membrane, watery otorrhea may be noted.

Prevention of this complication begins intraoperatively with the repair of any large bony defects along the middle fossa floor; with fascia and split-thickness calvarial bone grafts if rigid support is needed. Any exposed air cells in the petrous apex should be obliterated with bone wax or covered with fascia. If entry into the eustachian tube is made superiorly through the petrous apex, this site must be covered prior to release of the retracted temporal lobe.

Cerebrospinal fluid leaks via the temporal craniotomy and skin incisions, with or without fluid collections under the scalp flaps, are usually due to inadequate closure and failure to perform a layered suture reapproximation of the overlying soft tissues. Pressure dressings to prevent such fluid collections under the tissues often help in these respects.

Persistent leaks, despite failure to stop spontaneously and on conservative measures, require surgical intervention. Re-entry into the surgical site via craniotomy, with dural repair or reconstruction of the middle fossa floor; may be needed. Some have advocated eustachian tube plugging or obliteration; however, neither long-term results with this technique nor large series are available29–31.

Infectious complications
Many of the precautions taken to prevent infectious complications after surgery in the middle cranial fossa overall follow the same guidelines for clean neurosurgical procedures, unless the eustachian tube or potentially infected mastoid-middle ear spaces are entered. When the operation does not involve transgression into the upper aerodigestive tract, the neurosurgical literature supports the use of prophylactic perioperative antibiotics32. Wound infections after clean neurosurgical cases typically involve Gram-positive organisms. Therefore, spectrum coverage for *Staphylococcus* is necessary.

Temporal lobe injury
The success of the middle fossa, anterolateral, subtemporal and transtemporal approaches is dictated by the ability to obtain adequate surgical exposure. This will often come at the expense of temporal lobe retraction. The amount of bone removal and degree of brain relaxation also play a critical role for exposure. The craniotomy may be enlarged to obtain the necessary visual and working angle instead of temporal lobe retraction. Measures are taken to enhance brain relaxation, such as the administration of intravenous mannitol, release of spinal

fluid via lumbar drain or release through a controlled small dural opening, and cerebral vasculature constriction in hypocapneic conditions (pCO2<25 mmHg).

Direct trauma to the temporal lobe may result from excessive intradural brain retraction. Special care should be taken to provide gentle yet stable retraction. Moist cottonoids or non-adherent gauze are placed between the temporal lobe and the retracting blade to provide protection and to prevent dural dessication. This will also help to stabilize the retractor blade. Periodic release of the retractor blade will reduce the chances for any compressive ischemic events on the cerebral vasculature. Careful avoidance of excessive hypotension by the anesthesiologist will also help to prevent placing the patient at further risk of compressive ischemic injury. Temporal lobe encephalomalacia may result

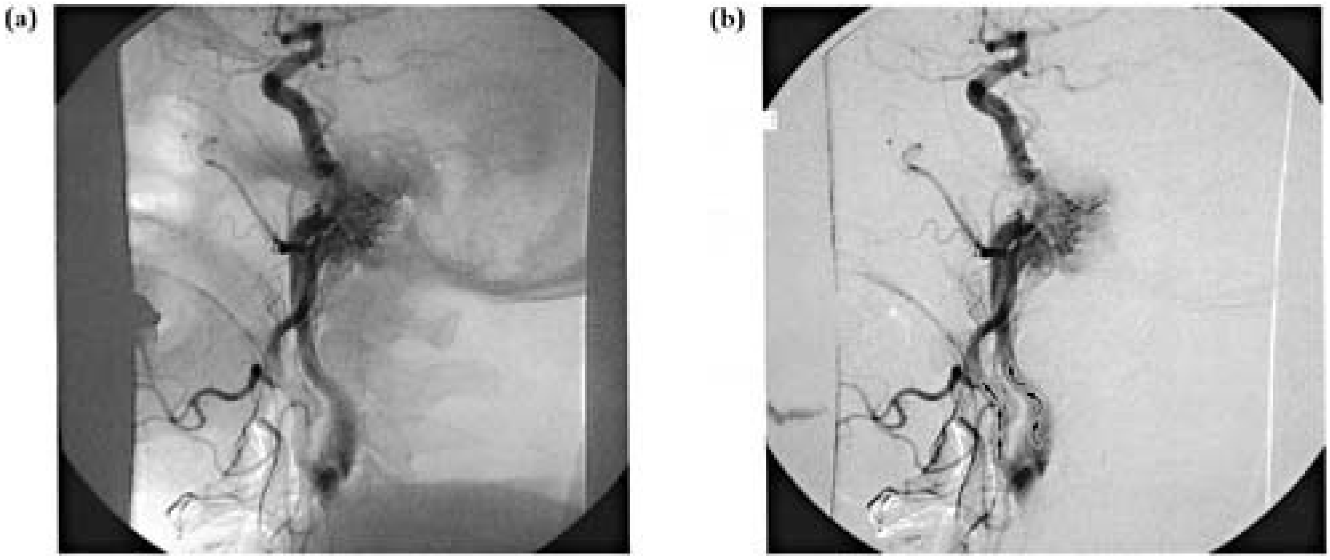

Figure 1

Rotated lateral view of a left carotid arteriogram demonstrating the arterial supply to the glomus jugulare tumor. (a) Plain film with bony contours; (b) subtraction film demonstrating external carotid (straight arrows) and internal carotid (curved arrows)

from excessive, prolonged traction and may not be noted immediately on postoperative scans. It may become evident on follow-up brain imaging after several months.

Retraction to the cerebrum may incite an epileptogenic focus and result in postoperative seizure. Retraction of the temporal lobe for aneurysm surgery has been shown to be associated with an increased incidence of postoperative seizures in patients previously without history of seizures33. This appears to be more common during cerebral retraction than in situations when the cerebellum is retracted. If intradural cerebral retraction is performed, prophylactic anti-seizure medical therapy should be administered intraoperatively and postoperatively. For extradural temporal lobe retraction, such as that performed in middle fossa approaches for removal of intracanalicular tumors, postoperative seizures are a rare event.

Carotid artery management

The carotid artery in skull base surgery is usually encountered when lesions are situated in close proximity to the petrous or cavernous segments of the artery. These lesions usually occupy such regions as the petrous apex, infratemporal fossa, clivus, and parasellar regions. The approaches to these regions are typically through the middle cranial fossa or the cavernous sinus. Preoperative radiologic imaging with both CT and MRI/MRA scans will provide useful information regarding the extent of the tumor relative to the carotid artery. Particular attention is paid to arterial displacement, bony disruption of the carotid canal, direct invasion into the arterial lumen, or other types of vascular compromise. Management of the carotid artery will depend on whether the lesion is benign or malignant, the degree of involvement around the carotid artery and the adequacy of the contralateral carotid and posterior circulation (circle of Willis) to provide collateral blood supply should the carotid artery be sacrificed.

