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Selection of Surgical Approach to Acoustic Neuroma

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Centers with special expertise in the management of acoustic neuromas fall into three broad categories in terms of their preference for operative approaches: (1) suboccipital preferred, (2) translabyrinthine preferred, and (3) eclectic. The number of teams in the last group has steadily grown in recent years as cooperating neurotologists and neurosurgeons have become aware of the relative advantages and disadvantages of the various techniques [1–4]. At the University of California, San Francisco (UCSF), we use a mixture of the suboccipital, translabyrinthine, and middle fossa approaches according to the characteristics of the particular tumor undergoing treatment. In this article, we review the anatomic and clinical factors affecting the choice of operative approach, examine the differences in postoperative outcome among the surgical techniques, and present a protocol for the selection of approach based on tumor size and clinical manifestations.

Factors affecting the choice of surgical technique

Tumor size

For almost all acoustic neuromas removed at UCSF, we select either the translabyrinthine or suboccipital approach (Fig. 1). Tumor size, in and of itself, is not a criterion in choosing between the translabyrinthine and suboccipital techniques when removing an acoustic neuroma. Either approach provides a sufficient exposure of the cerebellopontine angle and brain stem to permit atraumatic and complete tumor removal of even very large acoustic neuromas. A few authors, who limit their practice to the suboccipital approach, have maintained that the translabyrinthine approach affords insufficient exposure for larger tumors. This point of view was well articulated by DiTullio, Malkasian, and Rand, who maintained that "because of the limited operative field, this approach precludes adequate visualization not only of the medial aspect of the tumor but also its anatomical relationship to the vital brain stem and vascular structures" [5]. In contrast to the opinion expressed by these authors, we have found that the exposure of the brain stem surface facing an acoustic neuroma provided by the two approaches is essentially identical. Much of the criticism of the exposure provided by the translabyrinthine approach has undoubtedly arisen when neurosurgeons collaborated with inexperienced temporal bone surgeons who provided an insufficient transtemporal exposure of the posterior fossa. It should be emphasized that adequate exposure of the cerebellopontine angle for large tumors by the translabyrinthine approach requires that the surgeon perform a wide retrosigmoid decompression of the posterior fossa dura, remove bone from the jugular bulb and horizontal course of the sigmoid sinus, and excavate well anterior to the porus acusticus. We also disagree that there are neurotologic and neurosurgical approaches to acoustic neuroma. Both the translabyrinthine and suboccipital approaches are posterior fossa craniotomies that differ primarily in the way the head is opened. The essential issue at hand, the removal of the intracranial tumor, properly resides within the armamentarium of both specialties, depending on the surgeon's training, experience, and microsurgical skills.

On first reflection, it may seem that the angle of view of the internal auditory canal,

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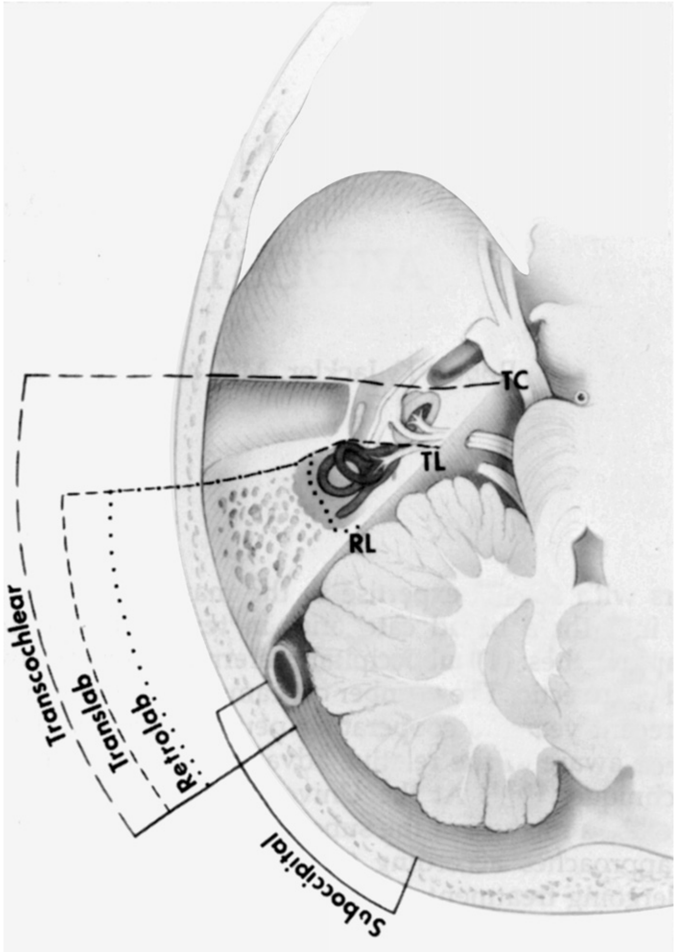

Fig. 1. Schematic view of suboccipital, translabyrinthine, retrolabyrinthine, and transcochlear approaches to the cerebellopontine angle as visualized in the axial plane.

cerebellopontine angle, and brain stem provided by the translabyrinthine and suboccipital approaches are quite different. After all, the areas of skull removed are quite separate, having only 1 to 2 cm of overlap behind the sigmoid sinus. Nevertheless, the exposure afforded by the two techniques is remarkably similar. The explanation for this lies in the fact that the angle of view employed is actually almost identical. In the translabyrinthine approach, the surgeon retrodisplaces the sigmoid sinus and looks along this posterior aspect of the craniotomy opening (Figs. 2 and 3). In the suboccipital approach, the surgeon removes bone up to the sigmoid sinus and then views along the most anterior edge of the craniotomy (Figs. 4, 5, and 6). In the average exposure, the angle of view of a translabyrinthine craniotomy is slightly more lateral and that of the Suboccipital more posterior, but this difference is usually less than a 10 degree angle.

Although the translabyrinthine approach provides excellent visualization of the internal auditory canal and cerebellopontine angle, it does not create as panoramic a view of the posterior fossa as the suboccipital approach. The translabyrinthine exposure, especially when the jugular bulb is high, is limited inferiorly. This may restrict access to the inferior-most portion of the cerebellopontine angle, the neural compartment of the jugular foramen, and to the foramen magnum region. This limitation is seldom problematic during surgery on acoustic neuromas because these

