Chapter 193: Extended Lateral Cranial Base Surgery

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Lateral approaches to the skull base compose numerous manipulations of intervening structures to gain access to the varied regions of the skull in and around the posterior and middle cranial fossae. Advancements in preoperative assessment, surgical techniques, and perioperative care have permitted removal of tumor previously viewed as unresectable. Concomitantly, the morbidity and mortality rates associated with these procedures have fallen significantly. A cohesive skull-base team affords the patient the best possible preoperative assessment, planning, and surgical execution. The team requires the expertise of an otolaryngologist - head and neck surgeon or neurootologist, working in concert with the neurosurgeon, neuroradiologist, and interventional arteriographer. The reconstructive surgeon may play a major role, especially if free flaps are required. This chaper reviews pertinent anatomy and the various approaches to the lateral skull base.

Anatomy

Lateral approaches to the skull base result in anatomic structures being approached from a vantage point different from those presented in classic anatomic text, both in terms of vector of orientation and particular anatomic detail important during surgical dissection. A thorough knowledge of the anatomy in this area is of absolute necessity for successful extirpation of base of skull lesions.

Infratemporal fossa

Lateral approaches to the skull base frequently involve the infratemporal fossa. Grant (1972) has described the limits of the infratemporal fossa. Superiorly it is bounded by the greater wing of the sphenoid and the temporal fossa containing the temporalis muscle. The medial limit is the lateral pterygoid plate and the lateral limit, the mandibular ramus, and condyle. The posterior wall of the maxillary sinus marks the anterior limit, and posteriorly and inferiorly the infratemporal fossa opens into the parapharyngeal space. Although fascial bands and ligaments divide this area into subcompartments, a definition as to what comprises the infratemporal fossa versus the parapharyngeal space is not clear in the literature (Gaughran, 1959; Proctor, 1989; van Huizen, 1984). Major structures to be enountered and managed by the surgeon exist throughout the area.

The facial nerve exits the stylomastoid foramen to enter the parotid gland and then emerges the gland distally encased in the superficial muscular aponeurotic system fascia (Stuzin et al, 1989). The glenoid fossa and its contents limit exposure of the roof of the infratemporal fossa in lateral surgical approaches. The lateral pterygoid muscle, arising from the lateral pterygoid process and the greater wing of the sphenoid, inserts on the temporomandibular joint capsule and neck of the condyle. The medial pterygoid muscle originates from the medial surface of the lateral pterygoid process and posterior maxillary wall to insert onto the angle of the mandible. The internal maxillary artery enters the infratemporal fossa between the condylar neck and sphenomandibular ligament, giving off multiple branches.

Anterior to the spine of the sphenoid the middle meningeal artery enters the foramen spinosum, and the mandibular division of the trigeminal nerve (V3) passes through the foramen ovale more anteriorly. Medial to these two foramina lies the eustachian tube, flanked by the tensor and levator veli palatini muscles, coursing medially to enter the nasopharynx. The horizontal portion of the petrous internal carotid artery is medial to the eustachian tube covered by a thin layer of bone.

Venous structures

As low-pressure, valveless channels, the venous system in the skull base is pivotal in lateral approaches. The torcular Herophili is the confluence of the transverse sinus (lateral sinus), superior longitudinal sinus, straight sinus, and occipital sinus. Bisaria (1985) found that this confluence of sinuses was missing in 24.5% of 110 cadaver dissections. Ligation of the transverse sinus may lead to massive cerebral edema if there is no torcular Herophili (Kaplan, 1984). The vein of Labbé, or inferior anastomotic vein, communicates the superficial middle cerebral vein with the transverse sinus, draining the superficial posterior temporal and inferior parietal lobes. It occurs on the right 66% and the left 77% of the time (Sasaki et al, 1977) and, when present, empties into the transverse sinus just proximal to the sigmoid sinus. Interruption of the vein of Labbé may lead to temporal lobe edema and venous stasis infarction (Kaplan, 1984; Sasaki et al, 1977). The superior petrosal sinus runs along the posterosuperior edge of the petrous bone from the cavernous sinus to the junction of transverse and sigmoid sinuses, receiving tributaries from the tympanic cavity, and the cerebellar and inferior cerebral veins (Schuknecht and Gulya, 1986). The mastoid emissary vein communicates between the sigmoid sinus and either the occipital or posterior auricular veins. The jugular bulb, averaging 15 mm in width, is usually separated from the tympanic cavity by bone, but may be dehiscent in 6% of cases (Graham, 1977). The inferior petrosal sinus courses between the jugular bulb and cavernous sinus in the petrooccipital fissure receiving tributaries from the internal auditory canal, pons, medulla, and inferior cerebellum (Schuknecht and Gulya, 1986). The inferior petrosal sinus, occasionally the vein of the cochlear aqueduct, and the occipital sinus drain into the jugular bulb. Cranial nerves IX, X, and XI pass through the anterior medial portion of the jugular foramen and may be compressed when obtaining hemostasis of the inferior petrosal sinus (Kveton and Cooper, 1988).

Internal carotid artery

The internal carotid artery ascends deep to the digastric and styloid muscles to enter the carotid siphon medial to the styloid process. The intrapetrous portion of the internal carotid artery is divided into the vertical and horizontal segments. In the vertical segment near the genu, the internal carotid artery is just deep to the eustachian tube orifice, posteromedial to the glenoid fossa, and inferomedial to the tensor tympani muscle and semicanal. The osseous eustachian tube orifice is separated from the internal carotid artery on average by 1.5 mm of bone and may have dehiscences (Leonetti et al, 1990; Savic and Djeric, 1985). The mid-portion of the vertical internal carotid artery is anteromedial to the basal turn of the cochlea. The distance to the cochlea averages approximately 1.34 mm (Muren et al, 1990). The average length of the vertical segment is approximately 10 mm (range 5 mm to 15 mm) (Leonetti et al, 1990; Paullus et al, 1977). The horizontal segment travels obliquely in a lateral to medial direction from the genu to the intracranial entry of the internal carotid artery at the superior aspect of the foramen lacerum. Its average length is 20 mm (range 14.5 mm to 25 mm) (Leonetti et al, 1990; Paullus et al, 1977).