If a lesion is in close proximity to the carotid artery and there may be a distinct possibility that tumor dissection will involve the carotid artery, with possible sacrifice of the vessel to obtain full removal of tumor, preoperative four-vessel angiography is performed to collect anatomical and functional information. Several pieces of information are obtained from such a study. The patency of the carotid artery and pattern of blood supply to the tumor should be determined (Figure 1). If the lesion is vascular or receiving

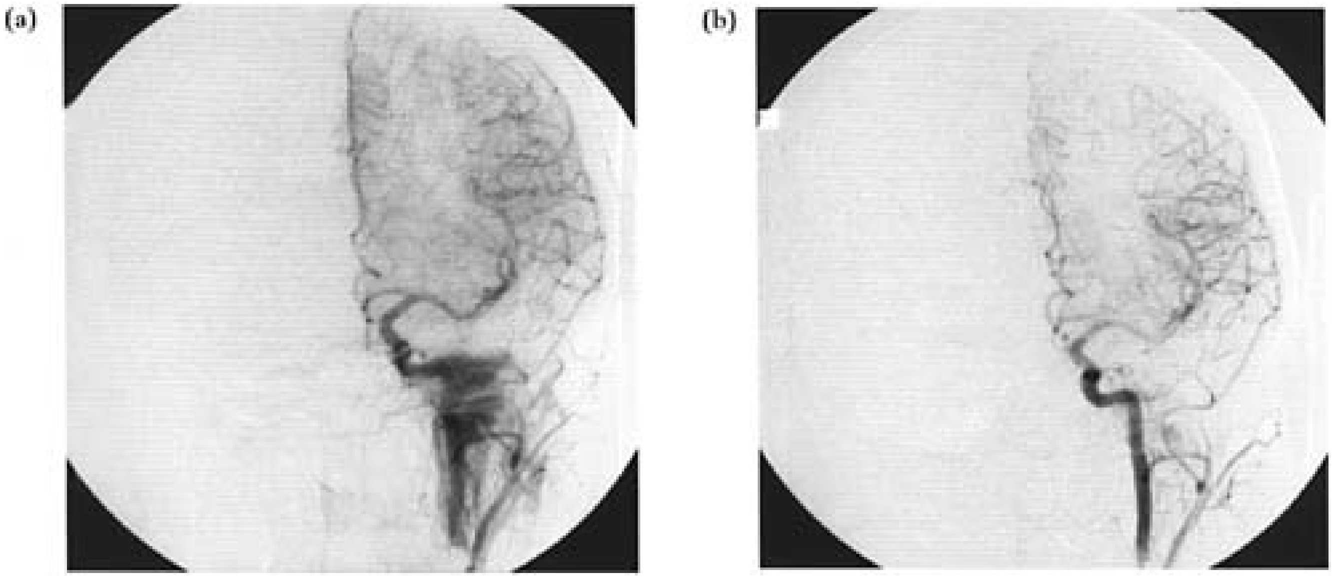

Figure 2

Anterior views of left carotid arteriogram demonstrating the arterial supply to the glomus jugulare tumor. (a) Before embolization; (b) after embolization

a rich blood supply, indicated often by a tumor blush on angiography, the feeding vessels are usually identified. The larger-caliber, named blood vessels of the external carotid artery are usually embolized if they are found to be providing a major blood supply to the tumor. Embolization is performed using polyvinyl alcohol, Gelfoam® particles, or coiled springs (Figure 2a and b). Balloons may be placed to interrupt blood flow temporarily. This will help to reduce the blood supply to the tumor and, in turn, the blood loss during resection of the tumor. If there is a chance that the carotid artery may need to be sacrificed, the status of the collateral circulation is further examined using the balloon occlusion test, in which clinical assessment of the patient is performed. This will help to determine if shunting and grafting of the carotid artery will be needed.

The balloon occlusion test, usually 15 min in duration, involves passing a catheter containing a balloon to occlude the internal carotid artery and determining the neurologic sequelae which result after the occlusion. The subject's neurologic complaints, clinical neurologic exam, and EEG in conjunction with the balloon occlusion test are used to determine whether patients can tolerate the effects of occlusion. Carotid stump pressures may also be measured. This is simply a reflection of the backflow pressures emanating from the collateral contralateral circulation after occlusion of the common carotid artery. Much investigation into the use of carotid stump pressures to determine adequacy of collateral cerebral circulation has been in the arena of carotid endarterectomy34,35. Such studies indicate that carotid stump pressures above 50 mmHg suggest adequate backflow. DeVries and colleagues reported their experience using balloon occlusion testing, but with stable xenon CT scanning to determine adequacy of collateral cerebral blood flow36. If collateral circulation and cerebral blood flow are adequate, sacrifice of the carotid artery may be performed without the need for vascular reconstruction with a graft. If there are insufficient collateral circulation; provisions must be made to perform bypass and vein graft reconstruction of the carotid artery.

If the lesion around the carotid artery is benign, near total resection of the tumor with preservation of the internal carotid artery may be performed. The situation will be different, however, if the lesion is malignant. If there is extensive involvement of the carotid artery by a malignant lesion, it may be rendered unresectable.

Should vascular disruption result during tumor removal, a balloon catheter is inserted into the lumen of the artery and inflated to temporarily occlude blood flow. This is best done by passing the balloon catheter up to the petrous segment of the carotid artery. Caution should also be paid to prevent excessive manipulation of the carotid artery which would result in vasospasm and subsequent vascular insufficiency.

Temporal muscle and trigeminal nerve injuries
Disruption of the neurovascular supply of the temporalis muscle can result in temporal muscle wasting. Special care is paid to the preservation of the deep temporal artery and the motor branch of the trigeminal nerve during the lateral surgical approaches. This is especially true for the infratemporal fossa approaches to the floor of the middle cranial fossa. Temporal muscle devitalization may leave a depression (sunken appearance) in the temporal fossa and an unsightly cosmetic defect.

Limited mouth opening, or trismus, is another potential complication of the lateral approaches. If either the motor branch of the trigeminal nerve is injured or if the mastication muscles and their attachments are disrupted or if the temporomandibular joint is displaced inferiorly, trismus will ensue. Postoperative aggressive rehabilitation of the joint is an adjunct of therapy. Early mobilization of the joint and mouth-opening exercises, starting as early as postoperative day 2, are essential.

POSTERIOR CRANIAL BASE SURGERY

Surgery at the posterior cranial base is performed commonly for neurogenic tumors, such as schwannomas of the lower cranial nerves, meningiomas, aneurysms of the posterior arterial circulation, and for access to the brain stem. The infratentorial space contains cranial nerves III–XII, the brain stem, cerebellum, and vessels of the posterior circulation. Each of these components is critical for life-sustaining function. Surgical access to the infratentorial compartment and posterior basicranium may be achieved from the posterior direction by a suboccipital (retrosigmoid) craniotomy, from the lateral direction via the translabyrinthine-transcochlear approaches or the far-lateral transcondylar approach, or anteriorly from the transoral transclival approach.

Caudal cranial nerve injury
One of the most feared complications in posterior fossa surgery is injury to the lower cranial nerves. Procedures that gain access to the lower clivus, foramen magnum, petrous temporal bone and parapharyngeal space place these nerves at risk. The caudal cranial nerves are essential for oromotor function, articulation, coordinated deglutition, phonation, and airway protection. If any one of these functions is interrupted, it can lead to life-threatening consequences. Aspiration pneumonia may result with inadequate airway protection. Bilateral hypoglossal nerve dysfunction is an equally devastating injury, rendering the patient unable to articulate, swallow and clear the oropharyngeal secretions for airway protection. Patients with such injuries must undergo intensive and chronic rehabilitation. Some will be dependent on a tracheostomy and enteral feeding via gastrostomy tube. In most severe cases, laryngotracheal separation or laryngectomy may be necessary to avoid aspiration.

Preoperative assessment of the patient undergoing surgery in the posterior cranial base should include a thorough cranial nerve examination to identify pre-existent cranial nerve deficits. Patients who have long-standing unilateral ninth, tenth, or twelfth nerve palsies usually compensate well and a fleeting physical examination may miss these nerve deficits. Examination should include flexible nasopharyngoscopy to examine pharyngeal motion and oropharyngeal secretion clearance, vocal fold motion, and endolaryngeal sensation with appropriate reflexic glottic closure.