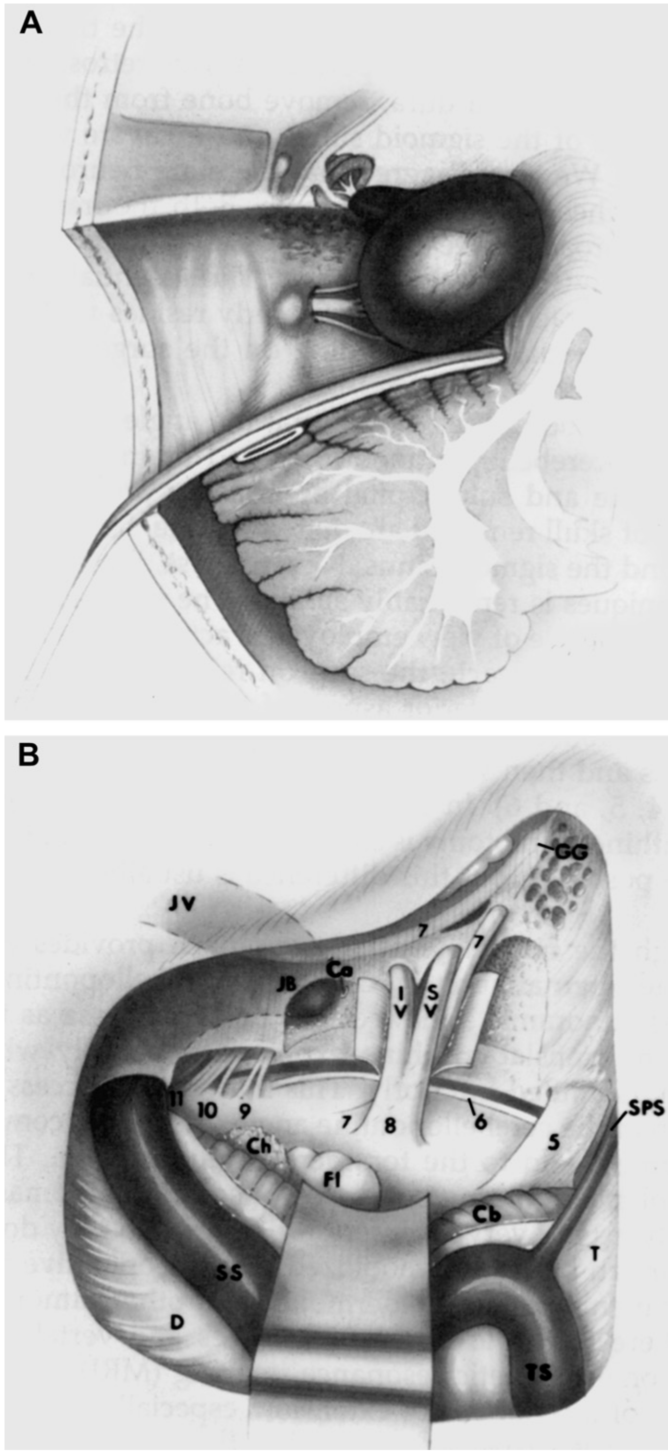

Fig. 2. Translabyrinthine approach viewed schematically in axial section (*A*) and from the surgeon's viewpoint (*B*) demonstrating key points of anatomy. JV, jugular veinz; JB, jugular bulb; SS, sigmoid sinus; TS, transverse sinus; SPS, superior petrosal sinus; Cb, cerebellum; D, retrosigmoid dura; Ca, cochlear aqueduct; IV, inferior vestibular nerve; SV, superior vestibular nerve; 5, trigeminal nerve; 6, abducens nerve; 7, facial nerve; 8, audiovestibular nerve; 9, glossopharyngeal nerve; 10, vagus nerve; 11, accessory nerve; GG, geniculate ganglion; Ch, choroid, Fl, flocculus.

Fig. 3. Translabyrinthine approach to a medium-sized acoustic neuroma. Inspection of the lateral end of the internal auditory canal reveals that the tumor originated from the superior vestibular nerve. Note deformation of the facial nerve over the ventral surface of the tumor.

tumors rarely extend very far inferiorly, and when they do, the lower pole of the tumor can be readily mobilized into the operative field. This is not the case for meningiomas, epidermoids, and other tumors, however, that tend to adhere to the lower cranial nerves and vertebrobasilar system. When a coronal magnetic resonance imaging (MRI) scan reveals an unusual degree of inferior tumor extension, especially when a non–acoustic neuroma tumor is suspected, we choose the suboccipital approach.

The middle fossa approach is generally considered to be suitable only for wholly intracanalicular lesions (Figs. 7 and 8). A few authors have advocated an extended middle fossa approach in the management of tumors with large cerebellopontine angle components [7–8]. They point out that through extensive removal of the temporal floor, accompanied by division of the superior petrosal sinus and a portion of the tentorium, a limited exposure to the cerebellopontine angle may be obtained via the middle fossa approach. In our opinion, this variation affords insufficient exposure of the inferior aspect of the cerebellopontine angle to assure control of vessels arising beneath the tumor. Also, the extended middle fossa approach to the cerebellopontine angle requires rather vigorous and prolonged retraction of the temporal lobe, a maneuver less forgiving than comparable displacement of the cerebellum. For these reasons, the extended middle fossa technique has not gained widespread acceptance.

Depth of internal auditory canal penetration

Each of the three major approaches to acoustic neuroma is capable of completely exposing the contents of the internal auditory canal for removal of the intracanalicular portion of the tumor. Only the middle fossa technique permits complete canal opening without violation of the inner ear. In the translabyrinthine approach, the

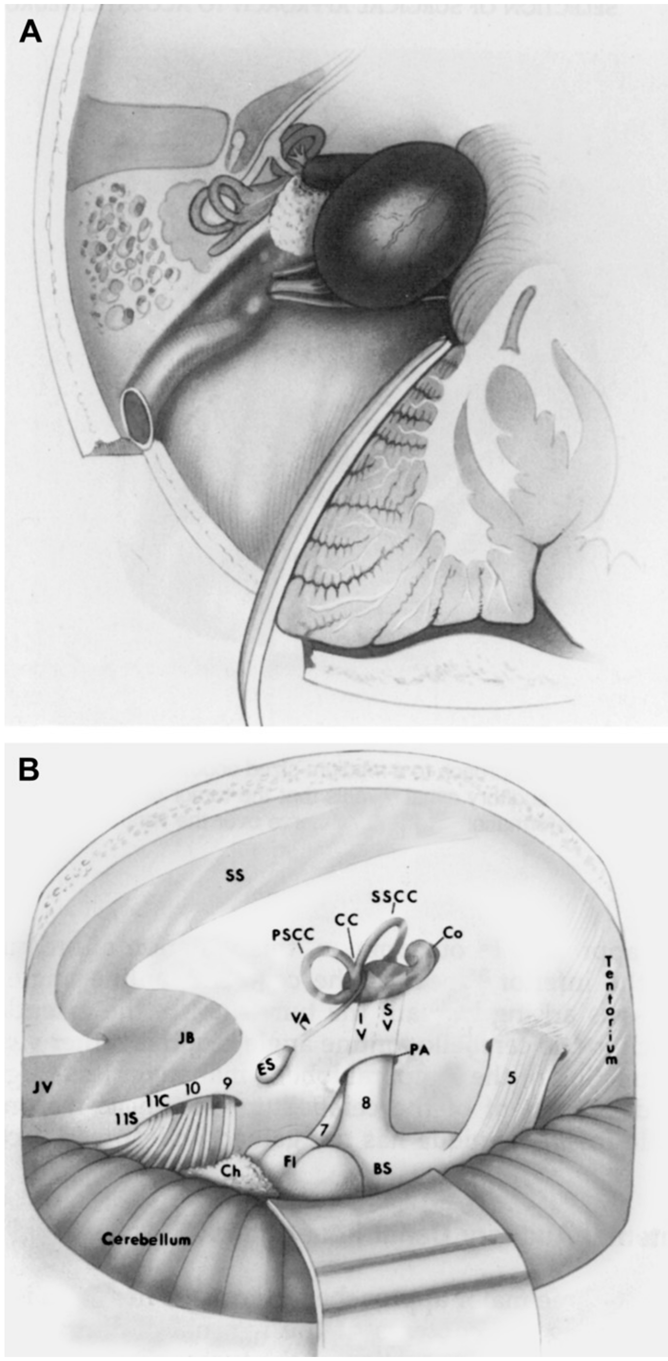

Fig. 4. Suboccipital approach viewed schematically in axial section (*A*) and from the surgeon's viewpoint demonstrating key points of anatomy (*B*). Note that the inner ear overlaps the lateral one third of the distal internal auditory canal. JV, jugular vein; JB, jugular bulb; SS, sigmoid sinus; 11S, spinal division of the accessory nerve; 11C, cranial division of the accessory nerve; 10, vagus nerve; 9, glossopharyngeal nerve; ES, endolymphatic sac; VA, vestibular aqueduct; PSCC, posterior semicircular canal; CC, common crus; SSCC, superior semicircular canal; Co, cochlea; IV, inferior vestibular nerve; SV, superior vestibular nerve; PA, poms acusticus; 7, facial nerve; 8, audiovestibular nerve; Ch, choroid; Fl, flocculus; BS, brain stem; 5, trigeminal nerve.

