Surgical Approaches for Resection of Acoustic Neuromas

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The internal auditory canal can be accessed through different surgical approaches based on different trajectories. This article describes the progressive widening of the posterior trajectory that begins with progressive drilling of the petrous bone (the retrosigmoid approach). A more lateral trajectory that attacks the tumor from a lateral (the translabyrinthine approach) and superior-inferior approach (the middle fossa approach) is then described. Imaging and relevant clinical information such as hearing status, facial nerve compromise, and tumor size are key considerations when selecting an approach to acoustic neuromas.

Key Words: acoustic neuromas, middle fossa approach, partial labyrinthectomy, retrosigmoid, transcochlear, translabyrinthine, transpetrosal

Acoustic neuromas are the most common tumors of the cerebellopontine angle. Most are benign lesions that grow from the transition point between the central and peripheral myelin. They cause a wide variety of symptoms such as hearing loss, tinnitus, and balance abnormalities. Large lesions compress the contents of the posterior fossa and may cause cranial nerve dysfunction, long tract compromise, and even hydrocephalus if they grow large enough to obstruct cerebrospinal fluid (CSF) pathways. The internal auditory canal (IAC) can be accessed from different angles, and decisions about the right approach are based on clinical and radiological information.

A "team approach" is standard for patients with cerebellopontine angle tumors, especially acoustic neuromas. The team is composed of otolaryngological surgeons specializing in temporal bone anatomy and neurotology and of neurosurgeons dedicated to microneurosurgery. A team approach offers patients the expertise of both disciplines. The neurotologist performs the surgical exposure, which frequently involves progressive drilling of the petrous bone, and the neurosurgeon removes the tumor. The microanatomy of these approaches, which is beyond the scope of this review, is illustrated elsewhere.[21,22] This article discusses the advantages and indications of each approach, relevant surgical anatomy, and surgical nuances.

Surgical Overview

The posterior petrosectomies involve progressive, stepwise drilling of the petrous bone: The presigmoid, trans-

Table 1. Surgical Approaches for the Treatment of Acoustic Neuromas

| Approach	Tumor size	Hearing preservation	Application	Risk of facial palsy	Risk of CSF leak
Retrosigmoid	All	Possible	Versatile workhorse All sizes	Based on size	Moderate
Translabyrinthine	All	No	All sizes	Least	Moderate
Transcochlear	All	No	Extensive prepontine tumors	High*	Moderate
Middle fossa	Small (mainly intracanalicular)	Possible	Limited posterior fossa access	Moderate	Low

*Temporary paralysis usually improves within one year. CSF = cerebrospinal fluid.

labyrinthine, and transcochlear approaches are discussed (Table 1). Transpetrosal approaches progressively flatten the temporal bone to maximize surgical exposure and to minimize retraction on the cerebellum. The surgical corridor between the cerebellum and the petrous bone is also progressively widened during transpetrosal approaches.

Anterior transpetrosal approaches aim for the petrous apex region while posterior approaches target the region posterior and lateral to the IAC. The middle fossa approach and Kawase's approach are examples of anterior petrosectomies.

Retrosigmoid Approach

The retrosigmoid approach, with which most neurosurgeons are familiar, is versatile for the treatment of different pathologies. It is the most common approach for exposing the IAC with a trajectory parallel to the petrous surface. It allows resection of tumors of different sizes with the possibility of preserving facial and cochlear function. Preservation of hearing depends on the size of the lesion. If the tumor is less than 2 cm, the chance of preserving hearing is as high as 53%. This figure increases to 83% if the lesion is 1 cm or less.[20] The narrow corridor created provides adequate exposure of the contents of the posterior fossa and IAC. When a tumor is limited to the IAC or when it extends laterally beyond the "accessible" region after the posterior lip of the IAC has been drilled, other approaches should be attempted.
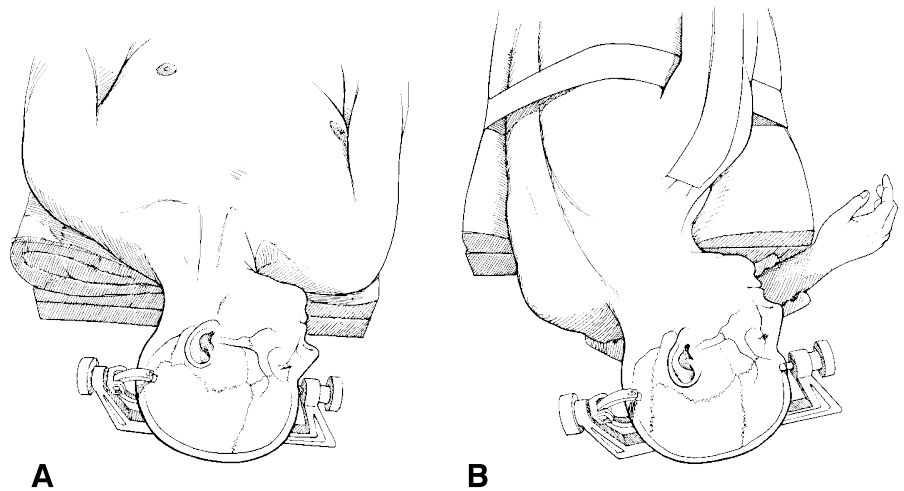
Figure 1. (A) The patient can be positioned supine with a long roll under the ipsilateral shoulder and the head rotated toward the contralateral side and fixed in a Mayfield head holder to obtain simultaneous flexion and rotation. If the patient's body habitus precludes this positioning, the (B) modified park-bench position can be considered. The patient is then in a lateral position with the head supported outside the surgical table by the Mayfield head holder. The dependent arm is supported on a swing attached to the Mayfield. An axillary roll under the dependent arm prevents brachial plexopathies; the ipsilateral shoulder can be taped to minimize its profile. *From Zubay G, Porter RW, Spetzler RF: Transpetrosal approaches. **Operative Techniques in Neurosurgery 4(1):24-29, 2001. With permission from Elsevier.***

Surgical Technique

The patient is placed (Fig. 1) supine or in the park bench or sitting position. The sitting position has almost been abandoned because it is associated with a significant risk of air embolism. The sitting position, however, does offer a clean field because blood and CSF drain from the surgical field. The head is slightly flexed and rotated toward the ipsilateral side. This position can be uncomfortable for the surgeon, leading to early interruption of the procedure.

In the supine position, the patient's head is rotated toward the contralateral side and is supported on a Mayfield three-point fixation device. A sand bag or a foam roll can be placed under the ipsilateral shoulder to minimize rotation of the neck. This same position is used for all posterior transpetrosal approaches. If the patient's body habitus precludes contralateral head rotation due to neck compression or an elevated ipsilateral shoulder, a modified park bench position can be used. After anesthesia is induced, we routinely place a lumbar drain to help minimize retraction on the

cerebellum and to avert a CSF leak after surgery. Frameless stereotactic image guidance and monitoring of the facial nerve and somatosensory evoked potentials are standard adjuncts.