Injury to the lower cranial nerves is best avoided by a thorough knowledge of the anatomy of the root entry zones at the brain stem, as well as the intracranial course through the cisternal spaces and intraosseous course. Intraoperative neurophysiologic monitoring of the Xth, XIth, and XIIth nerves is possible with placement of electromyographic needles in the trapezius or sternocleidomastoid muscles for the XIth nerve and the tongue for the XIIth nerve. Specially designed endotracheal tubes that detect vocal fold contraction may be used in a similar manner to alert the surgeon of impending nerve trauma to the Xth nerve. Similar monitoring has been used for thyroid/parathyroid surgery37,38.

If lower cranial neuropathy is an expected consequence from surgery, several measures may be taken prior to the operation to facilitate postoperative recovery. A tracheostomy may be placed to avoid airway problems after extubation, as well as to provide pulmonary toilet due to the inability to protect the airway from aspiration. Likewise, a gastrostomy tube may be placed to institute enteral feedings earlier to provide adequate nutrition.

If the functional status of the lower cranial nerves is unknown, care must be taken during extubation, as the possibility of airway distress exists if the Xth nerve is not functioning. The vocal fold may not be able to abduct. Stridor may be evident shortly following extubation. Medialization thyroplasty or vocal cord injection with absorbable gelatin sponge or fat are reversible procedures that may be performed soon after surgery to help to strengthen the voice and decrease aspiration.

Unilateral hypoglossal dysfunction is usually tolerated by patients. If XIth nerve injury occurs, physiotherapy for shoulder mobilization must be delivered as soon as possible to avoid complications with frozen shoulder and winging of the scapula due to the inability to raise/abduct the arm past the Horizontal plane. A host of other rehabilitative measures after posterior skull base surgery have been described39

Posterior circulation problems/brain stem and cerebellar infarcts
The arteries of the posterior circulation system are often end arteries from the vertebrobasilar arterial system, supplying blood to the vital coordinating centers such as the brain stem and cerebellum. Collateral blood circulation in this area may be poor. Therefore, extreme care must be taken when operating in the vicinity of the arteries to avoid injury. Brain stem infarcts from vascular injury may result in death, as the centers for driving respiration are located at the brain stem level.

The vertebral artery is also susceptible to injury in both the suboccipital (retrosigmoid) approach and in the far-lateral transcondylar approach. In the former situation, muscular dissection carried forward toward the atlas and axis may disrupt an aberrant vertebral artery In the latter situation, the vertebral artery may be injured when trying to gain exposure of the artery during bone removal of the atlas and axis. The entire unilateral distribution of the vertebral artery may be interrupted from vertebral artery injury outside the foramen magnum in its cervical portion prior to its entry. If there is inadequate collateral circulation, ischemia will ensue. The surgeon should be prepared to reconstruct the injured vessel if possible. If the vessel cannot be repaired, the operation must be postponed until all neurologic sequelae from this injury can be assessed. Postoperative MRI will confirm any ischemic changes. Vertebral artery angiography may be considered to ensure that an arteriovenous fistula or aneurysm has not formed as a result of the injury.

Cerebellar infarcts may result from interruption of the vascular supply by injury to the end arteries to the cerebellum or from excessive, prolonged cerebellar retraction causing compression of the vasculature. When cerebellar infarcts occur, cerebellar edema usually follows. This may prevent primary dural closure. If cerebellar edema develops *after* dural closure, brain stem compression or hydrocephalus or upward tentorial brain stem herniation may ensue with dire consequences. Serial postoperative imaging can trace the progression and prevent potential herniation.

Hemorrhage

Postoperative hemorrhage after posterior cranial fossa surgery may rapidly progress to fatality if unrecognized. This is especially true when it develops in the immediate postoperative period, when the surgeon is not sure whether the patient's poor mental status is due to an anesthetic effect or not. Bleeding can occur from an injured blood vessel. The astute surgeon should always keep this in mind in light of rapid deterioration of mental status and neurologic function. Often times; time may not permit imaging with CT scanning to identify a hemorrhage within the posterior fossa. Blood collections may create brain stem compression, in turn leading to cardiovascular and respiratory collapse, and transtentorial herniation.

The most immediate management includes withdrawal of cerebrospinal fluidto relieve intracranial pressure if an indwelling lumbar drain or other shunt is present, or returning to the operating room for emergency exploration and evacuation of hematoma. In cases of rapid progression of deterioration, the incision is opened to allow immediate release of blood. In patients who have undergone a translabyrinthine approach, the incision may be immediately opened at the bedside and the free fat grafts removed from the mastoid cavity to relieve the pressure from a rapidly enlarging hematoma.

Seizures
Although less common than operations in the supratentorium, surgery in the posterior fossa may incite postoperative seizures. It appears, however, that the incidence of postoperative seizures increases with the amount of cortical injury, whether produced by the lesion or the surgeon40. On the other hand, seizures resulting after posterior cranial fossa surgery are comparatively less frequent. In a study of 740 posterior fossa operations via suboccipital craniotomy for a variety of pathologies, postoperative seizures occurred in 1.8% of the cases41. These commonly occurred after surgeries for medulloblastomas, astrocytomas, meningiomas, hematomas, and for microvascular decompression. In operations for acoustic neuromas from this same study, the incidence was 1.1%. This brings into question whether anti-seizure prophylaxis is necessary in the postoperative period, as with the supratentorial procedures.

Cerebrospinal fluid leaks
Cerebrospinal fluid leaks resulting after posterior cranial fossa surgery occur in the setting of the suboccipital approach when air cells of the temporal bone are opened to the subarachnoid space (Figure 3). This may happen during the craniotomy if the mastoid air cells are entered or when the exteriorization of the internal auditory canal is performed with entry into the perilabyrinthine air cells. Cerebrospinal fluid will enter the various air cell tracts communicating with the middle ear and egress through the eustachian tube to clinically manifest as cerebrospinal fluid rhinorrhea.

In the latter situation when the porus acousticus is opened, the perilabyrinthine air cell tracts may be exposed. After tumor removal, careful inspection and palpation of the drilled surfaces for any opened air cells must be performed to identify potential entry sites for cerebrospinal fluid. Any opened air cells may be obliterated with bone wax. An alternative technique is to plug free muscle, dura, or fascia into the exposed air cells and fill the trough formed by the exteriorized internal auditory canal with tissue glue.

If a cerebrospinal fluid leak is persistent after the suboccipital approach, transmastoid repair of the cerebrospinal fluid leak may be performed by mastoidectomy and identification of the precise site of leak. Thorough exenteration of all air cell tracts is performed. Abdominal free fat graft is then harvested and used to slightly overfill the mastoid cavity. If no useful hearing is present, the incus is removed, the eustachian tube packed in the protympanum, and the middle ear filled with fat, taking care not to disrupt the stapes. Layered closure of the musculoperiosteum over the mastoid defect and watertight skin closure are performed. Mastoid dressing is applied for several days to exert a constant pressure over the surgical site.

Cerebrospinal fluid leaks from the posterior fossa are less likely to close spontaneously. This may be due to the presence of the cisternal spaces in and around the posterior fossa that contain cerebrospinal fluid.

Pneumocephalus
Pneumocephalus in the posterior fossa is a familiar condition that occurred when patients

historically underwent surgery in the sitting position[42,43]. This condition, however, may still occur when the patient is placed in the alternative park-bench or prone position[44]. In fact, the presence of postoperative pneumocephalus is common and sometimes cannot be prevented. The intradural collection of air results from entry of air after the cerebrospinal fluid is drained. The situation has been equated to an inverted bottle phenomenon where the fluid that is drained is replaced with air[42,45]. The presence of air in small amounts may not create a harmful situation as it slowly becomes resorbed.