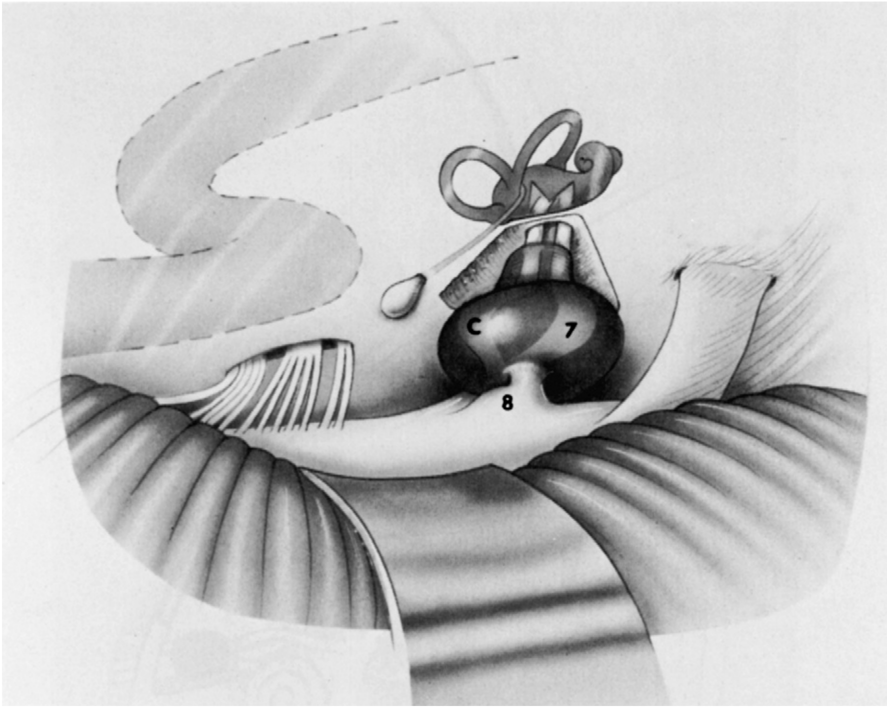

Fig. 5. Suboccipital approach to a small acoustic neuroma that does not deeply penetrate the internal auditory canal. It is usually possible to expose the tumor without entering the inner ear when the tumor is confined to the medial two thirds of the canal. Note that the surgeon has used the endolymphatic sac and aqueduct as guides to avoid entry into the common crus and vestibule. C, cochlear nerve; 7, facial nerve; 8, audiovestibular nerve.

internal auditory canal contents are exposed through exenteration of the semicircular canals.

In the suboccipital approach, only the proximal two thirds of the internal auditory canal can be exposed without traversing inner ear structures (see Fig. 4B). Optimally the internal auditory canal should be opened only as far laterally as required to visualize the deepest penetration of the tumor. Creating unneeded additional exposure may unnecessarily open petrous apex air cell tracts and thereby increase the risk of post-operative cerebrospinal fluid otorhinorrhea. Also, excessive exposure of the lateral end of the internal auditory canal may injure the inner ear and jeopardize efforts at sparing hearing. During an attempt to preserve hearing, the endolymphatic sac and vestibular aqueduct are useful landmarks to avoid violating the inner ear. After identifying the sac operculum, the aqueduct may be traced lateral to the common crus and is useful in demarcating the posterior and lateral extent of bone removal [9]. When using the suboccipital approach to tumors that deeply penetrate the internal auditory canal, complete exposure to the fundus can be achieved by removing portions of the vestibule, posterior semicircular canal, and common crus (see Fig. 6). To avoid entering the inner ear during a suboccipital approach to a tumor that deeply penetrates the internal auditory canal, some surgeons address the most lateral intracanalicular portion indirectly, through use of angulated instruments and a mirror. We do not favor this maneuver because of the considerable risk of leaving residual tumor at the terminus of the internal auditory canal. The laterally placed junction between tumor and the vestibular nerve of origin often tapers to become quite thin and fragile. During blind dissection, this tongue of tumor is easily torn from the main intracanalicular portion, giving the false impression of complete removal even though a nubbin of residual tumor remains in the fundus. These tumor cells, unlike those in a small bit of tumor capsule left on an attenuated facial nerve in the mid–cerebellopontine angle, are well vascularized and have considerable potential for generating a recurrence.

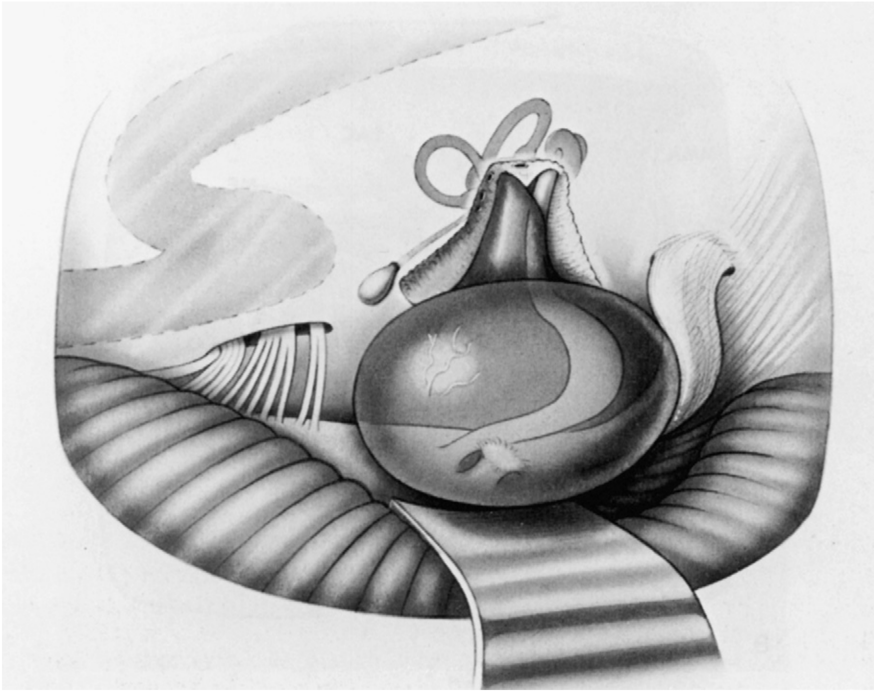

Fig. 6. Suboccipital approach to a large acoustic neuroma that deeply penetrates the internal auditory canal. In tumors that extend into the distal one third of the internal auditory canal, portions of the inner ear must be removed in order to expose the lateral extremity of the tumor. This eliminates any possibility of preserving residual hearing.

An accurate preoperative assessment of the depth of internal auditory canal penetration is important in selecting the optimal approach to an acoustic neuroma. We have found T_2-weighted MRI scans to be most helpful in making this determination. Although gadolinium-enhanced, T_1-weighted images most clearly delineate the tumor, T_2 images best elucidate the structures of the inner ear. The surgeon is less concerned with the absolute depth of the tumor in the internal auditory canal than the relationship between the tumor's deepest penetration to the posterior semicircular canal and vestibule. By drawing a line from a point on the suboccipital convexity approximately 2 cm behind the posterior edge of the sigmoid sinus to the lateral terminus of the tumor, the surgeon can predict whether a portion of the inner ear must be removed to visualize directly the lateral-most extension of the tumor via the suboccipital approach.

Hearing status

Hearing conservation is possible, in certain cases, using either the middle fossa or the suboccipital approach. With intracanalicular tumors, either technique may be employed, whereas with larger tumors, only the suboccipital approach is appropriate. The criteria we use for choosing among operative approaches to intracanalicular tumors is described in detail later. Selecting candidates for a hearing conservation approach involves a number of factors, including pure tone threshold, speech discrimination score, auditory evoked responses, tumor size, depth of tumor penetration in the internal auditory canal, status of the contralateral ear, and patient age. Hearing conservation would be attempted in every patient with significant residual hearing if there were not occasional adverse consequences from undertaking the effort. In our hands, the suboccipital approach has a slightly higher morbidity than the translabyrinthine approach, particularly with regard to cerebrospinal fluid leakage and persistent postoperative headache. As is discussed later, our recommendation to the patient depends on the probability of maintaining useful levels of hearing balanced against the somewhat increased likelihood of these bothersome (but seldom serious) complications.