The incision is usually located two fingerbreadths behind the pinna. During this phase, image guidance helps place the incision as close as possible to the junction of the sigmoid and transverse sinuses. The aponeurotic fascia is dissected and the opening is made. During closure this extra layer helps to achieve a more hermetic closure. We start the craniectomy by using a round bur to drill over the junction of the transverse and sigmoid sinuses until the blue venous hue (blue lining) becomes evident. The posterior aspect of the sigmoid sinus is exposed using various cutting and diamond burs. The craniectomy is then completed with rongeurs. Skeletonization of the transverse-sigmoid sinus junction permits the dura to be opened as close to the sinus as possible.

Venous bleeding, which is common during drilling, should be covered with hemostatic agents such as Nu-Knit (Johnson & Johnson, Arlington, TX) or Gelfoam (Pharmacia & Upjohn Company Kalamazoo, MI). To avoid sinus thrombosis, no hemostatic agent should be introduced within the lumen. Exposure of mastoid cells is unavoidable; they should be waxed to prevent CSF leakage.

If image guidance is unavailable, the sinuses are located using traditional landmarks. The transverse sinus is located beneath the imaginary line between the external occipital protuberance and the origin of the zygomatic arch. The sigmoid sinus is identified by drawing a line two fingerbreadths behind the ear aimed toward the mastoid tip. Alternatively, once the mastoid has been exposed, an imaginary line can be drawn from the parietomastoid suture to the mastoid tip. The dura is opened in a semicircular fashion (Fig. 2) with its base facing the sigmoid sinus. Before the dura is opened, the lumbar drain is opened to drain 20 to 30 cc of CSF, which relaxes the cerebellum. Retractors are seldom neces-
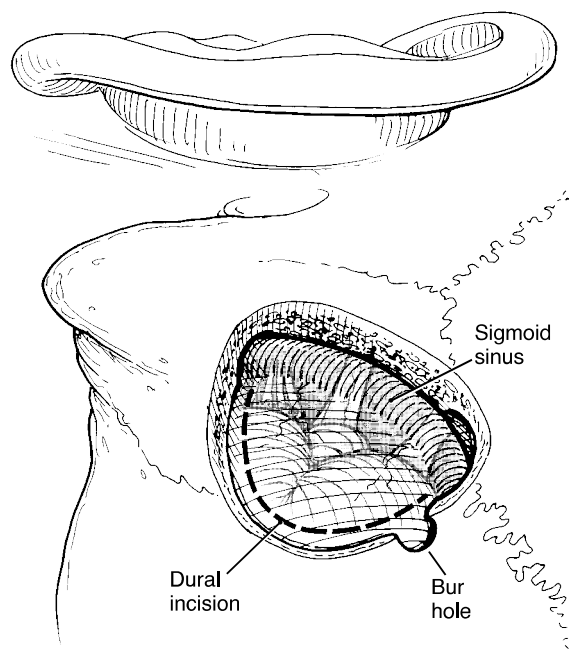
Figure 2. Illustration shows the semicircular opening of the dura with a wide base toward the sigmoid sinus. Note the underlying anatomic structures.

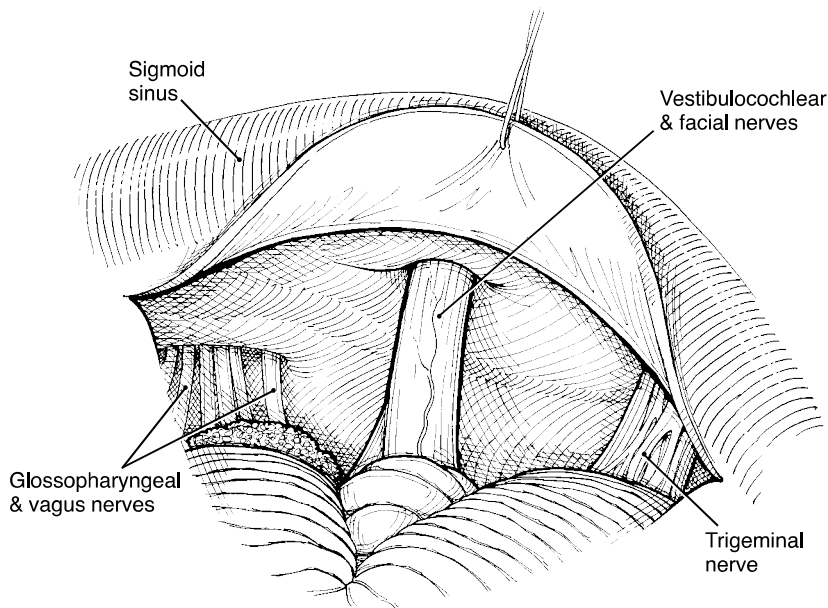sary (Fig. 3). The cerebellar surface is covered with Telfa paddies.

Early in the dissection when it is easier to distinguish tumor from surrounding tissues, arachnoid adhesions are released and the cerebellum and lower cranial nerves are separated from the tumor. The internal auditory canal should be drilled before the arachnoid over the facial and vestibulocochlear nerve complex is opened. This maneuver protects the nerves from bone dust generated during drilling. The cerebellum can be protected with an aluminum suture pack. The canal should be drilled approximately 8 mm. More aggressive drilling will violate the common crus and can result in hearing loss.

Once the cranial nerves have been identified, the tumor is morcellized from its core. Ultrasonic aspiration is especially helpful when resecting the core of the tumor. Small fragments are removed. As the anterior aspect is approached, the facial nerve is monitored. If there is evidence of facial nerve irritation, the area of dissection is changed. Once the facial nerve is identified, it is dissected from the tumor with a round knife. The facial nerve is usually displaced anteriorly against the anterior rim

of the IAC, and this spot is most susceptible to injury during dissection. However, the facial nerve also can be superior or posterior to the tumor.

Once the extracanalicular portion of the tumor is removed, the posterior rim of the IAC should be opened (Fig. 4). The dura is cut in an arciform fashion with the base of the arc facing the cranial nerves. The posterior lip is drilled with a diamond bit drill with copious irrigation to prevent thermal injury. At this stage continuous monitoring of the facial nerve is essential. As the anterior portion of the tumor is approached, the dissection is performed with a round knife. The use of bipolar coagulation is avoided. The facial nerve usually takes a superior course from the brain stem and is located anterior to the vestibulocochlear nerve and anterior and inferior to the flocculus.