Evaluation of Skull Base Lesions

Tumors of the lateral skull base often present with cranial nerve deficits, including hearing loss, pulsatile tinnitus, and eustachian tube dysfunction. A thorough history and physical examination with special attention to the cranial nerves should be undertaken. Audiometry is useful in surgical planning, particularly when removal of the labyrinth is needed. Radiographic evaluation provides information regarding location, extensions, surrounding structural relationships, and probable histology (Brown et al, 1990; Daniels et al, 1985; Franklin et al, 1989a; Gentry et al, 1987; Griffin et al, 1987; Greenberg et al, 1988; Matsushima et al, 1989; Meyerhoff et al, 1989; Teresi et al, 1987). Preoperative computed tomography (CT) and/or magnetic resonance imaging (MRI) is indispensable to modern skull base surgery.

Preoperative carotid artery assessment

In extirpation of skull base tumors, appropriate management of the internal carotid artery remains paramount. Preoperative four-vessel vertebral-carotid arteriography with assessment of collateral circulation is imperative to determine the potential risk of internal carotid artery injury or the need for intraoperative occlusion. The morbidity for carotid artery occlusion is well known, as the first carotid ligation for a sword injury in 1585 by Paré resulted in stroke (Watson and Silverstone, 1939). Significant neurologic sequelae have been reported in 19.3% of patients with surgical occlusion of the carotid artery for intracranial saccular aneurysms (Landolt and Millikan, 1970) and 30% with head and neck cancer (Konno et al, 1981). Ligation at the level of the internal carotid versus the common may reduce the neurologic morbidity in head and neck cancer patients (Konno et al, 1981). Gradual occlusion, as with a "Silverstone" clamp, does not appear to alter morbidity. Bernstein et al (1984) noted that a significant reduction of blood flow or pressure does not occur until a cross-sectional area of less than 2 mm^2 is reached, regardless of the diameter of the vessel. Late-onset complications from cervical internal carotid artery ligation may result after several hours, secondary to stasis with distal thrombosis and embolic phenomena.

Some understanding of cerebral blood flow levels is essential to carotid management. Normal cerebral blood flow approximates 50 mL/100 g/minute (Lassen and Astrup, 1990). In alert humans, cerebral blood flow below 20 mL/100 g/min produces failure of brain function resulting in, at least, temporary hemiparesis or hemiplegia (Morawetz, 1990). At this point, the electroencephalogram (EEG) usually reveals changes reflecting synaptic transmission failure (Lassen and Astrup, 1990; Sundt, 1990). As cerebral blood flow drops below 15 mL/100 g/min, electrical activity is lost (Lassen and Astrup, 1990; Morawetz, 1990). Metabolic failure occurs below 10 mL/100 g/min with irreversible membrane failure and neuronal death (Astrup et al, 1981). Jones et al (1981) found that long-lasting ischemia in monkeys produced by local cerebral blood flow below 17 to 18 mL/100 g/min resulted in infarction. The time course of irreversible neuronal damage at various cerebral blood flow levels in humans is unknown.

Various methods have been proposed to assess collateral circulation in the circle of Willis. Simplest is the Matas test in which the ipsilateral carotid is compressed against a vertebral transverse process while observing for deterioration of neurologic function (Matas, 1940). Cross-compression carotid arteriography or temporary balloon catheter occlusion arteriography (Osguthorpe and Hungerford, 1984) give a qualitative feel for ipsilateral cerebral blood flow. Direct intraoperative carotid stump pressures can estimate collateral circulation. A back pressure of 50 mmHg has been considered as indicative of adequate cerebral blood flow (Miller et al, 1977), but stump pressures recently have been shown to be unreliable (de Vries et al, 1990; McKay et al, 1976). Ocular plethysmography and transcranial Doppler velocitometry of the middle cerebral artery (Kontos, 1989), have similar theoretical limitations. In a series of patients undergoing carotid surgery, intraoperative EEG revealed no change in 18% to 56% of patients with cerebral blood flow levels less than 20 to 24 mL/100 g/min depending on anesthetic used (Sundt, 1990). EEG, therefore, may be too insensitive for prolonged internal carotid artery occlusions.

Xenon-133 (Xe133) clearance shows excellent correlation with quantitative assessments of cerebral blood flow in a defined region using a scintillation counter on the scalp (Sundt, 1990). Xe 133 clearance may also be used intraoperatively. Xenon-CT blood flow mapping is similar to X133 clearance (Yonas et al, 1985). Inhaled xenon acts as a contrast agent whose uptake and diffusion from cerebral tissue is proportional to blood flow. Blood flow in the middle cerebral artery distribution is estimated using specialized computer software before and after temporary balloon occlusion of the internal carotid artery during serial CT scans and a blood flow map calculated.

Positron emission tomography (PET) has the advantage of measuring both cerebral blood flow and metabolic parameters simultaneously (Powers, 1990). Of the tests mentioned, PET provides the most accurate knowledge regarding cerebral hemodynamics.

Other methods for estimating cerebral blood flow, such as single photon emission CT, magnetoencephalography, and magnetic resonance spectroscopy are still investigational (Latchaw et al, 1990; Nuwer, 1990; Weinsteni and Vink, 1990).

If the decision for occlusion of the carotid is reached preoperatively, a transarterial detachable balloon may be inserted before surgery. Placement proximally at the level of the carotid bifurcation and distally just before the ophthalmic artery minimizes late thromboembolic sequelae (Valavanis, 1988; Valavanis and Fisch, 1989a) and compares favorably with the results of surgical ligation. The long-term sequelae of carotid occlusion is unknonw. Theoretically, arterial reconstruction using interposition grafting should obviate these risks (Sekhar, 1987a; Sekhar and Janecka, 1991). Intraoperative balloon occlusion or intraarterial shunts may be required if the internal carotid artery is lacerated and control is difficult (Andrews et al, 1989). A role for temporary intraoperative balloon occlusion followed by arterial reconstruction with saphenous vein graft is evolving (Fisch and Mattox, 1988; Urken et al, 1985).