The situation becomes dangerous when tension pneumocephalus occurs. In tension pneumocephalus, the collection of air becomes so great that it compresses the brain and increases intracranial pressure. It clinically manifests as a change in neurologic status. The progression

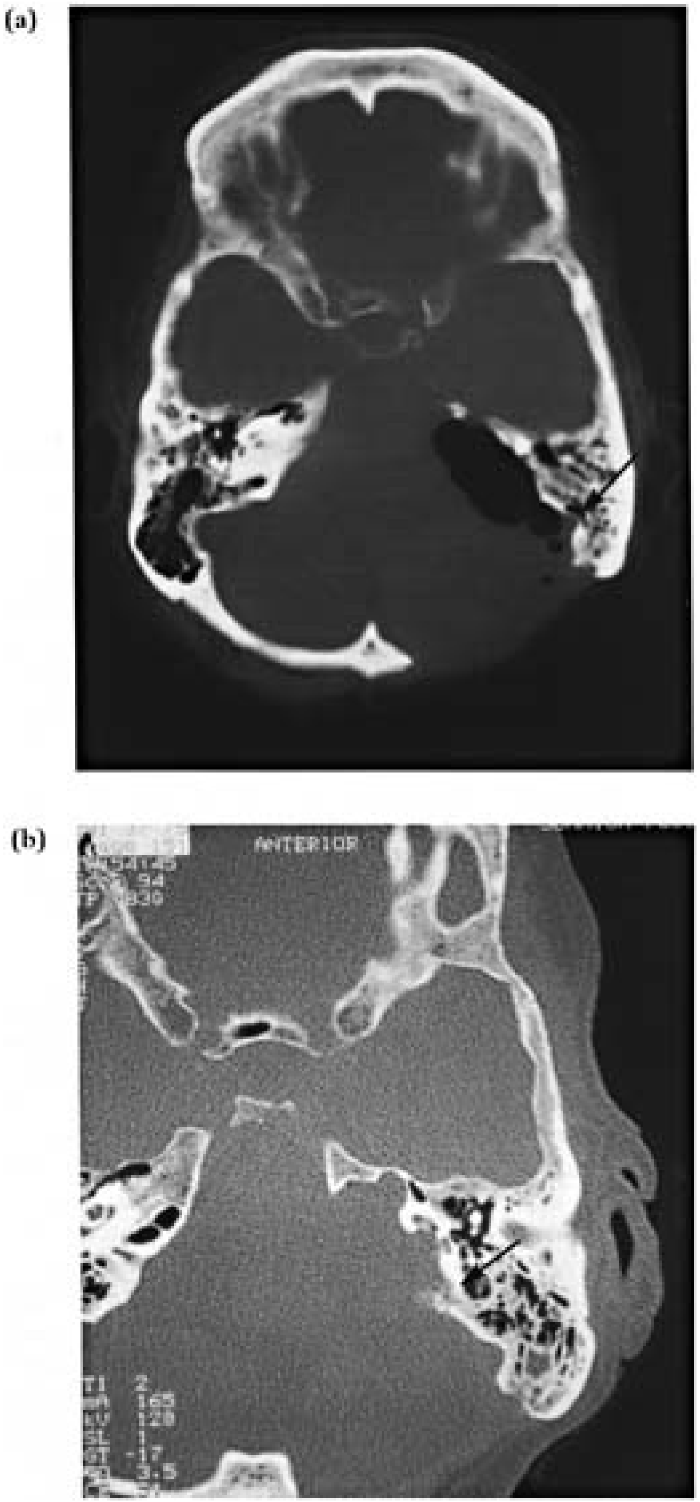

Figure 3

Axial CT scans of the temporal bone in two patients with cerebrospinal fluid leak after suboccipital craniotomy depicting the principal sites of leakage into air cell tracts. (a) Pneumocephalus and fluid in left mastoid after suboccipital craniotomy with the site of cerebrospinal fluid fistula at the lateral aspect of the craniotomy (arrow); (b) fluid in the left mastoid with site of the cerebrospinal fluid fistula in the area of the subarcuate air cell tract (arrow) to tension pneumocephalus, however, is rare. Pneumocephalus, therefore, does not necessarily portend impending tension pneumocephalus. Identification of the possible factors which lead to tension pneumocephalus has been attempted. Those which have been postulated, but not proven, include use of the inhalational anesthetic agent nitrous oxide during dural closure (nitrous oxide rapidly diffusing to air-containing spaces to worsen pneumocephalus), postoperative use of a cerebrospinal fluid shunt with excessive drainage, aggressive intraoperative use of a dehydrating agent, and reduced cerebrospinal fluid volume within the ventricular system45.

Hydrocephalus

Hydrocephalus usually develops in the postoperative period due to obstruction of cerebrospinal fluid outflow from the fourth ventricle. This may result from postoperative cerebellar edema or obstruction from blood clots within the basal cisterns. Prevention is best handled by removing accessible blood clots intraoperatively. If hydrocephalus is persistent, treatment is best carried out with shunting and cerebrospinal fluid diversion from the ventricles.

Aseptic meningitis

Aseptic meningitis is often called ‘chemical meningitis’ or the ‘posterior fossa syndrome’. Although it usually occurs in the setting of posterior fossa surgery, its presence is not always related to surgery in this region. It may occur in supratentorial procedures as well. Aseptic meningitis is characterized by a clinical presentation similar to that of bacterial meningitis. The patient may have meningismic symptoms and clinical signs of meningitis, such as nuchal rigidity and spiking fever. The biochemical profile of the spinal fluid will even resemble that of an acute bacterial meningitis with leukocytosis, decreased glucose, and increased protein concentrations. However, the key differentiating feature between the two conditions is a positive bacterial culture in bacterial meningitis.

Aseptic meningitis was noted to occur in children who had undergone posterior fossa surgery46. However; the condition was also found in patients who had not undergone posterior fossa surgery. In one study examining the differentiation between aseptic and bacterial meningitis, about one-half of the 18 patients with aseptic meningitis had surgery in areas besides the posterior fossa47. The incidence of aseptic meningitis was 4.8% in Cushing’s observations and 7% in Finlayson and Penfield’s series48,49.

The etiology of aseptic meningitis is largely unknown. It has been speculated that the cause is due to the presence of blood or tumor breakdown products creating a focus of irritation. This has never been proven. Improvement of this condition, however, seems to occur after administration of systemic corticosteroids.

SKULL BASE COMPLICATIONS RELATED TO RADIATION THERAPY

Radionecrosis

Radiation therapy of the central nervous system, skull base and head and neck malignancies has proven effective in well-selected cases. However, the effects of ionizing radiation on local tissues and organs present potentially serious complications50–58. There is an increasing awareness of the effects of radiation on the temporal bone and its associated structures. The most devastating of these problems, because of its long incubation period, persistent course, and resistance to simple treatment strategies, is osteoradionecrosis of the temporal bone. Temporal bone osteoradionecrosis generally presents years after the primary course of high-dose irradiation.

The area of necrosis may be localized, in which only the tympanic ring is involved, or diffuse, in which disease has extended throughout the temporal bone with clival involvement owing to regional vascular insufficiency Diffuse forms of temporal bone osteoradionecrosis require further radiographic studies for assessment of the extent of disease and evaluation for extratemporal complications of osteoradionecrosis. The best imaging study is a CT scan with intravenous contrast, which will demonstrate areas of bone destruction and opacification of involved air cells. In addition, CT scanning can reveal the presence of neoplasms, abscesses, or lateral sinus thrombosis. Indeed, Ramsden and colleagues59 found that approximately one-third of patients with diffuse osteoradionecrosis had intracranial infections. They found temporal lobe abscesses, a cerebellar abscess, and an extradural posterior fossa abscess. The remaining patients demonstrated exposure of the dura and lateral sinus, erosion of the Fallopian canal with facial nerve palsy, and erosion of the horizontal semicircular canal with vertigo and deafness.