Removal of an acoustic neuroma from an only hearing (or better hearing) ear represents a therapeutic dilemma. We avoid this unless the

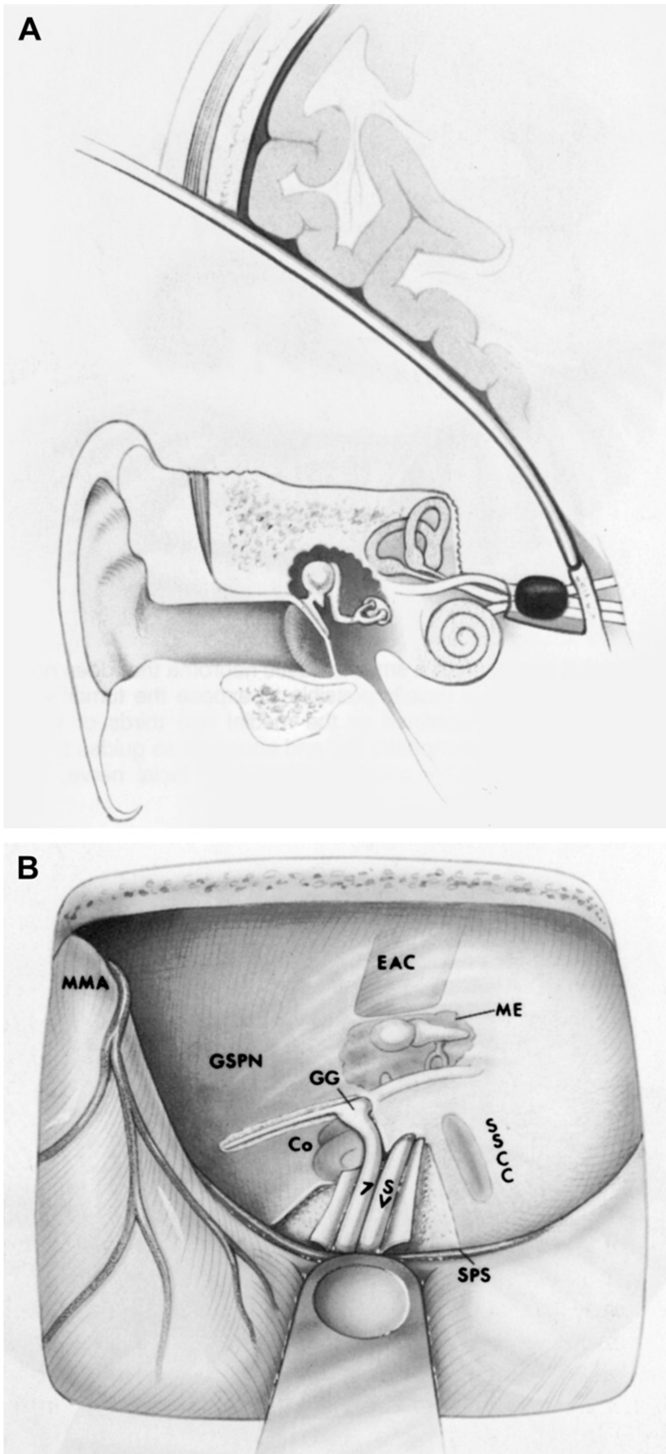

Fig. 7. Middle fossa approach viewed schematically in coronal section (*A*) and from the surgeon's viewpoint, demonstrating key points of anatomy (*B*). MMA, middle meningeal artery; EAC, external auditory canal; ME, middle ear; GSPN, greater superficial petrosal nerve; GG, geniculate ganglion; Co, cochlea; 7, facial nerve; SV, superior vestibular nerve; SSCC, superior semicircular canal; SPS, superior petrosal sinus.

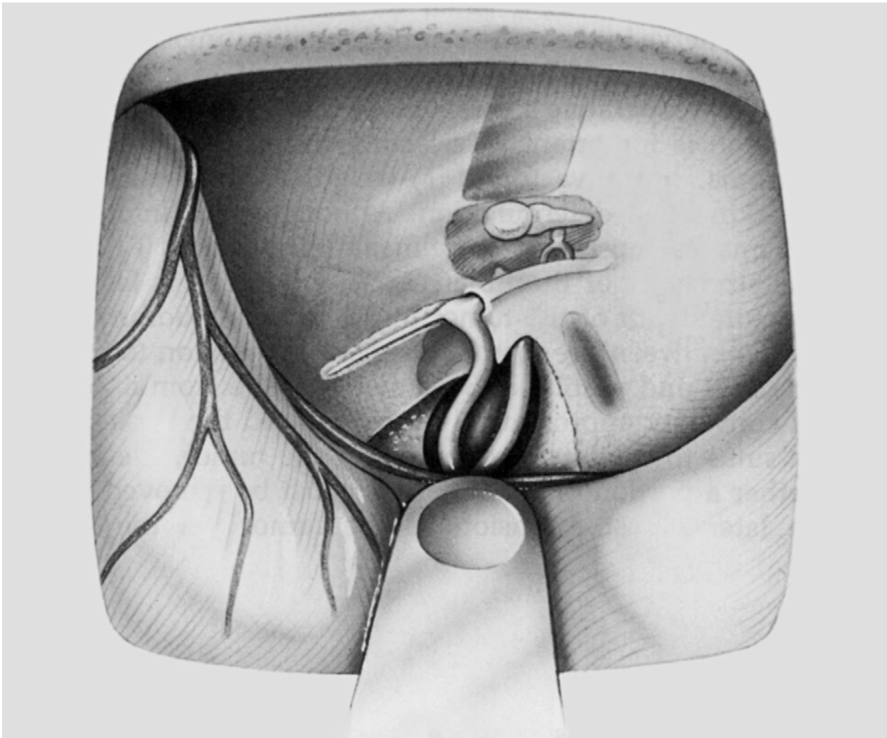

Fig. 8. Middle fossa approach to an intracanalicular tumor arising from the inferior vestibular nerve. Note that the facial nerve is draped on the superior surface of the tumor and must be manipulated during tumor resection. This increases the risk of postoperative neurapraxia.

tumor has been shown to grow rapidly or produce substantial brain stem compression. In such cases, we advocate debulking the cisternal component via the suboccipital route, taking great pains to avoid manipulating the cochlear nerve. During this procedure, the posterior margin of the porus acusticus is removed with a drill to help decompress the internal auditory canal. It is unwise to attempt removal of tumor from the internal auditory canal in large tumors because this usually results in loss of residual auditory function. Slitting the internal auditory canal dura, particularly the ring at the poms acusticus, may help to improve the decom-pressive effect further.

The translabyrinthine technique is the only approach to acoustic neuroma that inherently sacrifices hearing in the course of the procedure. Recently a modification of the translabyrinthine approach intended to afford a slight hope of maintaining hearing has been proposed [10]. The authors reported that atraumatic removal of the membranous labyrinth, sealing of the vestibule with bone wax, and replenishment of lost perilymph with lactated Ringer's solution maintained hearing in one case. Nevertheless, it is doubtful that this fortunate outcome will be realized with enough regularity to consider the translabyrinthine approach suitable for attempts to preserve hearing.

Exposure of the facial nerve

The challenge of preserving the facial nerve in acoustic neuroma surgery can be divided into three steps in ascending order of difficulty: (1) identification of the nerve in the distal internal auditory canal beyond the most lateral extension of the tumor, (2) identification of the nerve at its exit from the brain stem, and (3) separation of the nerve from its region of greatest splaying and adherence.