Lateral Skull Base Techniques

Although the biologic behavior of the tumors involving the skull base may vary, certain general principles should be followed in their extirpation. The operative approach and intraoperative techniques should maximize safe exposure and minimize morbidity. Surgeons should be well versed in all methods of exposure for various regions of the skull base. Circumferential exposure of tumor margins, minimization of blood loss by preoperative selective embolization and intraoperative selective vessel ligation, proximal and distal control of the internal carotid artery around the tumor, and preservation of cranial nerves wherever possible are essential to a successful outcome.

Attacking various problems of the skull base via a lateral approach transgresses the temporal bone and infratemporal fossa. The postauricular infratemporal fossa approaches as described by Fisch (Fisch, 1982; Fisch and Mattox, 1988; Jenkins and Franklin, 1991) and the preauricular (Sekhar and Møller, 1986; Sekhar et al, 1986, 1987; Sen and Sekhar, 1990) approaches offer the best access to the jugular bulb, internal carotid artery, petrous apex, clivus, pterygomaxillary fossa, and nasopharynx. These authors have written extensively on this subject, and the techniques described here have been adapted from their work. Anatomic maneuvers may be added as needed to facilitate tumor exposure and extirpation.

Postauricular approaches to the infratemporal fossa

Fisch (1982) has been the primary innovator of these techniques and should be credited for his work. He has divided these into three basic approaches. Type A dissection entails radical mastoidectomy, anterior transposition of the facial nerve, exploration of the posterior infratemporal fossa, and cervical dissection permitting access to the jugular bulb, vertical petrous carotid, and posterior infratemporal fossa. Type B dissection explores the petrous apex, clivus, and superior infratemporal fossa. Type C allows exposure of the nasopharynx, peritubal space, rostral clivus, parasellar area, pterygopalatine fossa, and anterosuperior infratemporal fossa.

Incisions and skin flaps

The planned incision must allow for further extensions without devascularization of the elevated skin flap, Fig. 193-1, A. Cervical exposure to varying extents and anterior extension for dissection toward the clivus and parasellar area must be permitted. Keeping the inferior limb posteriorly over the mastoid tip allows extension into the cervical area for dissection, while protecting the ramus mandibularis nerve. Similarly, extending the incision anterosuperiorly into the frontal area permits elevation over the zygoma to the orbital rim.

The flap should be elevated superficially to the temporalis and postauricular muscles, leaving a periosteal flap based on the external auditory canal, Fig. 193-1, B. The external auditory canal is transected being careful to protect the branches of facial nerve anterior to the canal.

The plane of dissection anteriorly is in the subcuticular tissue over the temporal, parotid, and cervical areas. In the type A approach, the tertiary branches of the facial nerve are identified and protected, whereas in the types B and C approaches the frontal branch is exposed and protected near the lateral orbital rim.

Closure of the external auditory canal

The external auditory canal is closed in a watertight blind sac. The cartilaginous canal skin is undermined to approximately the conchal bowl with tenotomy scissors. The cartilaginous canal skin is then everted and sutured with absorbable sutures and reenforced medially with the periosteal flap elevated off the mastoid cortex, Fig. 193-1, C-F (Coker et al, 1986).

Removal of external auditory canal wall skin and tympanic membrane

The skin of the osseous external auditory canal wall is elevated circumferentially down to annulus. With an operating microscope, the tympanic annulus is elevated, the incudostapedial joint separated, the tensor tympani tendon cut, and neck of malleus nipped, allowing total removal of the canal wall skin, tympanic membrane, and attached manubrium (Fig. 193-2).

Cervical dissection

Cervical dissection is carried out as needed to expose the inferior margins of the tumor. This part of the procedure is not required in most type B and C approaches, except to gain cervical control of the vascular structures if needed. The greater auricular nerve should be sectioned as distally as possible in the parotid for potential use as an interpositional graft if needed. Major structures including the common, external, and internal carotid arteries; internal jugular vein; and CNs IX to XII are identified (Fig. 193-3). Division of the posterior belly of the digastric near the mastoid facilitates identification of these structures up to their entrance in the skull base. Ligation of the occipital and ascending pharyngeal artery is indicated when these arteries prove to be the vascular supply to the tumor on arteriography. Transection of the glossopharyngeal nerve is often necessary to follow the carotid artery into the skull base. Vascular loops are placed around the internal carotid artery and jugular vein for quick identification and control in the event of bleeding (see Fig. 193-4, A).

Extratemporal facial nerve dissection

The extratemporal facial nerve may be located deep to the midpoint of a line between the tragal pointer cartilage and mastoid tip. After release of parotid tissue from the sternocleidomastoid muscle, the tragal cartilage is dissected medially, identifying the facial nerve just inferior to the pointer. The facial nerve is dissected out to tertiary branches by cutting overlying parotid and freeing it from the underlying tissues. This much exposure is required for anterior transposition in the type A approach (Fig. 193-3). In the type B and C approaches, facial nerve transposition is not required; only the frontal branch is followed distally to allow its preservation when the zygoma is transected. The parotid is bluntly dissected off the masseteric fascia to reduce traction on the facial nerve when the mandible is retracted.

Radical mastoidectomy

The radical mastoidectomy removes the air cell tracts lateral and adjacent to the otic capsule (Fig. 193-4, A). Exenteration of all tracks is important to prevent long-term complications after cavity obliteration (Coker et al, 1986). The stapes suprasturcture is removed to prevent inner ear trauma. The facial nerve is skeletonized in preparation for transposition. The eustachian tube is obliterated with bone wax impregnated with bone dust and a muscle plug. Removal of the external canal, tympanic membrane, ossicles, and air cells of the temporal bone lateral to the otic capsule constitute the radical mastoidectomy.