Therapeutic options include local debridement, with topical and oral antibiotics in limited disease, whereas, in more extensive disease, surgical ablation of necrotic bone and reconstruction with vascularized tissue may be required. In all situations, the course of therapy is usually prolonged and recovery may require months of conservative care. Surgical resection is reserved for those cases in which the osteoradionecrotic process advances to produce worsening symptoms (typically pain) or cranial neuropathies. Hyperbaric oxygen may be considered as an adjunct to medical or surgical interventions. However, the best treatment for temporal bone osteoradionecrosis is prevention. A greater awareness of otologic complications of radiotherapy combined with efforts to minimize the amount of unnecessary radiation delivered to the temporal bone will help in designing safer but effective radiation protocols.

Tumor resection after stereotactic radiation failure

The mainstay of vestibular schwannoma management has traditionally been microsurgical resection by an experienced neurotologic and neurosurgical team. Excellent outcomes may be obtained from surgery for vestibular schwannoma with regards to anatomic preservation of the facial nerve, facial nerve function, and serviceable hearing preservation. Complete tumor removal can be achieved through meticulous microsurgical dissection, resulting in minimal morbidity and mortality. Another alternative modality of treatment for vestibular schwannomas is stereotactic radiotherapy or the ‘gamma knife’. This type of therapy is usually reserved for patients who are elderly or who have co-morbidities that place them as a high surgical risk, or ‘the poor surgical candidate’60.

Stereotactic radiation involves the biologic inactivation of a three-dimensional target by a single dose of ionizing radiation61. Fractionated stereotactic radiosurgery (FSR) involves multiple treatment sessions to deliver a therapeutic radiation dose to the tumor. Tumor volume is not substantially reduced or removed with radiosurgery. Treatment success, therefore, is measured in terms of tumor growth suppression, as demonstrated radiographically. When stereotactic radiotherapy fails, there is persistent growth of the tumor. Rates of persistent growth of vestibular schwannomas following radiation therapy range from 2 to 9% over the limited phases of follow-up reported to date62–64.

Stereotactic radiotherapy is employed more often as imaging with MRI is detecting smaller tumors in elderly patients. The contemporary skull base surgeon will certainly encounter patients who have completed stereotactic radiotherapy that has failed to control tumor growth. Salvage microsurgical resection may be an alternative treatment.

Surgery may be complicated by scarring and increased perioperative morbidity65–68. Slattery and Brackmann reviewed a series of five patients with recurrent vestibular schwannoma following stereotactic radiation66. Three of five patients had complete facial palsy preoperatively and significant scarring to the facial nerve and brain stem was encountered intraoperatively.

In our series of four patients who experienced a failure after stereotactic radiotherapy, capsular fibrosis on the medial or anterior surfaces of the irradiated tumor was evident. Such changes can substantially complicate microsurgical dissection to liberate the facial nerve and the caudal cranial nerves from the tumor surface. Although preservation of facial nerve integrity was achieved in our four cases, tumor dissection was difficult and significant facial and caudal cranial neuropathies were found in half of our cases. There was no evidence of fibrosis within the internal auditory canal in three out of the four cases.

Radiation-induced tumors

One of the principal challenges in determining the epidemiology of radiation-induced malignancy is ascertaining whether a tumor is truly radiation-induced, or simply an unrelated second primary tumor. Approximately 10% of patients who present with cancer will develop a second malignancy, thus complicating the diagnosis69. In an effort to clarify likely pathogenesis, Cahan and colleagues70 have proposed the following criteria for a tumor to be considered radiation-induced. Alhough originally proposed for post-irradiation sarcoma, these criteria have become widely accepted for all radiation-induced malignancies:

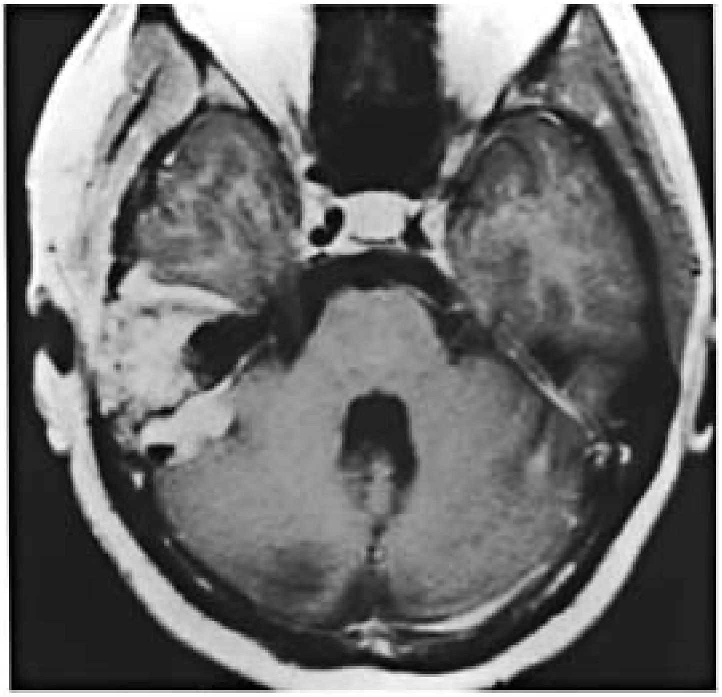

Figure 4

Axial T1-weighted MRI scan with gadolinium enhancement of an osteogenic sarcoma in a patient receiving radiotherapy 8 years previously for an astrocytoma. The lesion is a 15×20×25 mm enhancing mass involving the right anterior petrous bone with extension across the tentorium to involve the temporal lobe, and extension into the middle ear and mastoid

(1) The second neoplasm must arise in the irradiated field;

(2) A latent period of at least several years must have elapsed between the radiation exposure and the development of the second neoplasm;

(3) There must be histologic and roentgenographic evidence of the pre-existing condition, in addition to microscopic proof of a tumor;

(4) The second tumor must be of a different histologic type from that previously irradiated, to eliminate the possibility of recurrence of the original tumor.

Examples of lesions fitting Cahan's criteria are demonstrated in Figures 4–6.

Although reports of sarcomatous tumors in the head and neck following radiation therapy predominate in the literature, tumors of other histologic types have been described. Sixteen patients with intracranial meningiomas following irradiation for tinea capitis were reported by Beller and colleagues71. Sogg and colleagues72 described a posterior fossa schwannoma and a parotid carcinoma developing 23 years after radiation, and Preissig and co-workers73 presented an anaplastic astrocytoma which developed 8 years after radiation therapy for large glomus jugulare.