We have seldom found it difficult to identify a distal interface between the tumor and the facial nerve at the lateral end of the internal auditory canal, regardless of the surgical technique employed. With the translabyrinthine, suboccipital, or middle fossa technique, it is possible to drill open the internal auditory canal sufficiently to identify the facial nerve in the first segment of the fallopian canal before it becomes involved with tumor. In both the middle fossa and translabyrinthine approaches, exposure of the far lateral segment of the internal auditory canal is an inherent part of the technique. In the suboccipital approach, exposure of the distal portion of the internal auditory canal is optional and is usually tailored to the depth of penetration of the tumor within the canal. Some surgeons who primarily employ the translabyrinthine approach have argued that a facial nerve plane in the distal internal auditory canal is more easily and atraumatically established using this technique [11]. Having performed a substantial number of each of these procedures, we believe that identification of the facial nerve plane distally is accomplished equally well via either the translabyrinthine or the suboccipital approach.

Within the internal auditory canal, the facial nerve is virtually always located on the anterior surface of the tumor. It may lie relatively anterosuperior or anteroinferior depending on whether the tumor arose from the superior or inferior division of the vestibular nerve. Both the suboccipital and the translabyrinthine approaches view the internal auditory canal contents from a posterior perspective, where the facial nerve lies on the deep surface of the tumor (see Figs. 3, 5, 6, 9, 10). This is favorable for removing the tumor from the nerve with minimal disturbance to it. With the middle fossa approach, however, the internal auditory canal is viewed from above. When the tumor arises from the inferior vestibular

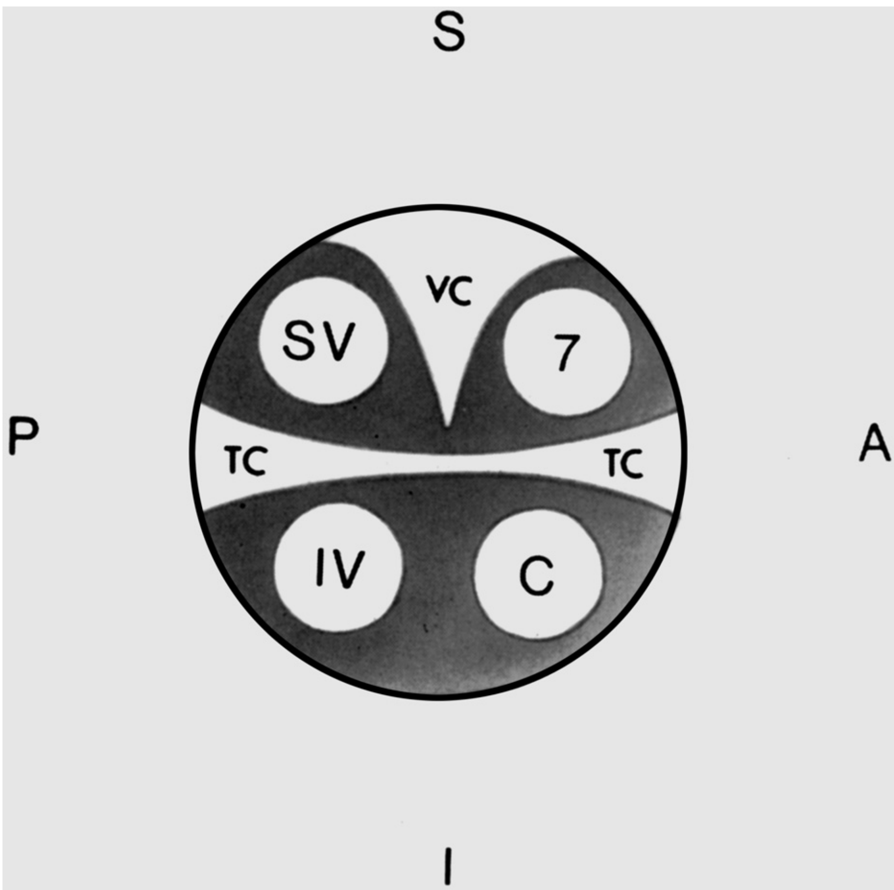

Fig. 9. Relationships at the lateral extremity of the internal auditory canal. The superior compartment is partitioned by the vertical crest (VC), also known as Bill's bar, which separates the superior vestibular nerve from the facial nerve. The canal is completely divided in the horizontal plane by the transverse crest (TC). SV, superior vestibular nerve; IV, inferior vestibular nerve; 7, facial nerve; C, cochlear nerve.

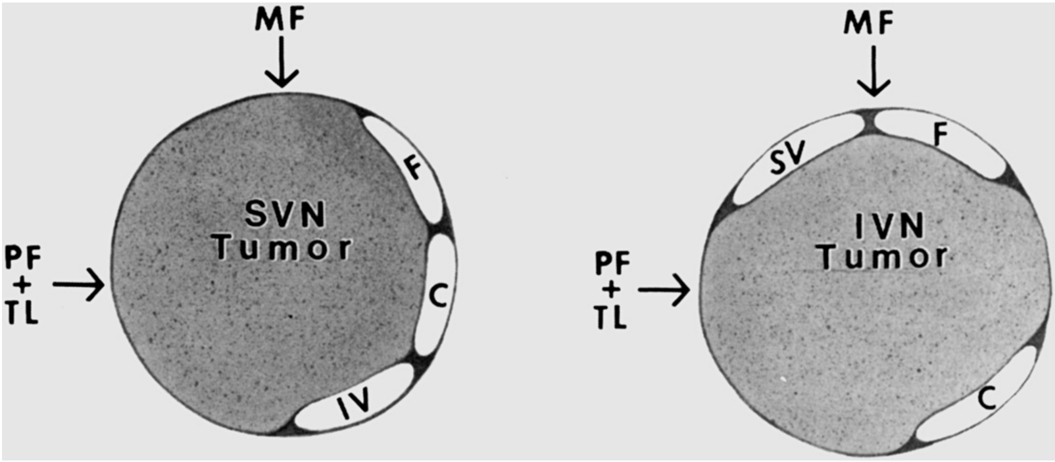

Fig. 10. Schematic representation of a superior vestibular nerve (SVN) tumor and an inferior vestibular nerve tumor (IVN) viewed in cross section through the mid–internal auditory canal (IAC). The surgeon's perspective of the contents of the IAC from the middle fossa (MF) approach is compared with that of the suboccipital (PF) and translabyrinthine (TL) approaches.

nerve, the facial nerve lies in the surgeon's view and must be manipulated from the tumor (see Figs. 8, 10). This increases the chances of transient postoperative facial weakness but is unlikely to result in lasting cosmetic deficit.

Identification of the facial nerve at its exit from the brain stem is straightforward in tumors with little or no brain stem interface. In large tumors, finding the facial nerve proximally may be quite challenging, although it was achieved in virtually every case in our series and is seldom the limiting factor in facial nerve preservation. Routine use of a flexible tip stimulating electrode for facial nerve identification has proved very helpful in locating the root entry zone when it is visually obscure. We have found no difference in exposure of the facial nerve at the brain stem between the translabyrinthine and suboccipital approaches.

The critical portion of the facial nerve dissection is at its region of greatest splaying and adherence, which is almost always located on the tumor surface in the cerebellopontine angle just medial to the porus acusticus. At this point, the nerve makes an acute angulation over the anterior surface of the tumor. In the vast majority of cases, dissection of the facial nerve from the tumor is done equally well with either the translabyrinthine or suboccipital approach. In a few instances, when the facial nerve takes an extreme anterior course, there is a slight advantage to the somewhat more posterior angle of view provided by the suboccipital approach. As a general rule, we prefer not lifting the facial nerve from its diverted course while dissecting the tumor capsule from it. Leaving the facial nerve in situ minimizes potentially injurious traction and torsion on delicate neural fibers. Although dissection of such an anteriorly angulated facial nerve can be accomplished by the translabyrinthine approach, it may require pulling the tumor capsule and attached nerve out of their native position into a more favorable line of sight.