Type A approach

Facial nerve transposition. The facial nerve should be skeletonized and freed of its bony canal 180 degrees circumferentially from the geniculate ganglion distally to stylomastoid foramen. The horizontal semicircular canal is in jeopardy at the second genu, and bone should be removed only on the tympanic side of the facial nerve. The air cells of the mastoid tip are exnterated lateral to the digastric ridge; the cortical shell is removed with a rongeur after incising the attached digastric muscle. At the stylomastoid foramen, the facial nerve is densely adherent to the surrounding fibrous tissue, and these tissues are elevated as a unit to prevent devascularization and stretch injury to the nerve. A new bony canal is drilled in the anterior wall of the epitympanum to receive the nerve. The facial nerve is carefully elevated from the geniculate ganglion to the pes anserinus and is transposed into the new groove and secured within the parotid soft tissue (Fig. 193-4, B).

Meticulous handling of the facial nerve decreases the risk of permanent facial nerve dysfunction after transposition. Use of the operating microscope, diamond burr, and constant irrigation minimizes direct trauma. The epineurium is kept intact. The stapedius nerve, the soft tissue of the stylomastoid foramen including periosteum and enclosed facial nerve, and all medial attachments to the nerve should be sharply dissected to prevent stretch injury.

Intraoperative facial nerve monitoring with electromyography (EMG) is of great benefit during transposition in preventing injury (Leonetti et al, 1989). Immediate feedback is available to the surgeon during manual manipulations, helping to prevent direct trauma and stretch injury, the latter being the most common reason for postoperative dysfunction. With feedback monitoring, the surgeon can remove bone over the facial nerve more aggressively.

Occlusion of the sigmoid sinus. Bone is removed over the posterior fossa dura anterior and posterior to the sigmoid sinus to allow ligation. The mastoid emissary vein is left undisturbed and ligation performed below it if possible. Dural vessels are coagulated; the dura is elevated with dural hooks, incised in front of and behind the sigmoid sinus; and a blunt-tipped aneurysm needle is used to pass a double 2-0 silk ligature (Fig. 193-5, A-C). A small cerebrospinal fluid (CSF) leak may occur and is easily controlled with a sutured muscle plug. Other methods of sigmoid sinus interruption are used by Jackson et al (1989) and Holliday et al (1986), which involve intraluminal absorbable packing (Fig. 193-5, D).

Exposure of jugular bulb and internal carotid artery. A clamp is passed medial to the styloid process to protect the internal carotid artery while the process is fractured and removed with the attached muscles. The parotid gland is dissected from the tympanic bone, and a modified self-retaining laminectomy retractor (Karl Storz, D-7200 Tuttlingen, Germany) is placed behind the ramus of the mandible subluxing it anteriorly. The facial nerve EMG activity is monitored to avoid stretch injury or compression of branches in the parotid. Exposure of the posterior infratemporal fossa now permits isolation of the vertical intrapetrous internal carotid artery. With removal of bone over the carotid and beneath the otic capsule, the jugular fossa is exposed for tumor removal (Figs. 193-6 and 193-7, A-B).

Tumor removal. After exposure and distal control of the internal carotid artery is accomplished, tumor may be carefully removed (Jenkins and Fisch, 1981). The jugular vein is ligated to prevent tumor and air embolism. Dissection begins by freeing the carotid and rotating the tumor posteriorly (Fig. 193-7, C). The lateral wall of the sigmoid sinus is removed along with intraluminal tumor (Fig. 193-7, D). The medial wall forms the barrier to the CSF. The inferior margin of the tumor is elevated and the extracranial tumor removed (Fig. 193-7, D). If tumor extends intracranially, it is amputated sharply at this point. Profuse bleeding may occur from the entrances of the inferior petrosal sinus into the jugular bulb. Control is achieved by surgical packing.

After hemostasis is obtained, the posterior fossa dura is opened and the intracranial portion of the tumor excised (Fig. 193-8, A-C) at the same setting for intracranial tumors less than 2 cm in size. Larger tumors may be staged and removed at a later time (Fisch and Mattox, 1988; Jackson et al, 1987). Care must be taken to preserve the blood supply to the brainstem.

Closure of wound. The dura usually has a defect too large for primary closure. Fascia lata provides the best material for reconstruction, although lyophilized dura can be used to seal the defect. Abdominal fat is used to obliterate the dead space of the temporal bone and the temporalis muscle rotated inferiorly for reenforcement of the wound (Fig. 193-9). The skin is closed routinely and a bulky pressure dressing applied for a minimum of 5 days to prevent leakage of CSF.

Type B approach

The type B approach differs from the type A in that facial nerve transposition is usually not required. The steps to transposition are identical to those of the type A approach. Reflection of the temporalis muscle still attached to the coronoid process and the zygoma allows the retractor to expose the superior infratemporal fossa (Fig. 193-10, A). Monitoring of facial nerve EMG activity during mandibular displacement helps prevent stretch injury. The limits of operative exposure in the type B approach are defined by the MCF floor, mandibular condyle, and reflected temporalis muscle (Fig. 193-10, B).

Thinning bone under the MCF dura improves exposure. The middle meningeal artery and V3 branch of the trigeminal nerve require bipolar cauterization and transection, thereby giving exposure to the superior 4 cm of the infratemporal fossa. The carotid artery may now be uncovered from its vertical segment to its anterior limit at the foramen lacerum after separation from the soft tissues around the eustachian tube (Fig. 193-11, A). The geniculate ganglion of the facial nerve and cochlea may be prone to injury if not properly recognized.

Petrous apex lesions such as cholesteatoma or low-grade chondrosarcomas may be removed at this point with careful anterolateral retraction of the internal carotid artery. The internal carotid artery can be elevated from the foramen lacerum to the canalis caroticus to permit temporary internal carotid artery transposition (Fig. 193-11, B). This maneuver may easily result in hemorrhage and must be performed with care. Extensive benign lesions involving the petrous apex and perilabyrinthine area may require a transotitic approach combined with posterior facial nerve transposition accomplished by cutting the greater superficial petrosal nerve and liberating the facial nerve from the porus acusticus to the stylomastoid foramen (House and Hitselberger, 1976; House et al, 1978) (Fig. 193-12, A-B). Additionally, the middle fossa may easily be accessed with a temporal craniotomy.