The histologies of all reported radiation-induced tumors involving the temporal bone identified in the English literature since 1966 are outlined in Table 1. Though small in number, their distribution roughly reflects the histologic spectrum of post-irradiation malignancy seen throughout the body. The largest series to date discusses five cases of radiation-induced tumors involving the temporal bone53. All five patients met Cahan's criteria for being considered radiation-induced; each developed their malignancies in the radiation field from the previous primary tumor and the second lesions were of a different histologic type than the primary tumor. Four of the tumors were sarcomatous (two

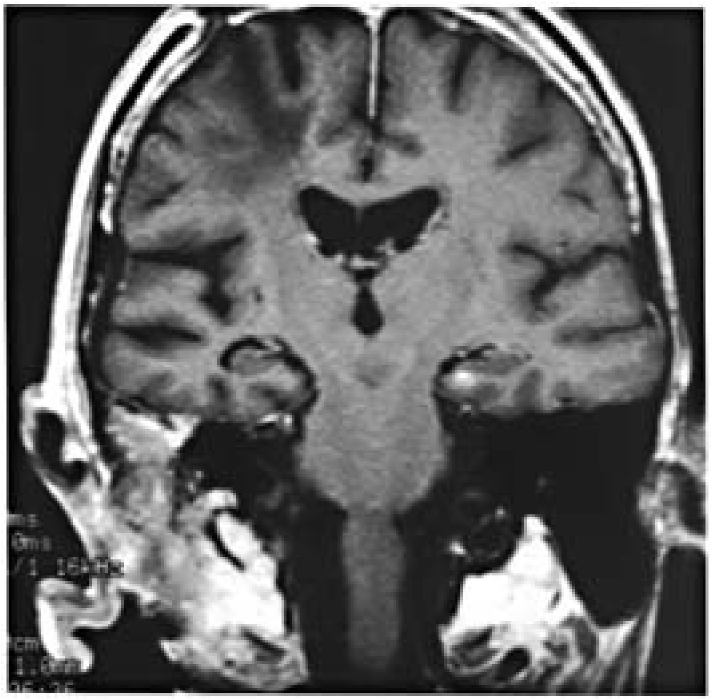

Figure 5

Coronal T1-weighted MRI scan with gadolinium enhancement in a patient with a fibrosarcoma presenting 11 years after receiving radiotherapy and 1251 implants for melanoma. The tumor involves the right temporal bone with extension of the tumor mass around the ipsilateral parotid gland, and extension into the upper neck

fibrosarcomas, two osteosarcomas) and one was a squamous cell carcinoma. Tsukamoto and colleagues discussed a case of a post-irradiation middle fossa meningioma abutting the temporal bone74. Fuller and co-workers reported on a fibrosarcoma of the ear following radiation for a glomus jugulare tumor75. Coatesworth and colleagues presented a case of post-irradiation liposarcoma of the temporal bone arising after radiation therapy for a benign parotid lesion76. This distribution is typical for a series of radiation-induced tumors. Tumors involving the temporal bone are predominantly sarcomatous, and a smaller percentage are squamous cell carcinoma.

One of the hallmarks of radiation-induced malignancy as stipulated by Cahan; is the latency between radiation exposure and the development of the tumor70. Typical latency periods for radiation-induced sarcomas average 11–13 years77. Based upon reported cases in the literature, the latency of radiation-induced tumors of the temporal bone is even longer (Table 1). In the series of five patients by Lustig and Jackler, the average latency between radiation therapy and diagnosis of the radiation-induced malignancy ranged between 8 and 23 years, with an average of approximately 15 years53. Considering the reported cases taken together, the average latency for radiation-induced malignancy of the temporal bone is of the order of 23 years, with a range between 8 and 47 years. This prolonged latency underscores the need for long-term follow-up in all patients who have received radiation therapy

Comparison of the amount of radiotherapy delivered among studies describing radiation-induced malignancy is difficult, since numerous differences exist between dosage parameters, frequency of treatments, type of radiation employed, the changing patterns of therapy over the past several decades, and incomplete documentation in the literature. However, studies typically report radiation doses ranging from 1.6 to 8 Gy delivered to the original tumor, prior to the onset of the radiation-associated malignancy[77–79]. Similarly, all the reported cases of

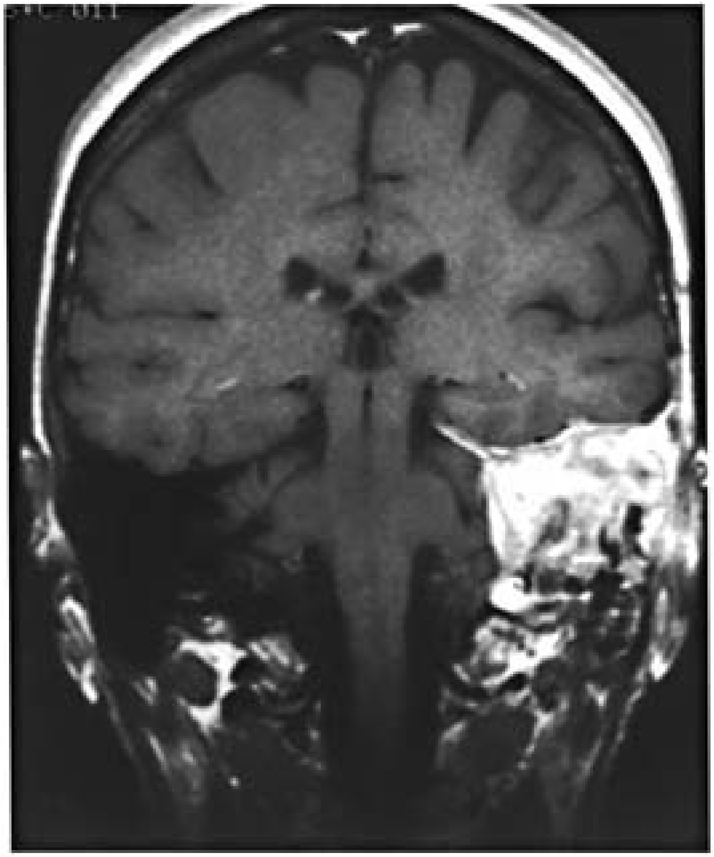

Figure 6

Coronal T1-weighted MRI scan with gadolinium enhancement of an osteosarcoma arising in the radiated field of an astrocytoma treated 23 years previously. The MRI demonstrates a left petrous apex lesion, extending to the skin surface, involving the external auditory canal, and invading the cerebellum inferiorly

post-irradiation tumors involving the temporal bone received comparable dosages of radiation. In Lustig and Jackler's report, all five patients had originally received at least 5 Gy of radiation with the initial treatment53. These radiation dosages are well within the values reported for radiation-induced malignancy throughout the rest of the body.

Malignant transformation of tumors after stereotactic radiation

Low-dose, stereotactic radiation therapy has been shown to increase the risk of developing neoplasms of the central nervous system. An association between low-dose radiation therapy in childhood and the risk of benign and malignant intracranial neoplasms has been demonstrated in previous studies, with latency periods ranging from 16 to 30 years59–66. The risk of neoplastic transformation was greatest 15–24 years following irradiation. In our series of four patients, there were no histologic changes, such as cellular atypia, suggestive of malignant degeneration.

There is also a theoretical risk of second tumor formation following stereotactic radiation. Published cases are rare. There are several reports of radiation therapy-associated malignancies in the cerebellopontine angle58,59,67,69. These are summarized in Table 2. Several other reports of malignant transformation following radiosurgery for benign intracranial neoplasms have been reported53,70–74. Malignant schwannomas are certainly rare, with only seven reported in the literature. Four of these seven cases have been associated with radiation therapy.