All exposed air cells are covered with bone wax to prevent CSF leakage. Once the tumor is removed and hemostasis is obtained, the dura is closed in a watertight fashion. The suture line is reinforced with fibrin glue. We routinely use a lumbar drain to help prevent CSF leakage. During closure the mastoidectomy should be filled with fat

Sigmoid sinus

Vestibulocochlear & facial nerves

Glossopharyngeal & vagus nerves

Trigeminal nerve

Transverse crest

Cochlear nerve

Superior vestibular nerve

Inferior vestibular nerve

Facial nerve

Figure 3. Note the advantage of opening the dura as close as possible to the sigmoid sinus. Illustration shows the intradural anatomy once the cerebellopontine cistern has been opened. After the cistern is opened, CSF drainage and early opening of the lumbar drain minimize the need to retract the cerebellum. Retractors are seldom necessary. Early identification of the cranial nerves is critical to preserve them.

Figure 4. A close-up of the cranial nerves as they enter the internal auditory canal (IAC). The posterior rim of the IAC has been drilled about 8 mm deep into the canal to avoid inadvertent penetration of the semicircular canals, which could cause hearing loss. All exposed mastoid cells should be waxed to avert CSF leaks.

strips harvested from the abdomen. The bony defect is filled with acrylic or polymethyl methacrylate (PMMA) to reduce the risk of postoperative headache.[9]
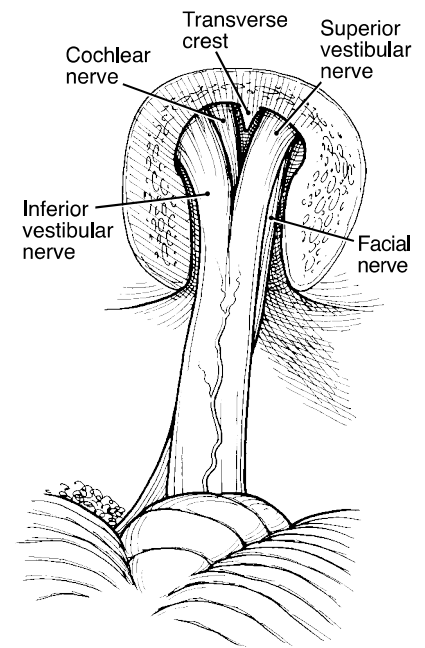
Transpetrosal Approaches (Posterior Petrosectomy)

Drilling the temporal bone in a stepwise fashion is known as a posterior petrosectomy. The anatomy of the temporal bone is constant. Therefore the contents of the posterior fossa are exposed predictably as drilling proceeds. The risk of complications (e.g., facial paralysis, deafness, CSF leakage) increases as the amount of petrous bone removed increases.

Mastoidectomy is the basis for the transpetrosal approaches, which involve progressively more removal of bone as described in the following sections. This sequential drilling implies that one step must be completed before proceeding with the next. Closure follows the same principles: watertight dural closure, the use of fibrin glue and fat

graft implants harvested from the abdomen, coverage of bone defects with synthetic materials, and multilayer soft tissue reapproximation. The routine use of lumbar drains is recommended.

Presigmoid Approach

The surgical position and incision are the same as described for the retrosigmoid approach. Trautmann's triangle (Fig. 5) is a triangular-shaped area of dura with an inferior vertex (jugular bulb), limited by the sigmoid sinus (posteriorly) and the otic capsule (anteriorly). The middle fossa dura and superior petrosal sinus form its superior base. This area is small and provides a narrow corridor that makes it difficult to manipulate instruments. The exposure can be enlarged by combining it with a traditional retrosigmoid exposure (see above). The sigmoid sinus is located in the middle of the exposure and provides limited access on each side of the exposure. The sigmoid sinus can be resected in selected cases. The narrow corridor (Fig. 6) and potential to injure the endolymphatic sac that runs medial to the sigmoid sinus

and inferior to the posterior semicircular canal are disadvantages of this approach. Opening the endolymphatic sac can cause hearing loss related to leakage of the endolymphatic fluid.[1] This approach was originally developed for vestibular neuroectomies and is not particularly useful for acoustic neuromas.[25]

Translabyrinthine Approach

The translabyrinthine approach is ideal for tumors confined to the IAC (although there is no size limitation for a tumor removed via the translabyrinthine approach) and when hearing is severely compromised or is not an issue because the tumor is large (Gardner-Robertson grade III or IV).[4] This approach tends to be used for tumors larger than 2 cm when hearing preservation is unlikely. To gain access to the lateral recess of the IAC, hearing must be sacrificed.

A C-shaped skin incision starts 1 cm superior to the auricle at the anterior-
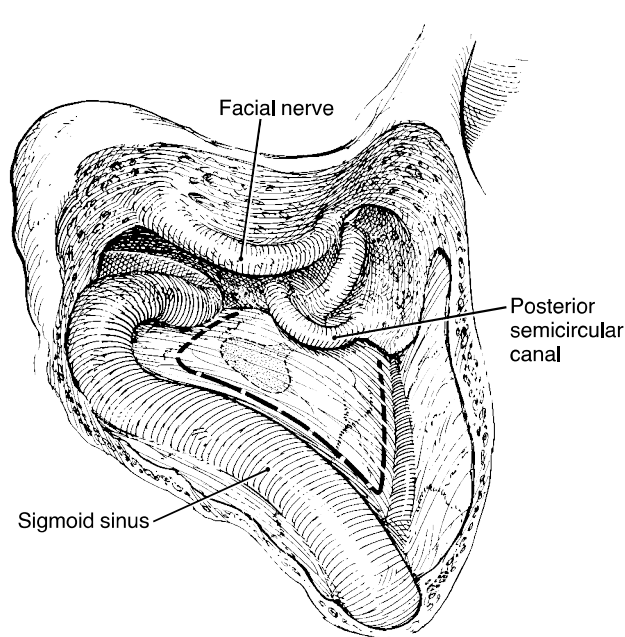
Figure 5. Illustration of early stage of the retrolabyrinthine presig-moid approach. Trautmann's triangle corresponds to the area of dura limited by the jugular bulb inferiorly, the middle fossa dura su-periorly, the superior petrosal sinus and sigmoid sinus posteriorly, and the otic capsule anteriorly. The endolymphatic sac can be seen along the inferior portion of Trautmann's triangle. The dural open-ing parallels the sigmoid sinus and floor of the middle fossa. Mod-ified *from Zubay G, Porter RW, Spetzler RF: Transpetrosal approaches. **Operative Techniques in Neurosurgery 4(1):24-29, 2001. With** permission from Elsevier.*
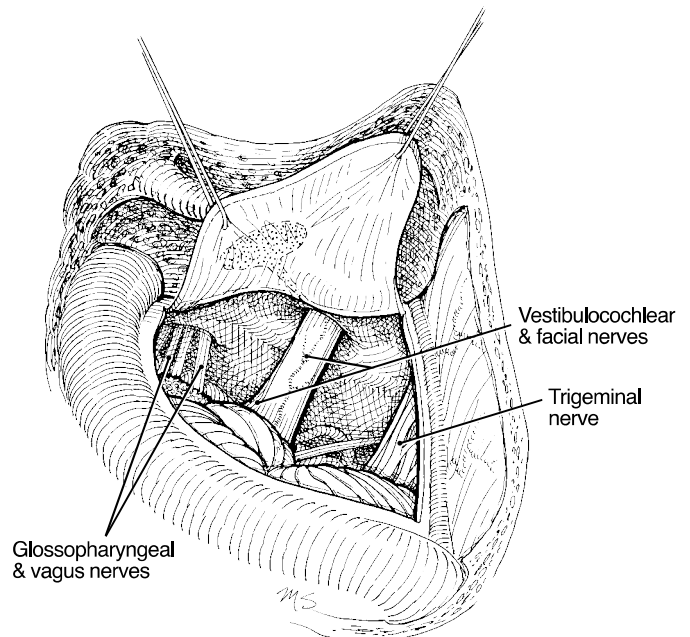