In the few cases in which anatomic continuity of the facial nerve cannot be preserved, the translabyrinthine approach has certain advantages. When the facial nerve deficiency is short, it may be possible to reroute the facial nerve out of the mastoid and gain sufficient length to permit a primary anastomosis. This is desirable because the success of a nerve repair is, in part, dependent on the number of anastomoses. It may also be easier to accomplish an interposition graft via the translabyrinthine approach. Anastomoses of interposition grafts are better done to a nerve of normal diameter than they are to a nerve end that has been flattened out by tumor. With the suboccipital approach, it may be difficult to find and manipulate a normal segment of nerve lateral to the tumor, particularly when it has invaginated the internal auditory canal deeply.

Anatomic variations

An anteriorly placed sigmoid sinus reduces the size of the mastoid and makes the translabyrinthine approach technically more difficult (Fig. 11). In our experience, it has been possible to

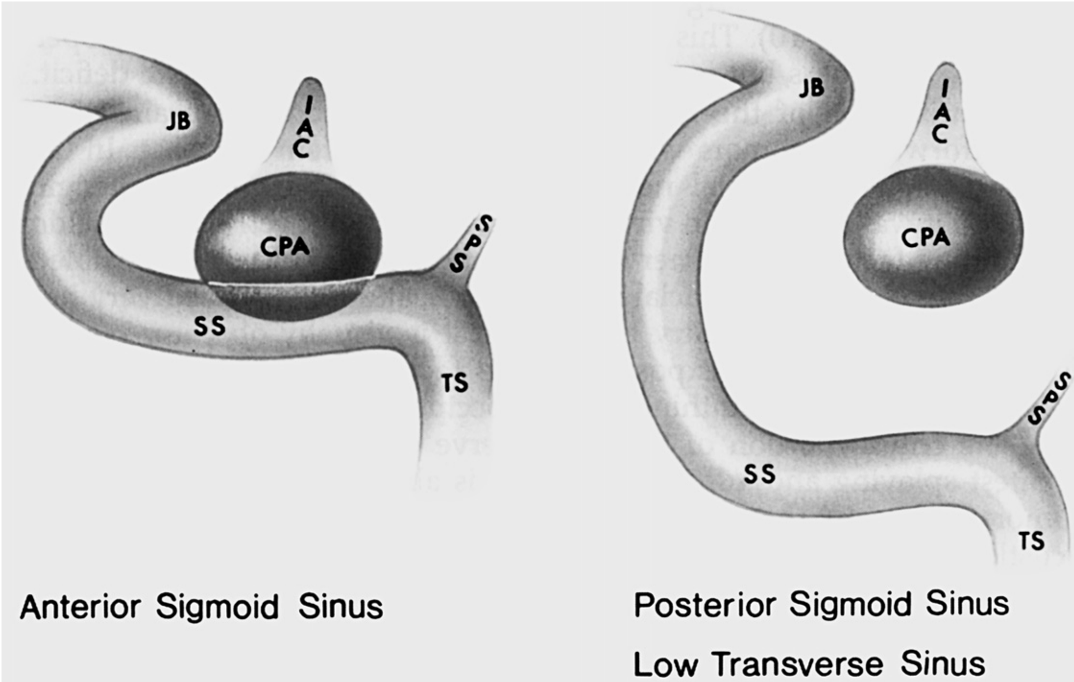

Fig. 11. Anatomic variations of the sigmoid and transverse sinus. When the sigmoid sinus is anteriorly located, a greater degree of retraction is required to obtain adequate exposure during translabyrinthine craniotomy. When the sigmoid sinus lies relatively posterior, especially when the transverse sinus is also low, exposure of the cerebellopontine angle (CPA) and internal auditory canal (IAC) through the suboccipital approach is more difficult.

compensate for this anatomic variation, in every instance that it has been encountered, by increasing the amount of retrosigmoid bone removal and retracting the sinus somewhat further posteriorly.

In the suboccipital approach, access to the cerebellopontine angle may be hindered somewhat when the sigmoid sinus takes an unusually posterior course (see Fig. 11). This mandates that the anterior edge of the craniectomy lie more posteriorly, thus necessitating a greater degree of cerebellar retraction. When a posteriorly placed sigmoid sinus is accompanied by a low-lying transverse sinus, the location of the craniotomy may force an awkward angle of operation. This is particularly true for patients with a short neck and a prominent shoulder.

A high jugular bulb restricts access to the internal auditory canal in both the suboccipital and the translabyrinthine approaches (Fig. 12). When the dome of the bulb lies adjacent to the inferior aspect of the internal auditory canal, it becomes difficult, by either operative route, to create an optimal trough around the canal. This usually constitutes a nuisance only that slows tumor exposure and dissection within the internal auditory canal. In rare cases, the bulb extends superiorly to overlap part or all of the internal auditory canal. When we have encountered this in the past, retraction of the tentorium has permitted creation of a sufficient bony trough superiorly to obtain complete removal of the internal auditory canal portion of the tumor. In extreme cases, however, atraumatic removal of the tumor from the facial nerve in the obscured midportion of the internal auditory canal may be rendered impossible, necessitating incomplete removal. In such cases, a middle fossa approach may allow complete removal of residual tumor within the internal auditory canal, regardless of how high the jugular bulb lies.

A high jugular bulb does not, in and of itself, impair exposure of the cerebellopontine angle. This anatomic variation, however, is occasionally associated with a relatively superior sigmoid sinus course that may restrict access to the inferior portion of the cerebellopontine angle in the region of the neural compartment of the jugular foramen when using the translabyrinthine approach (see Fig. 12). This anomaly is not problematic with

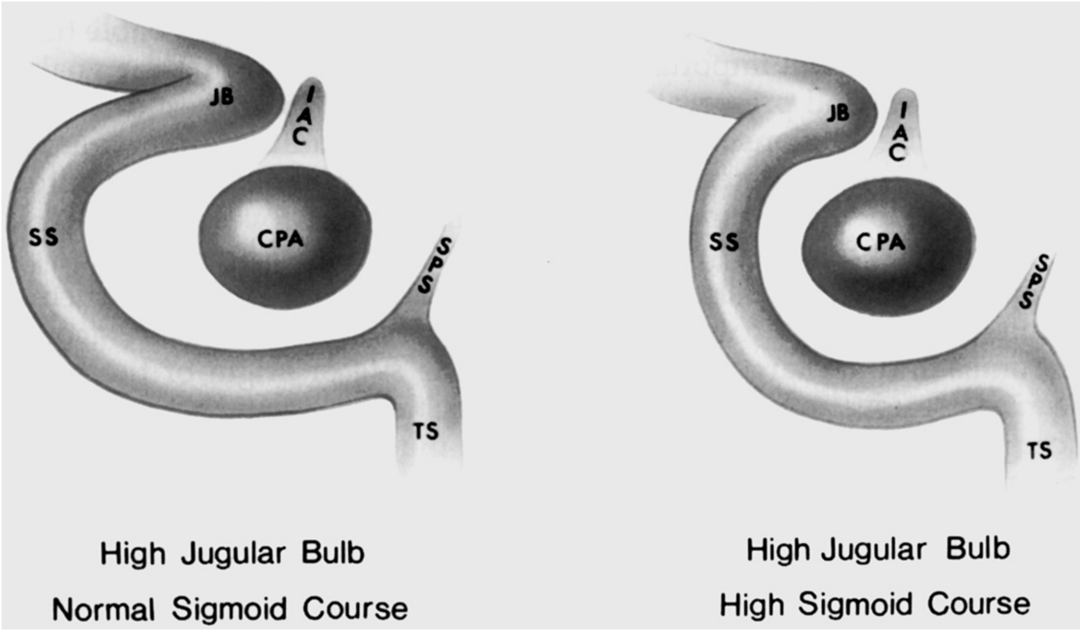

Fig. 12. A high jugular bulb impairs access to the internal auditory canal (IAC) during both the translabyrinthine and suboccipital approaches. When the bulb approaches the IAC it is difficult to create a trough wide and deep enough for unhindered exposure of the inferior compartment of the IAC. Creating additional superior exposure usually compensates well for this limitation. When the course of the sigmoid sinus is unusually superior, it may restrict access to the lower portion of the cerebellopontine angle (CPA) during the translabyrinthine approach.

acoustic neuromas because they typically are not adherent to the nerves of the jugular foramen and, once debulked, are readily mobilized into the operative field. With nonacoustic lesions of the posterior fossa that protrude into the medial aspect of the jugular foramen (neural compartment) or toward the foramen magnum region, this poor visualization of the lower cerebellopontine angle may be limiting. This is particularly true for meningiomas, which do not easily mobilize owing to their broad and tenacious dural attachment.