Table 1 Summary of documented radiation-induced tumors (RIT) of the temporal bone

Reference	Original pathology	RIT	Latency (years)	Presenting symptoms	Presenting signs	Treatment
Fuller75	glomus jugulare	fibrosarcoma	**25**	NA	NA	NA
Applebaum80	gonococcal urethritis	squamous cell cancer	**39**	otorrhea, otalgia, facial paralysis	granulation tissue, V–VIIth CN dysfunction	radiation
Tsukamoto74	Cushing's disease	fibrous meningioma	**25**	asymptomatic	altered blood sugar	tumor excision
Coatesworth76	benign parotid lesion	liposarcoma	**47**	otorrhea facial weakness	ulcerated lesion EAM, VIIth CN palsy	supportive
Lustig53	astrocytoma	osteogenic sarcoma	**8**	progressive HL	violacious mass filling middle ear	chemotherapy
Lustig53	acoustic neuroma	squamous cell cancer	**17**	bloody otorrhea	erosive lesion of EAC	TBR
Lustig53	malignant melanoma	fibrosarcoma	**11**	post-auricular swelling	post-auricular swelling	TBR+chemotherap
Lustig53	astrocytoma	osteosarcoma	**23**	supra-auricular swelling	supra-auricular swelling	chemotherapy+TB
Lustig53	glomus jugulare	fibrosarcoma	**15**	facial weakness diplopia	VI–XII CN weakness	tumor excision+chemothe

NA, information not available; HL, hearing loss; EAM, external auditory meatus; EAC, externa canal; CN, cranial nerve; TBR=temporal bone resection

Table 2 Review of malignancies associated with stereotactic radiation for vestibular schwannoma *(vs)* in the cerebellopontine angle

Reference	Diagnosis before radiation	Age (years)	Sex	Initial management	Radiation method	Radiation dose	Time to recurrence or new growth	Diagn surg
Shamisa81	VSa	57	F	radiation	gamma knife radiosurgery	17.1 Gy average dose (27.5 Gy central, 11 Gy margin)	1st surgery −8 months following radiosurgery 2nd surgery −7.5 years following radiosurgery	1st surge vestibula schwann 2nd surg glioblast multiforr
Comey68	VSa	44	M	radiation	gamma knife radiosurgery	**14.36 Gy margin, 34 Gy maximum**	5 years	malignar schwann triton tur
Kurita82	VSa	NA	NA	radiation	gamma knife radiosurgery	NA	6 years	malignar schwann
Noreng	VSa	18	NA	radiation	gamma knife radiosurgery	NA	6 years	malignar schwann
Hanabusa83	VSc	57	F	surgery	gamma knife radiosurgery (after 1 st surgery)	15 Gy margin, 30 Gy maximum core dose	recurrence following 1st surgery −4 years recurrence following radiosurgery −6 months	2nd surg malignar schwann
Thomsen84	VSa,e	19	F	radiation	stereotactic radiotherapy	12 Gy margin, 20 Gy maximum	6 years	meningo

aDiagnosed radiographically; bpatient died 1 year following new symptoms with intracranial dissemination, diagnosis made at autopsy; cdiagnosed at first surgery; patient died 6.5 years fo initial treatment; eneurofibromatosis type 2; fpatient died 8 years following the initial diagnosi gComey *et al.*, personal communication, 1917 NA, not available; M, male; F, female

TEMPORAL BONE SURGERY

Surgery in the temporal bone is performed to help to gain direct access to the posterior fossa, cerebellopontine angle, and petrous apex in the translabyrinthine and transcochlear approaches and to the jugular foramen in the infratemporal approach. The temporal bone and mastoid regions may also be traversed to extend the surgical exposure in the middle fossa approach or the suboccipital approach.

A number of structures encased within the bone will be encountered by the surgeon. These structures include the facial nerve, hearing and balance organs of the inner ear, sigmoid sinus, superior petrosal sinus, mastoid emissary vein, and major blood vessels (petrous carotid artery and jugular bulb). Fortunately, in many instances when a transmastoid approach is taken through the temporal bone, bone removal will be performed in non-disease states of the mastoid, facilitating identification of the anatomy. Nevertheless, thorough understanding of the anatomy is essential to perform safe temporal bone surgery, and this understanding is gained in a temporal bone dissection laboratory.

Facial nerve complications

The facial nerve generally courses in a predictable fashion within the temporal bone. The surgeon uses readily identifiable surgical anatomical landmarks within the temporal bone to identify and preserve the facial nerve. Therefore, *anatomical* preservation of the facial nerve can be achieved at very high rates. *Functional* preservation of the facial nerve may be achieved at equally high rates, but the rates are affected by such factors as disruption of the vascular supply, surgical trauma and manipulation, need for facial nerve translocation to gain improved surgical exposure, and the pre-existing functional state prior to surgery.

The relevant surgical anatomical landmarks leading to the facial nerve and their relationships may be studied in depth from sources focusing on temporal bone anatomy85,86. In general, the facial nerve is located by sequential identification of these anatomical landmarks. This technique is practiced by otologists who operate in this region everyday for chronic ear disease.

The introduction of intraoperative facial nerve monitoring for mastoid and skull base surgery has resulted in early recognition of impending trauma to the facial nerve, in identification and localization of the facial nerve relative to surrounding nerves (as within the internal auditory canal), and in confirmation of facial nerve integrity at the termination of an operation. Intraoperative facial nerve monitoring has proved to be helpful in reducing the incidence of permanent facial paralysis in one series in a comparison study with and without facial nerve monitoring87. Other studies report its favorable use in acoustic tumor surgery88–90. The facial nerve monitor may even have the capability to predict facial nerve outcome based on level of stimulation thresholds91–94.

There are several technical ways to help to preserve function of the facial nerve when operating in the vicinity of the Fallopian canal. Plenty of irrigation should be used when removing bone around the facial nerve, both to provide a surgical field free of bone dust and to help to cool the bone. Safer bone removal is performed with a diamond stone burr after the general course of the nerve is delineated. However, more heat is generated around the nerve compared to use of the cutting burrs. Preservation of the blood supply to the facial nerve is also critical, especially in procedures involving facial nerve transposition and dissection of the extratemporal course of the facial nerve. Ways to preserve the vascular supply during facial nerve re-routing have been suggested95.

Transection of the facial nerve must be repaired immediately via primary suture neurorrhaphy repair or nerve interposition if a large segment is missing. Nerve grafts from the great auricular nerve or sural nerve serve as good donors. Epineural repair is performed, maintaining the principle of tension-free repair under magnification. The best function usually expected from such a nerve graft repair would be House-Brackmann grade III96. If facial nerve injury occurs in the cisternal or canalicular segments where an epineural layer is absent or when nerve repair is not possible, a hypoglossal-facial nerve anastomosis may be performed. These may be performed with potential for good results, restoring facial symmetry, muscle tone, minimal to absent synkinesis, and restoration of a nasolabial fold97.

Attention to appropriate eye care should be paid if facial weakness develops after surgery. This may be in the setting of paresis or paralysis. The sequelae of exposure keratitis and corneal injury may be prevented. The chances of injury are increased when there is an additional Vth nerve deficit through loss of corneal sensation. A combination of artificial tears and lubricating ointment is applied. In cases of incomplete eye closure, moisture chambers have been used as well. Tarsorrhaphy sutures provide more long-standing corneal protection. Taping the eyes shut, however, is discouraged because this type of fixation is not absolutely secure. The lids may still open and the adhesive side of the tape can create corneal abrasions. Surgical implantation of a gold weight prosthesis in the upper eyelid, outside of the orbital septum and under the orbicularis oculi muscle, to allow the effects of gravity to aid lid closure may be considered. This technique is particularly useful and the gold weight may easily be removed if nerve function returns. If lower lid ectropion is developing, a lid-tightening procedure or lateral canthopexy may be performed.

Identification of facial nerve paralysis after surgery may be delayed due to poor bedside examination technique. Tight gauze head wraps may push the forehead tissues downward over the brow region to give the examiner the impression that the patient is able to close the eyes. In this setting, mere relaxation of the levator palpebrae superioris muscle, innervated by the oculomotor nerve, may give the appearance of active eye closure. The pull of actively contracting facial muscles on the opposite side to the facial paralysis can also mislead the clinician to think that there is facial movement on the paralyzed side.