Figure 6. Illustration shows the retrolabyrinthine presigmoid ex-posure after the dura has been opened. Access between the otic capsule and sigmoid sinus is limited.

most aspect of the ear behind the sig-moid and extends to the mastoid tip. Drilling follows that used for the ret-rolabyrinthine presigmoid approach. Once the mastoidectomy is completed (Fig. 7) to the point that the antrum is exposed, the incus is identified. Its tip points in the direction of the facial nerve. The drilling is performed ante-rior to the facial nerve (facial recess), and the ossicles are fully exposed. The en-tire vertical portion of the facial nerve is drilled. The anterior bone of the facial recess is drilled to expose the incus and malleus. The incus is removed and the tendon for the tensor tympani is cut. The eustachian tube is identified, and it and the middle ear are packed with tem-poralis muscle to minimize the risk of CSF leakage.

The vestibule (the junction between the lateral and posterior semicircular canals) that constitutes the lateral wall of the IAC is opened. The IAC is exposed superiorly, posteriorly, and inferiorly.
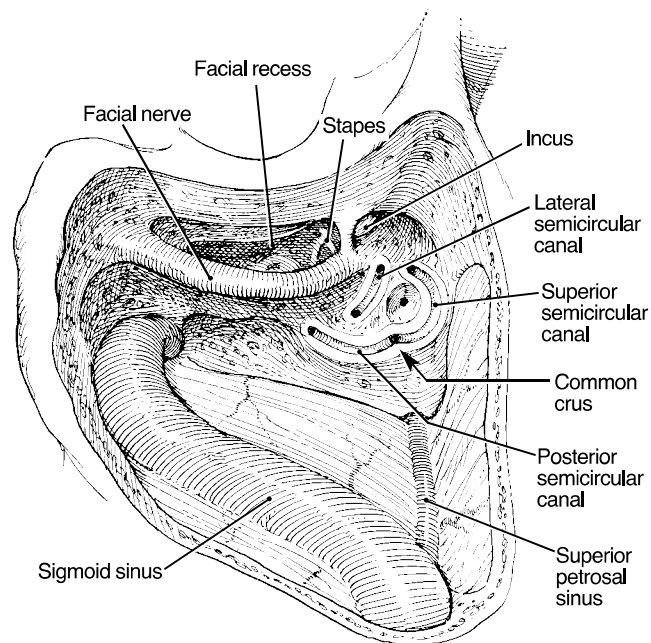
Figure 7. Illustration shows progressive drilling of the temporal bone identifying the three semicircular canals. The point where the posterior semicircular canal joins the superior semicircular canal is called the common crus. The incus points toward the vertical or mas-toid portion of the facial nerve. Anterior to the facial nerve, the middle ear is entered through the facial recess. *From Zubay G, Porter RW, Spetzler RF: Transpetrosal ap-proaches. **Operative Techniques in Neurosurgery 4(1):24-29, 2001. With permission** from Elsevier.*
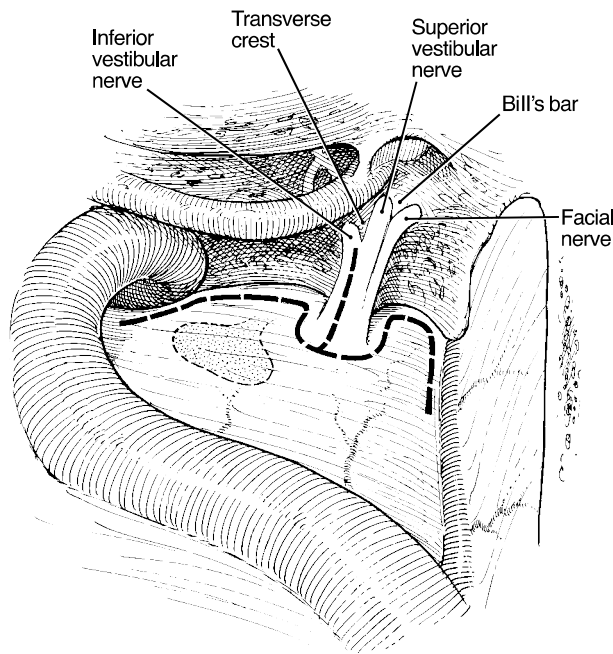
Figure 8. Illustration after the vestibule is opened. Progressive drilling exposes the contents of the internal auditory canal (IAC). Drilling superiorly, posteriorly, and inferiorly into the IAC exposes three-fourths of the entire canal. Two bony structures inside the IAC can help identify the cranial nerves within it. The transverse crest separates the superior vestibular and facial nerves from the inferior vestibular and cochlear nerves. Bill's bar separates the superior vestibular nerve from the facial nerve. The dural opening is outlined. *From Zubay G, Porter RW, Spetzler RF: Transpetrosal approaches.* **Operative Techniques in Neurosurgery 4(1):24-29, 2001. With permission from Elsevier.**
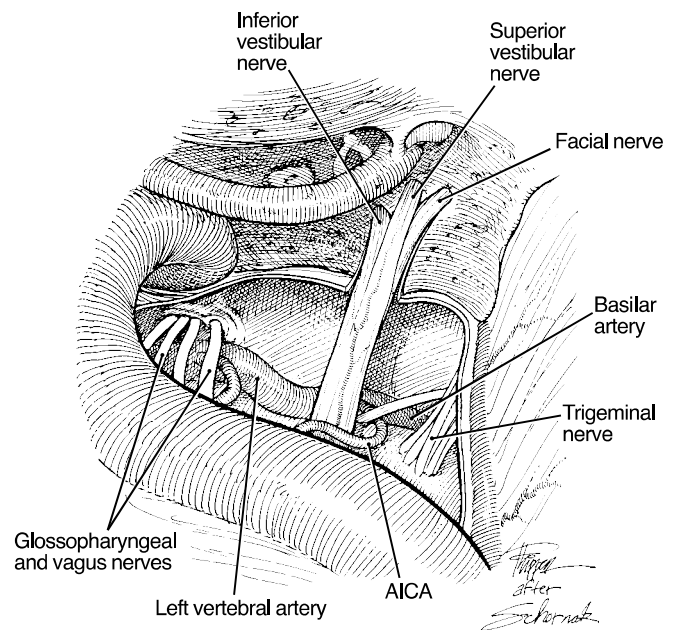
Figure 9. The dura is opened and the contents of the posterior fossa are exposed. AICA, anterior inferior cerebellar artery. *From Zubay G, Porter RW, Spetzler RF: Transpetrosal approaches.* **Operative Techniques in Neurosurgery 4(1):**24-29, 2001. With permission from Elsevier.