Exposure of the clivus can be obtained by sharp incision of the fibrous attachments at the petrooccipital fissure. Tumors of the clivus, such as chordomas, up to the parasellar area may be removed through the type B approach (Fig. 193-11, A-B). Removal of the mandibular condyle may give better exposure to the inferior clivus and upper cervical vertebrae. With inferior extension of the tumor, the facial nerve may be transposed as in a type A approach. Tumor located superior or medial to the horizontal portion of the internal carotid artery may require further mobilization of the cervical and vertical petrous carotid (Fig. 193-11, B) or the addition of an MCF craniotomy. The superior and inferior petrosal sinuses may require removal in these extended dissections.

Type C approach

The Type C approach is an anterior extension of the type B approach. The type C infratemporal fossa approach permits posterolateral access to the rostral clivus, cavernous sinus, sphenoid sinus, peritubal space, pterygopalatine fossa, and nasopharynx as well as the areas exposed by the type B approach. The type C infratemporal fossa approach, in essence, permits access anterior to the foramen lacerum up to the posterior aspect of the maxillary sinus and nasopharynx.

The base of the pterygoid process is removed to approach the sphenoid sinus and cavernous sinus (Fig. 193-13, A). Removal of the pterygoid base uncovers V2 in the foramen rotundum and the inferior orbital fissure. Removal of bone from the pterygoid base permits better visualization of the sphenoid sinus; with the sinus exposed, the floor of the sella turcica can be visualized (Fig. 193-13, B). The cavernous sinus is exposed by thinning the bone of the MCF floor anterior to the V2 stump. The MCF dura may be retracted, giving a inferolateral view of the cavernous sinus.

To enter the lateral nasopharyngeal cavity, the lateral and medial pterygoid processes are removed and the buccopharyngeal fascia and nasopharyngeal mucosa incised. Separation of the pterygoid muscles from the mandible allows en bloc removal of the lateral nasopharyngeal wall, peritubal space, and superior infratemporal contents when needed for tumor extirpation (Fig. 193-14).

Tumors involving the pterygopalatine space require removal of the pterygoid process and a portion of the greater wing of the sphenoid with sacrifice of the maxillary branch of the trigeminal nerve. A portion of the posterior maxillary wall may be removed for further access.

Preauricular infratemporal approach

The preauricular approaches to the skull base as described by Sekhar and colleagues (Schramm, 1987; Sekhar et al, 1986, 1987; Sen and Sekhar, 1990) can expose both the upper cervical internal carotid artery (without facial nerve transposition) and the intrapetrous internal carotid artery. These infratemporal dissections expose virtually the same areas as the Fisch B and C approaches, albeit from a purely lateral vector of exposure. The preauricular approach accesses the petrous apex, clivus, and superior infratemporal fossa and may be extended to include the nasopharynx, parasellar area, pterygopalatine fossa, and anterior infratemporal fossa. A frontotemporal craniotomy may be included for intracranial extension (Sekhar and Janecka, 1991). The petrous bone may be entered for access to the internal carotid artery, but the external auditory canal is not removed and the tympanic cavity is not obliterated; therefore, the middle ear function is preserved, although the eustachian tube may be sacrificed resulting in permanent serous otitis media. Although resection the mandibular condyle in the preauricular approach facilitates the exposure of the internal carotid artery, it is usually not required in the postauricular approaches as a posterior vector of orientation improves access.

The preauricular incision may be extended into the frontoparietal and upper cervical areas to expand exposure into the anterior infratemporal fossa (Fig. 193-15, A). Identification and control of vascular structures in the neck is similar to the postauricular approaches. The superior cervical dissection is hindered by the facial nerve exiting the stylomastoid foramen to enter the parotid gland. Retraction of the mandible anteroinferiorly permits exposure of the upper cervical internal carotid artery (Fig. 193-15, B). Constant EMG monitoring during application of retractors greatly reduces risks of facial nerve injury. Reflection of the temporalis muscles and zygoma as previosuly described for Fisch type B and C approaches permits dissection of the anterior infratemporal fossa (Fig. 193-15, C).

The added time spent performing a subtotal petrosectomy followed by obliteration is a disadvantage for the Fisch approach. Conductive hearing loss is inevitable. However, transposition of the facial nerve, required in the type A approach, does provide better access to the jugular fossa and the internal carotid artery at the skull base. The primary disadvantage of the preauricular approach is its limitation of exposure to those lesions that extend into the temporal bone or posterior cranial fossa.

Selected Skull Base Problems

Aneurysms of the upper cervical and petrous internal carotid artery

Primary lesions of the upper cervical and petrous internal carotid artery are decidedly rare. They include those with a congenital aberrant course (Glasscock et al, 1980; Sinnreich et al, 1984), aneurysms, spontaneous and traumatic dissections; and lacerations. Aneurysm types include congenital, infectious (mycotic), pseudoaneurysm (traumatic), atherosclerotic, luetic, and fibromuscular dysplasia.

Although upper cervical carotid aneurysms are associated with a very high incidence of ischemic attacks and strokes, reports of rupture are unusual (Moffat and O'Connor, 1980; Mokøri et al, 1982; Rhodes et al, 1976; Stringer and Kelly, 1980; Sundt et al, 1986; Winslow, 1926). Petrous internal carotid artery aneurysms have a high propensity of cranial nerve dysfunction and aural hemorrhage (Brandt et al, 1986). In light of the natural history, observation is undesirable in most patients with internal carotid artery aneurysms unless other medical exingencies take precedence. Cervical carotid occlusion carries a high risk of cerebrovascular complications. Surgical trapping, consisting of proximal cervical ligation and supraclinoid internal carotid artery clipping, avoids late thromboembolic phenomena (de Grood, 1977). Transarterial detachable balloon trapping and cervical internal carotid artery occlusion with extracranial/intracranial (EC/IC) arterial bypass have been used (Bernstein et al, 1984; Gewertz et al, 1980).