Suspicion that the lesion may not be an acoustic neuroma

Tumors other than acoustic neuromas constitute between 5% and 15% of lesions involving the cerebellopontine angle. The majority of these are meningiomas followed in incidence by epidermoids and a variety of other uncommon lesions. A preoperative awareness of the probable tumor type is of substantial importance to the surgeon in achieving the goals of tumor removal and preservation of adjacent neural structures. In acoustic neuromas, the relationships of cranial nerves around the tumor are quite predictable. The facial nerve is typically located on the anterior or anterosuperior surface of the tumor, the Vth cranial nerve above, and the nerves of the jugular foramen (IXth, Xth, and Xlth cranial nerves) below. In meningiomas, the relationships of critical neural and vascular structures within the posterior fossa are much less predictable than in acoustic neuromas and are largely dependent on the site of origin of the tumor. Hearing preservation, which is seldom possible in acoustic neuromas over 2 cm in size, is occasionally achieved with much larger meningiomas and epidermoids. Removal of these lesions leads to an improvement of hearing in some cases, a result rarely seen with acoustic neuromas. When a patient has significant residual hearing and preoperative imaging studies suggest the presence of a non–acoustic neuroma cerebellopontine angle tumor, a suboccipital craniotomy should be selected regardless of tumor size. An exception to this rule is a meningioma that deeply penetrates the internal auditory canal, a situation in which we recommend translabyrinthine removal to minimize risk of later recurrence within the temporal bone [12].

Until recently, it was often not possible to distinguish between a cerebellopontine angle meningioma and an acoustic neuroma preoperatively. With gadolinium-enhanced MRI, we are able to differentiate between these lesions in nearly every case. Unlike acoustic neuromas, meningiomas usually (1) do not penetrate the internal auditory canal; (2) have their main bulk eccentrically positioned with respect to the long axis of the internal auditory canal; (3) are sessile, possessing a broad base against the petrous face rather than being globular; (4) demonstrate hyperostosis of the subjacent bone; (5) possess intratumoral calcification; and (6) are characterized by a distinctive dural "tail" extending away from the tumor surface [13]. Epidermoids, unlike acoustic neuromas, are low intensity on T_1-weighted scans and high intensity on T_2-weighted scans and do not enhance with gadolinium.

Operating time

We have not found duration of the operation to be a significant criterion in selecting among approaches. The length of time it takes to expose the cerebellopontine angle and internal auditory canal components of the tumor completely is roughly the same, in our hands, with either the translabyrinthine or the suboccipital approach. For the tumor to be entirely exposed, the suboccipital technique requires a craniectomy, retraction of the cerebellum, and removal of the posterior petrous face overlying the internal auditory canal. In the translabyrinthine approach, the same goal is entirely accomplished by the transtemporal craniotomy. The relative operating time between approaches may vary significantly, however, for surgical teams that emphasize one method and are therefore more facile with it. When this is the case, duration of surgery may be a criterion in selecting the method of operation in patients with medical conditions that may be adversely affected by a prolonged anesthetic.

Operation for recurrent tumor

In reoperations for recurrent acoustic neuromas, we try to avoid using the same approach as was used in the primary procedure [14]. By revising suboccipital procedures translabyrinthine, and translabyrinthine procedures suboccipital, we are able to avoid areas of dural scarring. This permits more rapid and atraumatic establishment of favorable arachnoid planes.

Otologic considerations

Although uncommon, the presence of a perforation in the tympanic membrane contraindicates the translabyrinthine approach. Although the normal middle ear and mastoid mucosa are sterile, with an eardrum perforation the pneumatic spaces of the temporal bone are bacterially colonized, even in the absence of chronic otitis media. Although the translabyrinthine approach more extensively traverses the mucosa within the temporal bone, the suboccipital approach may also enter contaminated air cells surrounding the internal auditory canal. Cerebrospinal fluid leakage through a bacterially contaminated middle ear space carries a high risk of meningitis. Before surgery for acoustic neuromas, we favor grafting tympanic membrane perforations and controlling any active infection present in the temporal bone.

Patient age

Although the patient's age is a major influence over whether surgery is performed and the extent to which tumor is resected, age is only a minor factor in choosing among operative approaches. We avoid the middle fossa approach in patients over the age of 60 because of the thinness and fragility of the temporal floor dura. In older individuals, the dura is difficult to elevate and frequently tears, exposing the temporal lobe. This increases the chances of temporal lobe injury and cerebrospinal fluid leak. We prefer to approach intracanalicular lesions in the aged with either the suboccipital or the translabyrinthine approaches.

Most older individuals with small or medium-sized tumors are operated on only when sequential MRI scans document progressive growth that threatens to compress the brain stem within the patient's predicted life span. The most common reason for removing a relatively small tumor in the aged is disabling imbalance. Elderly patients tolerate perverted vestibular input poorly, and compensation is often improved by surgically ablating vestibular function on the affected side. When dysequilibrium is the primary indication for surgery, we prefer the translabyrinthine approach, which, by removing the semicircular canals, completely eliminates afferent input in the vestibular system on the side of the tumor. The translabyrinthine technique maintains the option of performing subtotal tumor removal without fear of leaving residual vestibular fibers. If an elderly patient with a significant balance disorder is operated on via the suboccipital approach, it is important to perform a thorough vestibular neurectomy at the time of tumor resection.

Medical considerations

The medical condition of the patient is of paramount importance in deciding whether to operate and the extent of resection but seldom dictates the choice of operative method. Medical factors that have impact on the selection of surgical approach are rare and highly specific. For illustrative purposes, we provide a few examples. In a patient with a history of temporal lobe epilepsy, it is best to avoid the middle fossa route because the required brain retraction may aggravate the condition. One of our patients had a history of jugular vein thrombophlebitis associated with recurrent pulmonary embolism. We recommended the suboccipital over the translabyrinthine route to avoid retraction on the sigmoid sinus, which, by slowing flow in the jugular vein, may have precipitated further thrombosis. When a patient has an only seeing eye ipsilateral to the tumor, we favor conservative tumor removal to avoid facial palsy with the risk of exposure keratopathy. In such cases, we prefer a subtotal removal, which is usually accomplished via the translabyrinthine approach. In one patient, who was severely deficient in abdominal fat (owing to anorexia nervosa), the suboccipital approach was chosen because it permits primary dural closure without the need for a tissue graft. In the great majority of thin patients, sufficient adipose tissue can be obtained to close a translabyrinthine craniotomy satisfactorily. When there is a paucity of fat in the anterior abdominal wall, the fat graft may be harvested from the hip via an incision placed just beneath the iliac crest. In extremely obese individuals, access to the operative site may be difficult, especially when the neck is short and the shoulder is large. This limitation of exposure equally affects the translabyrinthine and suboccipital approaches. In one massively obese individual, we elected to use a sitting position because the traditional lateral or supine positions provided insufficient access to the suboccipital region. In this patient, the translabyrinthine approach was not a viable option. Undoubtedly there are other uncommon medical factors that may influence selection of operative approach, each of which should be analyzed by the clinician according to its unique attributes.