The translabyrinthine approach exposes 270 degrees of the IAC. Inside the IAC (Fig. 8), the vertical crest ("Bill's bar"), which shows the position of the facial nerve at the fundus of the canal, must be identified. The facial nerve is anterior and the superior vestibular nerve is posterior to the vertical crest. A great advantage of the translabyrinthine approach is that the labyrinthine segment of the facial nerve can be identified. Exposing the entry of the facial nerve into the IAC enables the transition between normal facial nerve involved with tumor to be identified. To preserve the integrity of the facial and superior vestibular nerves, their early identification is important. Skeletonizing the facial nerve jeopardizes its function and makes it more susceptible to iatrogenic injury.

Once the dura is open, the entire subarachnoid, intracanicular, and vertical portions of the facial nerve are evident (Fig. 9). The facial nerve and the superior and inferior limits of the tumor are identified, and the tumor is debulked from it core (Fig. 10A). Once a significant portion of the tumor has been removed, the superior and inferior vestibular nerves are cut and the tumor is peeled away from the facial nerve (Fig. 10B). The tumor is separated from the cerebellum using the intervening arachnoid plane (Fig. 10C). Finally, the facial nerve is decompressed completely (Fig. 10D). During this stage, stimulation of the facial nerve is critical to preserve its function.

Once the tumor is removed, the closure proceeds as described. The bony defect is filled with fat strips harvested from the abdomen, and the bone defect is covered with PMMA or acrylic.

Partial labyrinthectomy (superior and posterior) may preserve hearing.[23] In a promising study, hearing was preserved in 100% of patients who underwent a "transcrusal" approach, in which only the superior and posterior semicircular canals, starting at the common crus, were removed. During resection of petroclival tumors, this partial labyrinthectomy adds millimeters to the exposure without sacrificing hearing. This approach plays a small role in the resection of acoustic neuromas.

Transcochlear Approach

This approach constitutes the most direct approach to the midclival region, prepontine cistern, and brainstem and follows the traditional principles of skull base surgery: maximizing bony resection and minimizing retraction on the adjacent brain. The approach provides the maximum amount of exposure from drilling the petrous bone by extending the amount of bone removed in the presigmoid and translabyrinthine
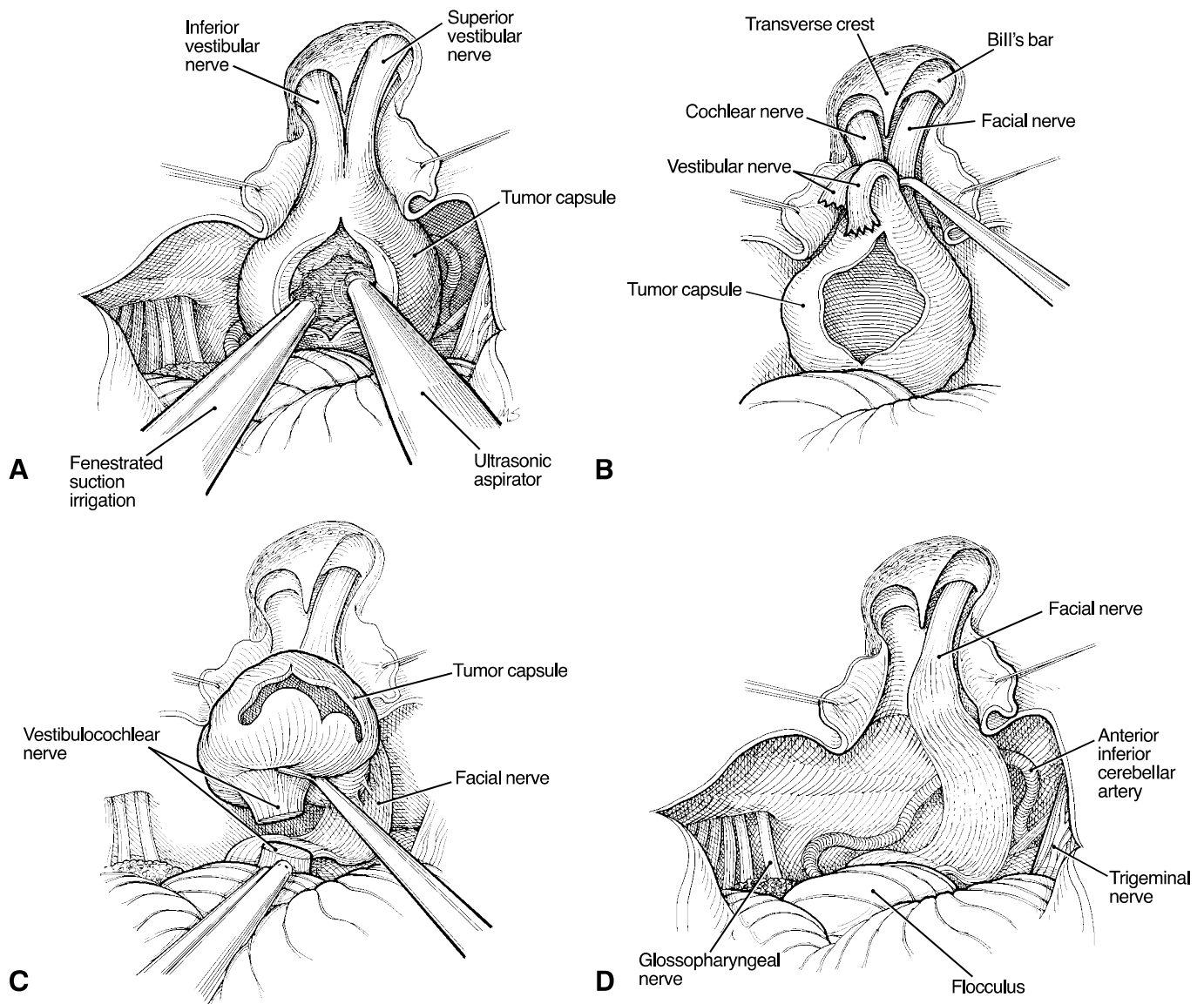
Figure 10. The steps for resecting an acoustic neuroma. Early identification of the cranial nerves is critical. The transverse crest and Bill's bar are useful landmarks during this stage. The superior and inferior extension of the tumor and the intervening arachnoid plane are identified. Bipolar coagulation is avoided to prevent potential injury to the cranial nerves. Neurophysiologic stimulation of the facial nerve should be repeated throughout this process. (*A*) The tumor is debulked with suction and ultrasonic aspiration. (*B*) The superior and inferior vestibular nerves are sectioned to expose the facial nerve. The tumor is dissected away from the facial nerve and (*C*) cerebellum. (*D*) Intraoperative view once the facial nerve has been fully decompressed and the tumor has been removed.

approaches. It offers a wide corridor to the midaspect of the clivus and anterior brainstem. This approach is not very useful for the resection of acoustic neuromas and is associated with intrinsic associated morbidity, such as facial paralysis and potential CSF leakage.