Labyrinthine injury

Inadvertent violation into or through the bony and membranous labyrinth of the inner ear during mastoid surgery may lead to hearing loss and vestibular symptoms. In the translabyrinthine and transcochlear approaches, however, the labyrinth is purposely obliterated to gain access to the cerebellopontine angle and internal auditory canal, with expectations of sacrificing hearing and balance function. In an approach such as the infratemporal fossa approach, subtotal petrosectomy is performed, featuring a complete mastoidectomy with preservation of the labyrinth. In the other approaches to the petrous apex through the mastoid or transcanal route, care is taken not to violate the basal turn of the cochlea.

Preservation of the vestibular labyrinth is best carried out by identifying the horizontal semicircular canal, which is one of the first readily identifiable landmarks after completion of the cortical mastoidectomy. The bone over the horizontal semicircular canal is more dense than the mastoid air cell bone and whiter in color. The horizontal semicircular canal may be found superoposterior to the body of the incus as the mastoid antrum is entered after removal of Koerner’s septum, a bony extension from the petrosquamous suture line. After identification of the horizontal semicircular canal, the posterior semicircular canal may be identified posterior and inferior to it. The horizontal semicircular canal nearly bisects the arc of the posterior semicircular canal.

Any bone removal to gain access to the petrous apex via the infracochlear or infralabyrinthine approach should be performed with identification of the basal turn of the cochlea. The bone over the promontory may be removed with preservation of the endosteum of the inner ear, so as to ‘blue-line’ the basal turn of the cochlea using the diamond stone burr. Additional bone removal to gain wider access to the petrous apex through these latter approaches must then come from the bone over the jugular bulb and petrous carotid artery.

Inadvertent entry into the labyrinth should be repaired by placing fascia over the defect immediately. Either bone wax or bone dust plate may be placed over the fascia to secure its position. Care is taken not to apply direct suction into the fistulous site to preserve the labyrinthine fluids.

Vascular injury

The major vascular structures encountered during mastoid surgery include the sigmoid sinus, jugular bulb, and the numerous venous connections by the mastoid emissary vein or superior petrosal sinus. Protection from injury of these structures entails careful bone removal of the sigmoid sinus and jugular bulb and judicious use of cutting and diamond burrs. The cutting burr is used to remove enough bone over the vascular structures to leave an egg-shell thickness, while leaving the remaining task of skeletonization and decompression to the diamond stone burr with copious irrigation. Control of the mastoid emissary vein is best obtained by its skeletonization with bone removal on each side of the vein and bipolar cauterization after a near 360° exposure around the vessel. Bleeding from the superior petrosal sinus may occur when attempting bone removal deep within the sinodural angle. If this occurs, extraluminal packing with a hemostatic agent (Surgicel®/oxidized cellulose or Avitene®/collagen) is usually sufficient for hemostasis.

Tears or rents into the sigmoid sinus and jugular bulb are best handled by placing Avitene® or Surgicel® over the defect. These hemostatic agents should be large enough to prevent intraluminal entry and subsequent embolization. Larger linear defects may be addressed with vascular suture repair. Uncontrollable hemorrhage from the sigmoid sinus and jugular bulb, despite extraluminal packing and bipolar coagulation, may necessitate transcervical ligation of the internal jugular vein for distal control. Proximal superior control is achieved either by ligation of the sigmoid sinus or extraluminal compression or intraluminal packing with a hemostatic agent of choice. If possible, ligation of the sigmoid sinus should occur at a level below the superior petrosal and transverse sinuses to preserve all possible remaining venous drainage. Close postoperative monitoring is essential to prevent cerebral edema from impaired central venous drainage, especially if the right dominantly draining sigmoid sinus is interrupted.

The potential for venous air embolism should be recognized. The chances are increased if the patient's head is positioned above the level of the heart. Expedient occlusion of a venous tear with a finger or moist sponge will often help to temporize the bleed and prevent entry of air. Significant venous air embolism is usually heralded by dropping blood pressures, tachycardia, and arterial oxygen saturation. Cardiac auscultation will usually reveal a machine-like churning sound or murmur. The patient should be immediately positioned in the left lateral decubitus position with the head down in the Trendelenberg position. This will localize the air collection to the right heart until it can be evacuated. This is performed through a central line with access to the right cardiac chambers. In the meantime, oxygen at *F*iO2 of 100% may be given to enhance oxygenation and pressors may be given to maintain blood pressure.

Injury to the petrous carotid artery during the transmastoid or transcanal approaches to the petrous apex is rare. However, when it occurs, bleeding is brisk, and packing with a hemostatic agent must be available immediately to tamponade the bleed. Packing is usually adequate to control the bleed from small tears in the adventitia. If bleeding is too copious, the operation may need to be aborted in favor of an alternative approach.

The potential for encountering abnormal anatomy, for example, an aberrant carotid artery, high-riding jugular bulb, or anteriorly positioned sigmoid sinus, should always be kept in mind. These are usually identified preoperatively from the imaging studies. In these cases, a plan must be made on how to achieve adequate exposure either by taking an alternative approach or working around the anomaly.

Dural violation with cerebrospinal fluid leak and brain herniation

During mastoidectomy, bone removal must be performed to delineate the floor of the middle cranial fossa and the posterior fossa dural plates to obtain the maximal exposure, for example, in the translabyrinthine approach. If the dura is lacerated during the bone removal, a cerebrospinal fluid leak may ensue. Additionally, if the dural laceration is large enough; an encephalocele may develop. Dural laceration repairs should be performed immediately when it occurs; trying to minimize any prolonged intradural openings. Repair is carried out by suturing the edges of the dural defect or by incorporating free muscle or fascia into the suture line, if the edges do not come together.

Postoperative cerebrospinal fluid leaks, emanating from the posterior cranial fossa after mastoidectomy, less frequently close spontaneously due to its proximity to the large, higher-volume subarachnoid spaces of the basal cisterns, from where it originates. In comparison, leaks from the middle fossa are more apt to spontaneously close, due to the smaller subarchnoid spaces and the inferior surface of the temporal lobe resting over the bony defect;

by gravity to help to create a seal.

Cerebrospinal fluid leak resulting after the translabyrinthine approach has been reported to be the most common complication from this procedure98. In larger series, the rate of postoperative cerebrospinal fluid leak ranges from 6.8% to 21% 99−102. Although fat is used to pack the mastoid defect, leaks may still occur and present as cerebrospinal fluid rhinorrhea or leak through the wound. Frequently these leaks halt with conservative measures: mastoid pressure dressings and lumbar drain. Reoperation may be required with plugging of the eustachian tube, closure of the ear canal, and obliteration of the middle ear and mastoid spaces.

In general during mastoidectomy there are large areas of bone removal. Breaches through the bone outside the dura are avoided to prevent brain herniation in the form of a meningocele or encephalocele. Such herniations are more common from the temporal lobe than the cerebellum. If large areas of bone are missing, they may be replaced by split-thickness calvarial bone graft. Free fascia, cartilage, or cortical bone fragments may be tucked intracranially from the mastoid cavity under the edges of the bony defect. Smaller areas of bone defects may be left alone.

If an encephalocele results from excessive bone removal and was not addressed at the time of the original surgery, repair via the middle cranial fossa floor may be necessary. This approach offers wide exposure of any tegmental defects along the floor of the middle fossa, even for the more anteriorly placed defects closer to the petrous apex.

SUMMARY

Surgery in the skull base is now safer than ever. Enhanced safety has been brought on by advancements in imaging, surgical technique, and reconstructive capability. However, even the most contemporary techniques do not eliminate the potential for complications. With more centers of excellence focusing on skull base surgery, more surgeons are gaining focused experience and understanding on why skull base dissection may cause problems. The surgeon's focus on *complication management* has now shifted to *complication prevention*. These complications are avoidable and are no longer necessarily the consequences of skull base surgery.

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