When surgical intervention is feasible, internal carotid artery reconstitution with direct reanastomosis or saphenoous vein interposition grafting is preferable. A preauricular approach as described by several authors (Dichtel et al, 1984; Mokøri et al, 1982; Rhodes et al, 1976; Sekhar et al, 1986; Sundt et al, 1986) may be used to expose the upper cervical carotid aneurysms (Fig. 193-15, B). These approaches, however, are hindered by the facial nerve, mandible, styloid process, and tympanic bone. For extension of the aneurysm to the skull base or vertical petrous internal carotid artery, the postauricular (Fisch type A or B) approach gives maximal vascular control with good distal exposure of the vessel (Fisch et al, 1980; Glasscock et al, 1983) (Figs. 193-16 and 193-17). Aneurysms involving the horizontal petrous internal carotid artery may be approached through a Fisch type B or preauricular approach as described by Sekhar et al (1986). Inadequate exposure and distal control of horizontal petrous internal carotid artery, however, may lead to uncontrolled entry into these aneurysms. Some form of trapping with or without EC/IC bypass should be considered in poorly accessible lesions.

Jugular foramen tumors

Tumors of the jugular foramen primarily include glomus jugulare (paraganglioma), and schwannomas of CNs IX, X, and XI. The Fisch type A approach with transposition of the facial nerve and the approach of Farrior (1984) approach with limited mobilization of the vertical segment of the facial nerve allow adequate exposure of the jugular bulb area. Donald and Chole (1984) advocate a transcervical-transmastoid technique to gain access to the jugular fossa without transposing the facial nerve. This procedure, although technically possible, provides less exposure and more limited vascular control but is benefitted by an absence of facial nerve morbidity. This technique is more feasible when there are extensive retrofacial air cells.

Schwannomas of the jugular foramen

Schwannomas arising from CNs IX, X, and XI at the jugular foramen are decidedly uncommon with only slightly more than 100 reported in the world's literature (Graham et al, 1991; Pellet W et al, 1990). These tumors may be intracranial, intraforamenal cervical, or a combination thereof (Kaye et al, 1984; Pellet et al, 1990). For intracranial tumors, the suboccipital approach is clearly the most direct and effective route. Infraforamenal and combination tumors are removed in the safest manner via the infratemporal fossa approaches described by Fisch. These tumors arise anatomically from the "pars nervosa" of the jugular foramen and are situated anteromedially to the jugular bulb and internal jugular vein and posterior to the upper cervical and petrous internal carotid artery. Transposition of the facial nerve, as in a Fisch type A approach (Franklin et al, 1989b) is helpful for control of these vascular structures and tumor exposure (Fig. 193-18). Farrior's limited approach may also have a role in small tumors (Farrior, 1984). Pellet et al (1990) gave consideration to the use of an "extended transcochlear" route in which a Fisch type A dissection is performed followed by sacrifice of the labyrinth to gain access to large tumors extending into the cerebellopontine angle.

Paragangliomas of the temporal bone

Several classification systems have described paragangliomas of the temporal bone (Alford and Guilford, 1962; Fisch and Mattox, 1988; Jackson et al, 1989; Valavanis and Fisch, 1989b). The classifications are similar and allow clinicians to communicate findings and results. Glomus tympanicum tumors confined to the middle ear may be approached through standard otologic techniques. Tumors involving the jugular bulb and infralabyrinthine compargtment and tumors with intracranial and cervical extensions are best approached by the Fisch type A route. Staging may be necessary in large tumors with extensive intracranial extension (Fig. 193-19).

Bleeding intraoperatively remains a major problem in removal of glomus tumors. The efficacy of preoperative embolization of glomus tumors in reducing intraoperative blood loss is debated (Jackson et al, 1989). Some studies do suggest significant reduction of intraoperative blood loss and operative time after embolization (Murphy and Brackmann, 1989; Valavanis, 1986, 1988; Young et al, 1988). Intraoperative ligation of the feeding vessels, such as the ascending pharyngeal, stylomastoid, caroticotympanic, internal maxillary, and superior tympanic arteries, before extirpation may lessen bleeding. However, ancillary blood supply from various other sources may mitigate this result (Young et al, 1988). Piecemeal tumor remvoal, as in acoustic neuroma surgery, is impractical in these vascular tumors and will often reslt in hemorrhage obscuring anatomic landmarks.

Lack of cranial nerve dysfunction is not a reliable indicator of intraoperative nerve status in these tumors (Makek et al, 1990). CNs VII and IX to XII may be involved at the skull base. In superficial involvement, segmental removal of involved epineurium may clear tumor. Neural invasion requires semgental neurectomy.

Paragangliomas often invade the periosteum of the carotid canal but rarely the adventitia itself (Andrews et al, 1989). Good preoperative angiographic assessment is of absolute necessity. A subperiosteal plane of dissection is developed intraoperatively. If the adventitia is involved, surgical manipulation may result in a large laceration of the carotid. Transarterial balloon trappings of the internal carotid artery should be considered in turmos with infiltration of the wall of the horizontal petrous segment of the internal carotid artery or in tumors with intracranial extension receiving significant blood supply from the internal carotid artery. If the status of the internal carotid artery is not appreciated preoperatively, several options are possible. Lacerations may be sutured directly. Saphenous vein interposition grafting may be performed with or without a shunt (Fisch and Mattox, 1988). The internal carotid artery may be transarterially balloon occluded intraoperatively with or without angiographic confirmation, depending on the urgency of the situation (Andrews et al, 1989; Fisch and Mattow, 1988; Valavanis, 1986).