There are two variations of the transcochlear approach. The original, as described by House and Hitselberger,[12] implies facial nerve transposition. It involves complete skeletonization of the

facial nerve to mobilize the nerve posteriorly and to obtain a flat exposure. The greater superficial petrosal nerve (GSPN) is cut where it emerges from the geniculate ganglion so that the facial nerve can be released and mobilized. Once the facial nerve is mobilized posteriorly, the cochlea is entered. In the transotic approach described by Fisch,[7] the facial nerve is not mobilized, but the external auditory canal is occluded and resected. Drilling continues through

the petrous apex up the inferior petrosal sinus. The petrous portion of the internal carotid artery (ICA) constitutes the lateral aspect of the exposure.[6]

Middle Fossa Approach

The middle fossa approach is versatile and associated with many potential uses. Anterior extension of this approach, known as the transKawase or extended middle fossa route, can be

helpful in the removal of petroclival meningiomas or lesions in the petrous apex (e.g., cholesterol granulomas).

In 1904 Parry[19] first described the middle fossa approach for section of the vestibular nerve. In 1961 House,[10] a neurotologist working with Dr. Theodore Kurze, a neurosurgeon, described the approach for decompression of the IAC for the treatment of otosclerosis. The technique was abandoned, but its utility for removing acoustic neuromas was evident.[13] Dr. House also described the middle fossa approach for the removal of small acoustic neuromas.

Compared to other approaches to the IAC, the middle fossa approach adequately exposes the IAC and its contents, including the facial and superior vestibular nerves, from a superior trajectory (Fig. 11). It permits exposure of the subarachnoid, intracanalicular, labyrinthine, and horizontal or tympanic segment of the facial nerve. It is useful for small lesions (up to 2 cm in diameter) mainly within the IAC, especially when preservation of hearing is desired.

Surgical Technique

The long axis of the head is positioned parallel to the floor, with the ear facing the ceiling and the neck slightly extended. A vertical incision is made anterior to the tragus and perpendicular to the zygomatic arch (Fig. 12). The blood supply of the temporalis muscle is preserved. Fascia and temporal muscle are exposed and opened with the Bovie electrocauterization device and then retracted with a self-retractor or fishhooks. The bone below the squamous suture, which is a good landmark for identifying the superior limit of the craniotomy, is exposed.

The craniotomy is square. A third of it is positioned posterior to and two-thirds of it is positioned anterior to the external auditory canal. This configuration adequately exposes the floor of the middle fossa, which must be flush to visualize and minimize retraction on the temporal lobe.

The dura is elevated in a posterior-to-anterior direction to prevent injury to the GSPN (Fig. 13). The geniculate
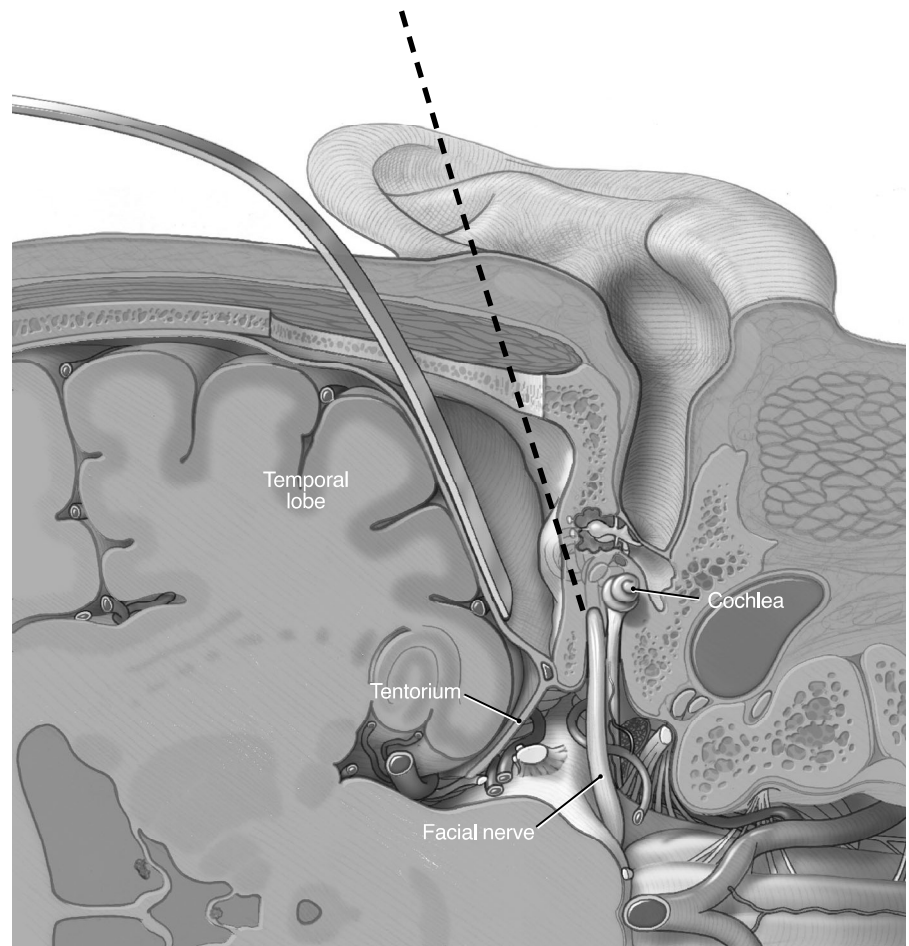
Figure 11. Illustration shows the trajectory and angle of attack through the middle fossa for exposing the internal auditory canal.
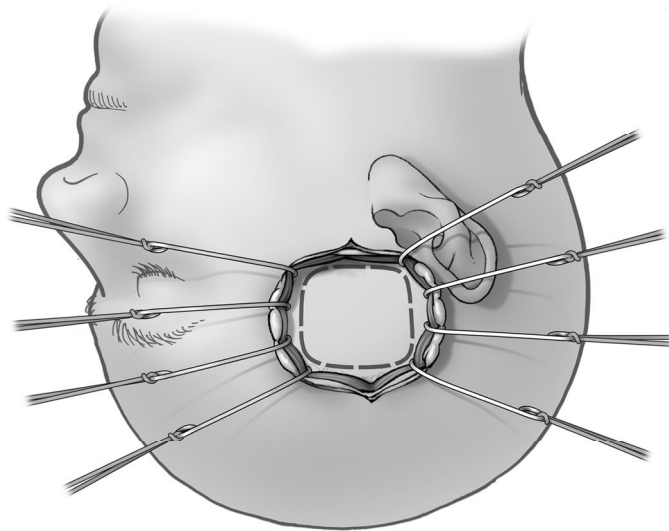
Figure 12. The head is placed in a lateral position. A vertical incision is made anterior to the tragus, and the skin and subcutaneous soft tissues are retracted with fishhooks. A square craniotomy is planned a third posterior to and two-thirds anterior to the external auditory canal.

ganglion is often dehiscent, and a posterior-to-anterior dissection minimizes facial nerve injury during elevation of the dura. The GSPN and lesser petrosal nerve are just beneath the dura and become visible once it is exposed.[2,24] Both nerves are delicate, and the operating microscope should be used to identify them. When the dura is retracted medially, the middle meningeal artery, with its anterior and posterior branches, can be seen emerging from the foramen spinosum. The middle meningeal artery is sectioned immediately after it exits the foramen spinosum, which is then exposed along with the mandibular nerve.

In the posterior part of the exposure near the petrous ridge, the arcuate eminence becomes visible. The angle between the arcuate eminence and the GSPN is about 120 degrees. After the GSPN, arcuate eminence, and petrous ridge are identified, the IAC can be localized by any of the following three techniques.

Garcia-Ibanez Technique. This technique (Fig. 14A) relies on the important relationship between the GSPN and the arcuate eminence, which are separated by 120 degrees. Bisecting this angle provides the site at which to start drilling the temporal bone to expose the IAC.[8]

Fisch Technique. A line is drawn over the long axis of the arcuate eminence (Fig. 14B). Another line is drawn 60 degrees to the first line away from the arcuate eminence. The second line provides the location of the IAC, which typically is 3 to 4 mm below the petrous ridge.[5] However, it may be as much as 7 mm below the floor of the middle fossa.[15]

House Technique. House proposed that once the GSPN was identified, the floor of the middle fossa could be drilled (2 to 3 mm) to identify the geniculate ganglion and to follow the labyrinthine portion of the facial nerve medially until the IAC was reached (Fig. 14C).[8,10] The junction between the geniculate ganglion and the facial nerve is not on the
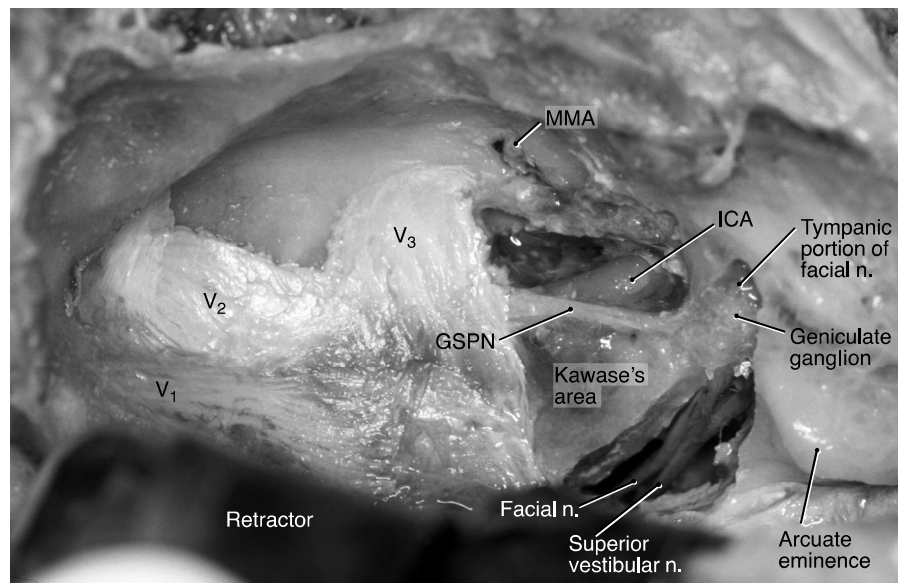
Figure 13. Photograph of the anatomic dissection from the right middle fossa showing the three branches of the trigeminal nerve (V_1, V_2, and V_3), the position of the middle meningeal artery (MMA) in relation to the mandibular nerve, the 60-degree angle between the facial nerve within the internal auditory canal and the greater superficial petrosal nerve (GSPN) anteriorly, and the same angle with the arcuate eminence posteriorly and laterally. Kawase's area is delimited by the mandibular branch of the trigeminal nerve anteriorly, the GSPN laterally, the internal auditory canal posteriorly, and the insertion of the tentorium medially. This area is devoid of important anatomic structures and can be drilled with impunity. ICA = internal carotid artery.

same plane as the IAC; rather, it is slightly posterior. Therefore, most of the geniculate ganglion must be uncovered to expose the facial nerve medially. The exposure extends to the posterior limit, which is the superior semicircular canal. The anterior limit along the petrous ridge is the facial nerve. More laterally, the cochlea is the limiting factor for exposure.

After the roof of the IAC has been drilled (3 to 4 mm below the floor of the middle fossa), the vertical bar (Bill's bar) of bone is easily identified. This bar separates the facial nerve from the superior vestibular nerve. Inside the IAC is the meatal portion of the anterior inferior cerebellar artery (AICA), which forms an important loop, enters the IAC, and then passes through the nerves. The anatomy of the AICA in this region is quite variable as is the percentage of its loop located inside the IAC.[18]

Early identification and preservation of these arterial branches inside the IAC are fundamental to the preservation of hearing during the resection of acous-

tic neuromas.