Petrous apex lesions

Primary tumors of the petrous apex, either benign or low-grade neoplasms, such as cholesteatoma, schwannoma, chondroma, meningioma, chordoma, and low-grade sarcomas, are best removed totally to prevent recurrence. The infratemporal fossa approaches to the petrous apex (that is, Fisch type B, or perhaps, type A) give better exposure and control of the internal carotid artery and may be combined with the middle cranial fossa or transcochlear or translabyrinthine routes as needed (Fig. 193-11, A-B). In patients with serviceable hearing, the petrous internal carotid artery may be temporarily transposed to gain acces to the petrous apex with significant risk of hemorrhage. The combination of the transcochlear or translabyrinthine route with posterior translocation of the facial nerve offers the best access to the petrous apex (Figs. 193-12, A-B and 193-20).

Approaches to the clivus

Planning and execution of clival tumor extirpation is perhaps the most difficult of skull base surgery. Surrounding neurovascular structures of the brainstem and both internal carotid arteryes are at risk during surgery.

House and Hitselberger (1976) reported a transcochlear route to the petrous tip and midclivus, sacrificing ipsilateral cochlear and vestibular function (Fig. 193-12). It may be useful in removing tumors that are not intrinsic (primary) neoplasms of the clival bone itself such as cholesteatoma and meningioma, because only the dorsal midclivus is exposed. The Fisch type B approach is useful for tumors involving the midclivus with extension to the petrous apex (Fisch and Mattox, 1988). Tumor extension medial and superior to the horizontal internal carotid artery in the petrous apex require temporary internal carotid artery transposition. Adding a middle cranial fossa subdural dissection may circumvent this problem. A transcochlear dissection added to a Fisch type B may also improve access to the clivus. Tumor of the posterior clinoid (retrosellar) is not accessible via this route, but an intradural middle cranial fossa approach may be of benefit (Derome et al, 1987). The preauricular approaches (Sekhar et al, 1987; Sen and Sekhar, 1990) have similar limitations to those already discussed, but the transcochlear route cannot be used for further exposure in combination with the preauricular apprach. Numerous anterior approaches to the clivus have also been described but in general lack vascular control (Arriage and Janecka, 1991; Biller et al, 1981; Guiot et al, 1968; Jenkins and Canalis, 1984; Panje et al, 1989).

Lesions involving the cavernous sinus

The cavernous sinus is a small plexus of veins enclosed by leaves of dura on either side of the sella turcica (Harris and Rhoton, 1976). In the cavernous sinus lie the internal carotid artery, sympathetic nerves, and CNs III, IV, VI, V1, and sometimes V2. Primary tumors of the cavernous sinus commonly include meningiomas or schwannomas (Sekhar and Møller, 1986), but this region is usually invaded secondarily. Operations involving the cavernous sinus are fraught with potential complications including bleeding, cranial nerve deficits, and internal carotid artery injury. Palliative therapy such as irradiation may be warranted for many lesions in this location.

Tumors of the parapharyngeal space

Tumors involving the infratemporal fossa or parapharyngeal space at the skull base and extending into the temporal bone or middle cranial fossa require lateral skull techniques. For tumors confined to the parapharyngeal space, a cervical approach, often with mandibular transection, may be indicated. Radical en bloc procedures for malignancy may require removal of the mandibular ramus and condyle (Friedman et al, 1981; Panje, 1986). A labiomandibulotomy (Attia et al, 1984; Krespi and Sisson, 1984) or extraoral mandibulotomy will give improved access to the tumor within the middle to upper infratemporal fossa. Reflection of the temporalis muscle and zygoma provides improved access to the superior infratemporal fossa. Further exposure may be obtained by retracting the madnibular condyle or resecting it. Middle cranial fossa approach may be added for superior extension (Fig. 193-21).

Approaches to the nasopharynx

In extensive benign tumors of the nasopharynx (for example, juvenile angiofibromas) a lateral approach may be indicated. These approaches may be combined with any of the anterior aproaches as the situation warrants. The Fisch type C (see Fig. 193-14) or Sekhar lateral approaches to the nasopharynx provide similar exposures, and either approach may be extended to include removal of tumor from the sphenoid sinus or pericavernous sinus area.

Excision of malignant lesions of the nasopharynx is fraught with controvery. Wang (1989) has shown that patients with recurrent squamous cell carcinoma of the nasopharynx staged T1-3 may have improved survival if they are excised. Fisch type C approach and Sekhar's approach permits en bloc removal of the lateral nasopharyngeal wall with the pterygoi and tubal musculature for persistent or recurrent tumor postradiation.

Complications

Intraoperative

Intraoperative complications mostly result from lack of vascular control or coagulopathy. Management of unexpected blood loss from an internal carotid artery laceration is facilitated by proximal and distal control before repair. A lack of exposure may result in the need for emergency intraoperative balloon occlusion and ligation when hemorrhage occurs. Bleeding from the cavernous sinus can be massive and an air embolus may occur. This bleeding, though, can be stopped with patient application of Surgicel. Carotid spasm may require termination of the procedure (Jackson et al, 1989).

Coagulopathy may occur due to massive transfusion of packed red blood cells (RBCs) due to citrate-induced hypocalcemia, depletion of clotting cascade proteins, hypothermia, thrombocytopenia, disseminated intravascular coagulopathy, or incomatible blood. Two units of fresh-frozen plasma and platelets should be given for every 10 units of packed RBCs

(Domino, 1987). Vasoactive glomus tumors or concomitant pheochromocytomas may lead to unexpected hypertension intraoperatively. For this reason, glomus patients should be screened preoperatively with urine vanillylmandelic acid and hydroxyindolacetic acid to rule out vasoactive tumors.

Cerebrospinal fluid leakage

CSF leakage is one of the more common postoperative complications from infratemporal fossa surgery when the dural space must be entered. The risk of meningitis with high attendant morbidity is increased, as is length of hospital stay. Postoperative lower cranial nerve deficits leading to aspiration and subsequent coughing increases CSF pressure, adding another adverse variable to the management equation. Most CSF collections beneath flaps may be treated with compressive dressings, head elevation, and repeated aspirations. Leakage of CSF through the wound or persistent otorhinorrhea are best managed by a lumbar subarachnoid drain.