Extended Middle Fossa Approach to the IAC and Clivus

House[11] first described an area of the temporal bone that can be removed with impunity. Kanzaki et al.[14] later modified the approach. For the treatment of low-neck basilar tip aneurysms (between the sellar floor and IAC on a lateral projection), they described an approach that later proved useful for resecting meningiomas of the petroclival region.[3,16,17] In 1986 Day et al.[5] developed a geometric construct by compartmentalizing structures in and adjacent to the cavernous sinus. They named the area described by Kawase as the posteromedial triangle and its limits were as follows: the porus trigeminus, cochlea, and posterior border of the mandibular branch (Fig. 13).[8] The triangle is devoid of any vascular or nerve branches. Posteriorly, it is limited by the margin of the mandibular nerve, the petrous ridge, the GSPN lat-
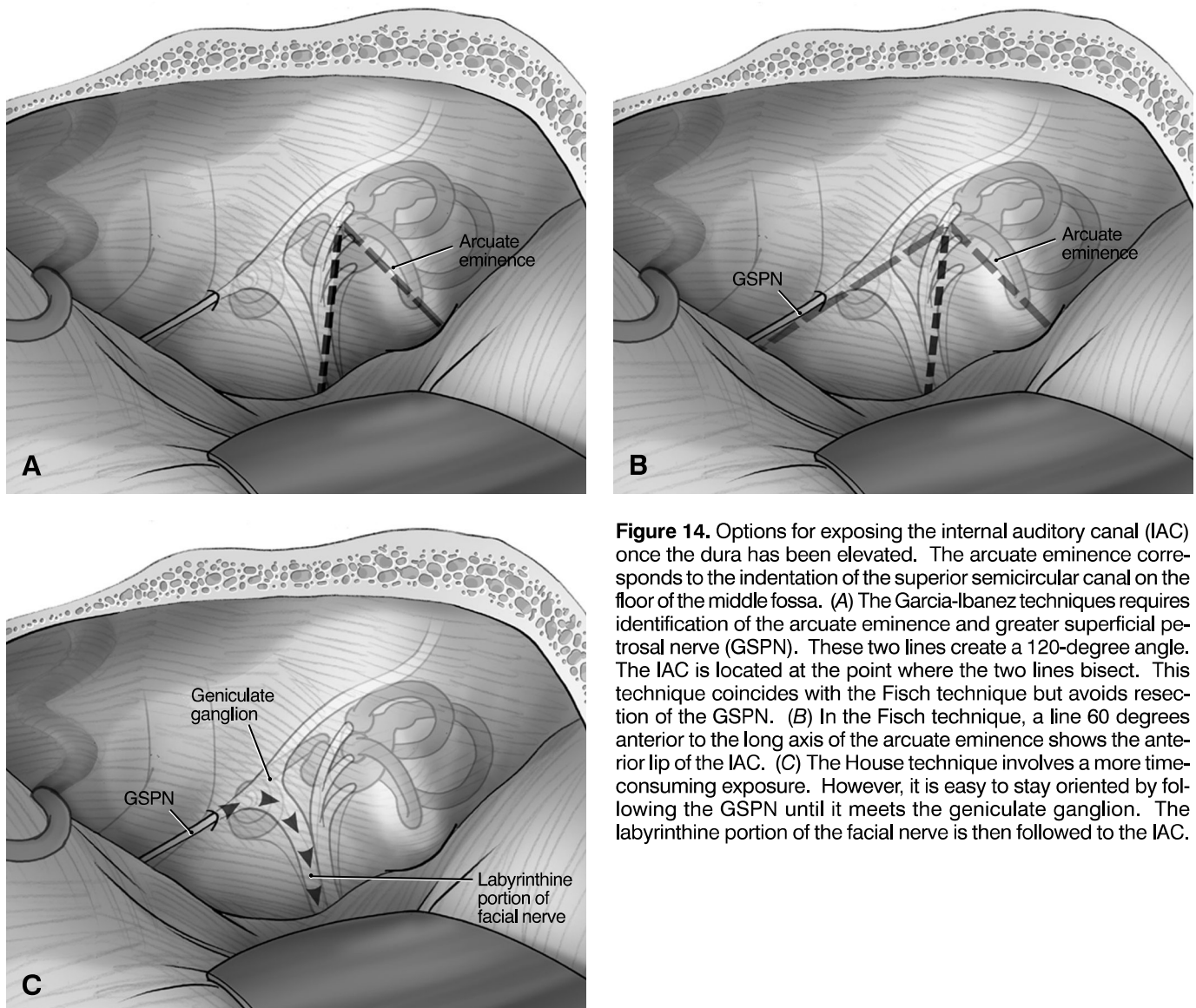
Figure 14. Options for exposing the internal auditory canal (IAC) once the dura has been elevated. The arcuate eminence corresponds to the indentation of the superior semicircular canal on the floor of the middle fossa. (*A*) The Garcia-Ibanez techniques requires identification of the arcuate eminence and greater superficial petrosal nerve (GSPN). These two lines create a 120-degree angle. The IAC is located at the point where the two lines bisect. This technique coincides with the Fisch technique but avoids resection of the GSPN. (*B*) In the Fisch technique, a line 60 degrees anterior to the long axis of the arcuate eminence shows the anterior lip of the IAC. (*C*) The House technique involves a more time-consuming exposure. However, it is easy to stay oriented by following the GSPN until it meets the geniculate ganglion. The labyrinthine portion of the facial nerve is then followed to the IAC.

erally, and the nerves inside the IAC. The principle of this approach is the same as for the middle fossa approach. Hence, early identification of the IAC is important.

Surgical Technique

The head is positioned as described for the traditional middle fossa approach. The incision is in the shape of a question mark big enough to include the squamous portion of the temporal bone and part of the sphenotemporal bone. Below the skin incision, the fascia is incised in a semicircular fashion. The craniotomy must include the sphenotemporal junction. Its position varies, depending on if it needs to be extend-

ed anteriorly enough to include the posterior part of cavernous sinus.

The petrous apex is exposed extradurally until the petrous ridge is identified. The dura is again elevated in a posterior-to-anterior direction, and the foramen spinosum is identified. The middle meningeal artery is coagulated so that the dura can be elevated and the mandibular nerve can be visualized. The petrosal nerves are located medially, just under the dura.

To expose the IAC, the superior petrosal sinus and petrous ridge must be identified. An incision is made above and below the ridge so that the sinus can be ligated just posterior to the porus

trigeminus. The sinus must be ligated before the entry point of the superior petrosal vein so that it will drain normally into the transverse sinus. Utmost care must be exercised to protect the trochlear nerve, which courses just below the tentorium and easily can be damaged. After the mandibular nerve, GSPN, and vestibulocochlear complex have been identified in the IAC and the superior petrosal sinus has been ligated, this piece of bone, which is devoid of important structures, can be drilled until the dura of the posterior fossa becomes visible.

In this exposure the basilar artery, the emergence of the AICA, and the abdu-

cens nerve are visible medially. The nerves inside the IAC are visible posteriorly. The brain stem is exposed from the medullopontine sulcus, and the anterolateral portion of the pons between the trigeminal and facial nerves is also visible.

Conclusions

The IAC can be approached from different directions, and the choice of approach is based on clinical and imaging factors. A team approach offers patients the expertise from two surgical specialties: neurosurgery and neurotology. Expertise in microneurosurgery and in-depth knowledge of the temporal bone anatomy are key for treating patients with acoustic neuromas.

The suboccipital-retrosigmoid approach is the workhorse procedure. It is useful for tumors of all sizes. Preservation of hearing is based on preoperative hearing and tumor size. For pure intracanalicular tumors, the translabyrinthine or middle fossa are reasonable options. Progressive drilling of the petrous bone is the basis for the transpetrosal approaches, which were developed to maximize bone resection to avoid retraction over the cerebellum. The progressive drilling, however, is associated with intrinsic complications (e.g., hearing loss, facial paralysis, CSF leakage). If preservation of hearing is a goal, the middle fossa or retrosigmoid approach would be preferable. If hearing is severely compromised, the translabyrinthine approach is indicated. Transcochlear and transKawase approaches are indicated for large tumors primarily anterior to the pons, clival lesions, and, rarely, acoustic schwannomas. Partial labyrinthectomy is promising, but larger series are needed to determine its efficacy for hearing preservation. The middle fossa approach is an option for removing small acoustic neuromas (inside the IAC).

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