With large tumors and intracranial extension, the subarachnoid space must be entered for tumor exposure and extirpation. Jackson et al (1989) secute autogenous fascia to existing bone or dural margins for small to medium dural defects with temporalis muscle rotations for reinforcement. Obliteration with fat is not used. For larger defects, Gulya et al (1986) have used an infant ventriculocardiac shunt from the wound bed to the jugular stump to right atrium to allow continuous drainage. Lumbar subarachnoid drains in combination with pressure dressing usually suffice to control leakage for large dural defects.

Cranial nerve deficits

The invasive nature of glomus tumors, especially those extending into the posterior fossa, has led historically to rather high rates of postoperative paralysis. Aside from intraoperative electrophysiologic monitoring (Leonetti et al, 1989; Møller, 1987), the proximal identification of CN IX, X, XI, and XII in the posterior fossa and distal identification at the skull base should improve preservation of these nerves (Jackson et al, 1987). Unfortunately, these cranial nerves are often encased in tumor extending extradurally into the posterior fossa toward the root entry zones, making their preservation extremely difficult.

Most preoperative cranial nerve deficits persist postoperatively if they are due to tumor invasion rather than compression. Creation of new cranial deficits, although necessary for complete tumor removal, can result in a prolonged rehabilitative phase and substantially reduce the quality of life. The patient's age and cardiopulmonary status must be carefully weighed against the tumor pathology, extent of disease, and natural coruse of disease. Responses to other forms of therapy, such as radiotherapy or chemotherapy, should be considered before embarking on extensive skull base surgery. Younger, healthier patients, in general, tolerate new cranial deficits better than older patients. Patients with marginal cardiac output become high-risk candidates for myocardial infarction or congestive heart failure when subjected to prolonged surgery and recovery; those with copromised pulmonary function tolerate very poorly the problems created by lower cranial nerve deficiency, that is, aspiration and diminished cough.

The oculomotor nerve can potentially be injured in cavernous sinus surgery or orbital apex. Neuropraxia or axonotmesis usually leads to a good functional recovery in 2 to 8 months, respectively. Functional recovery with reanastomosis after transection has been reported (Sekhar, 1987b). Loss of trochlear nerve is reported to be associated with minimal functional disability. Good recovery with reanastomosis has been reported (Sekhar, 1987b). The abducens nerve has the longest intracranial course and is, therefore, most prone to injury, especailly with tumors of the clivus, petrous apex, and cavernous sinus. Good functional return should be expected from stretch injury, as this is a purely motor nerve (Sekhar, 1987b).

Prevention of facial nerve paresis has already been mentioned. If transection is required and the site optional, it is best to section the nerve at tertiary branches to limit synkinesis. In order of reconstructive preference for the facial nerve are direct reanastomosis, interpositional grafting, and CN XII-VII crossover. Ocular care, with prevention of exposure keratitis, especially if the V2 has been sacrificed, is paramount in the postoperative period if the facial nerve has been injured. A lateral tarsorrhaphy affords the best protection to the eye for a combination CN V and VII deficit.

The approaches by Fisch to the infratemporal fossa by definition preserves cochleovestibular function. Inadvertent stapes subluxation or tumor invasion of the otic capsule may lead to sensorineural hearing loss.

Exposure of the upper cervical internal carotid artery commonly causes loss of the glossopharyngeal nerve. Little sequelae develop from its loss, except when combined with other lower CN defects, X and XII.

Intraoperative reanastomosis of a vagal nerve is not indicated as this leads to paradoxical vocal cord motion. High vagal injuries can lead to a prolonged rehabilitative period. Not only is the quality of voice and protective sphincter function breached, but deglutition impaired through disruption of the pharyngeal plexus; when combined with losses of CN IX and XII, its loss may be quite debilitating. Persistent aspiration will lead to pneumonia. Tracheostomy is indicated if paresis of this combination of nerves is expected. One may consider vocal cord medialization with endoscopic Teflon or Gelfoam injection to protect the airway. Modified barium swallow may help the decision as to the need of a temporary feeding gastrostomy when aspiration persists.

Injury to the spinal accessory nerve is usually well tolerated in skull base procedures, as C2 and C3 ventral roots supply some motor innervation to the trapezius muscle. The suprascapular muscle also has a role in shoulder girdle stabilization. Nevertheless, reanastomosis or interpositional grafting should be performed, if possible. Physical therapy and exercise instruction are often very helpful in preventing persistent should dysfunction.

The hypoglossal nerve is often involved with tumors of the clivus or jugular foramen. Because the hypoglossal nerve is an important reanimation option in facial nerve injury, its preservation is of added importance. Unilateral hypoglossal nerve loss is usually well tolerated unless combined with CN IX and X paralysis. Reconstruction of a transected hypoglossal nerve can lead to good functional recovery (Sekhar, 1987b).

Cerebrovascular complications

The extent of manipulation of the internal carotid artery required by lateral skull base techniques understandably may lead to stroke. Preoperative angiographic evaluation and collateral circulation studies are mandatory. Anesthetic techniques such as increasing blood pressure, hypervolemia, pharmacologic vasodilatation, calcium channel inhibitors, hemodilution, hyperosmolarity, and anticoagulation (when the carotid is occluded) theoretically reduce risk (Little et al, 1990).

Cerebral edema or venous stroke is a concern, especially if there is no connection at the torcular Herophili or if the vein of Labbé is interrupted (Kaplan, 1984; Sasaki et al, 1977). Ligation of the sigmoid sinus is potentially more hazardous than extracranial jugular vein ligation. Collateral drainage through the superior and inferior petrosal sinuses may not be available in skull base procedures. Presumptively the vertebral venous system compensates for posterior fossa outflow and cerebral edema from venous occlusion is uncommon. At present, there are no good preoperative tests to predict this risk. Therefore, anastomotic veins, such as the superior petrosal sinus, inferior petrosal sinus, and mastoid emissary vein, should not be indiscriminately sacrificed.