Incidence of postoperative complications

The incidence of serious complications, such as brain stem stroke, postoperative hemorrhage into the cerebellopontine angle, and death, is remarkably infrequent in acoustic neuroma surgery. Such rare events are largely attributable to the size and complexity of the tumor as well as the patient's age and medical condition rather than to which particular surgical approach was employed. In a few, less serious complications, there are some differences in the rate of occurrence among the various approaches.

In comparing approaches to medium-sized and large tumors, there are some differences in the incidence of complications with suboccipital and translabyrinthine approaches. Most importantly, we have found cerebrospinal fluid otorhinorrhea to be both more common and more difficult to manage following suboccipital craniectomy. Although most cerebrospinal fluid leaks respond to conservative management (lumbar drain, head elevation, fluid restriction, and acetazolamide administration), some require a secondary procedure (usually transtemporal obliteration of the eustachian tube) to stop the flow occurring through pneumatic tracts surrounding the internal auditory canal. This problem persists despite diligent efforts to seal the transected air cells with bone wax, fascia, muscle plugs, and fibrin glue applied to the drilled surface of the internal auditory canal at the time of suboccipital surgery. Fortunately, once cerebrospinal fluid leakage has been controlled, the patient suffers no lasting consequences other than the psychological and financial burden of a somewhat prolonged recovery period. Not all surgical teams report a higher incidence of cerebrospinal fluid leakage with the suboccipital as compared with the translabyrinthine approach. An equal incidence has been reported or even a higher rate with the translabyrinthine technique [15,16].

Another difference between the suboccipital and translabyrinthine approaches is the incidence of persistent headaches lasting from several months to a year postoperatively. This is more frequent following the suboccipital approach, presumably as a consequence of aseptic meningitis. In the suboccipital approach, the internal auditory canal is drilled open intradurally, whereas in the translabyrinthine approach, all bone removal is accomplished extradurally. During the suboccipital approach, some contamination of the subarachnoid space by bone dust is inevitable despite the liberal use of Gelfoam and a rubber dam to contain the debris. This is particularly true with small tumors, in which the cisternal space is not blockaded by tumor. In our experience, most patients with persistent headache have had small tumors operated on by a suboccipital hearing conservation approach.

The translabyrinthine technique has a few complications not shared with the suboccipital approach. Hematoma may form in the site of harvesting the abdominal fat graft. Meticulous hemostasis and the use of drains have rendered this uncommon, but a rare patient may require reoperation for persistent bleeding. The cosmetic effects of an abdominal scar may be significant, especially when aesthetic considerations are important to the patient. In these cases, we have avoided an abdominal scar by obtaining the fat graft from the hip via an incision just beneath the iliac crest. This technique is particularly suitable for women, who tend to have a fat deposit in this area. Finally the translabyrinthine approach is more likely to cause injury to the sigmoid sinus than the suboccipital approach. Although this injury is almost always well tolerated, we are aware of two potential complications. One patient succumbed to a massive pulmonary embolus that apparently derived from a thrombosis of the sigmoid sinus, which propagated into the jugular vein (Althaus S, personal communication, 1990). In another case, a partial visual loss resulted from venous congestion in the optic nerve as a result of occlusion of a dominant sigmoid sinus (S. Seiff, personal communication, 1991).

The middle fossa route is accompanied by a few risks not shared with the translabyrinthine and suboccipital approaches. Many patients suffer a degree of postoperative trismus as a result of manipulation of the temporalis muscle, but this is seldom prolonged. Retraction of the temporal lobe, particularly on the dominant side, may rarely lead to transient dysphasia or episodes of auditory hallucinations. Finally epidural hematoma has been reported and may have serious consequences. The risk of this may be minimized by meticulous hemostasis, tacking the dura up to the bone flap at the end of the procedure, and judicious use of a subtemporal drain.

Patient choice

A patient occasionally has a preference for a particular operative approach for personal reasons that may be well founded or arbitrary. For example, an individual may reject the middle fossa approach because it involves a more visible head shaving than the translabyrinthine or suboccipital approach. A musician may prefer an incomplete suboccipital removal to maximize chances of hearing conservation. In familial cases, a patient may prefer to have the same approach a relative had. In general, we are willing to accommodate patients' preferences if they have carefully considered their options and have strongly felt reasons for their decision, and the choice is medically reasonable.

Protocol for the selection of operative approach according to tumor size, location, and clinical presentation

Intracanalicular tumors

At first reckoning, therapeutic decision making in intracanalicular tumors would seem to be relatively straightforward. Actually it is quite complex (Fig. 13). Anatomically, intracanalicular tumors may be considered to occur in three varieties: (1) involving the entire internal auditory canal, (2) limited to the proximal canal adjacent to the porus acusticus, and (3) limited to the distal canal in proximity to the transverse crest and vestibule (Fig. 14). Any intracanalicular tumor with poor hearing (roughly $< 30\%$ speech discrimination score, or 70-dB speech reception threshold) is addressed via a translabyrinthine approach. When significant residual hearing persists, the size and location of the tumor become important.

Medially placed tumors that do not involve the distal one third of the internal auditory canal are approached suboccipitally in an attempt to preserve hearing. This permits exposure of the tumor under direct vision, without violating the inner ear, at an angle favorable for atraumatic dissection of the facial nerve.

Small intracanalicular tumors that are limited to the lateral portion of the internal auditory canal in ears with good hearing are usually approached via the middle fossa route because this is the only method that provides direct access to this region without violating the inner ear. When the tumor has arisen from the inferior vestibular nerve, the facial nerve may lie draped on the tumor surface between the surgeon and the

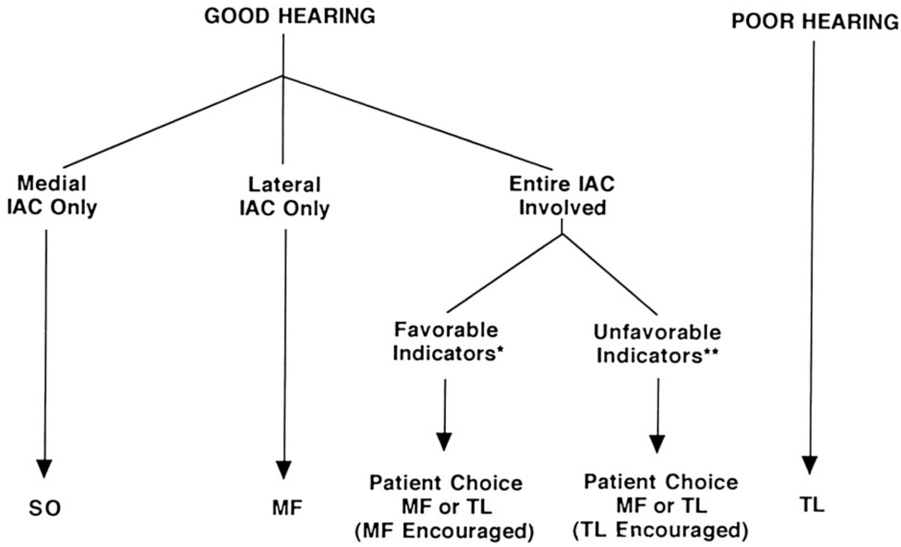

Fig. 13. Management of intracanalicular acoustic neuromas.

tumor (see Fig. 8). This requires a greater degree of facial nerve manipulation than with the suboccipital or translabyrinthine approaches, making postoperative facial neurapraxia more common following the middle fossa procedure. Fortunately this weakness is usually transient, and serious neural injury is unlikely to occur. We explain to the patient who has a small, laterally placed intracanalicular tumor that an attempt to preserve hearing comes at the price of a higher incidence of temporary facial weakness, but that a permanent, cosmetically significant deformity is improbable. The risk that the facial nerve will have an unfavorable relationship with the tumor via the middle fossa approach may be estimated, to some degree, by measurement of the preoperative caloric response. The caloric response is generated by the lateral semicircular canal that is innervated by the superior vestibular nerve. When the caloric response is normal (or nearly so), this suggests the

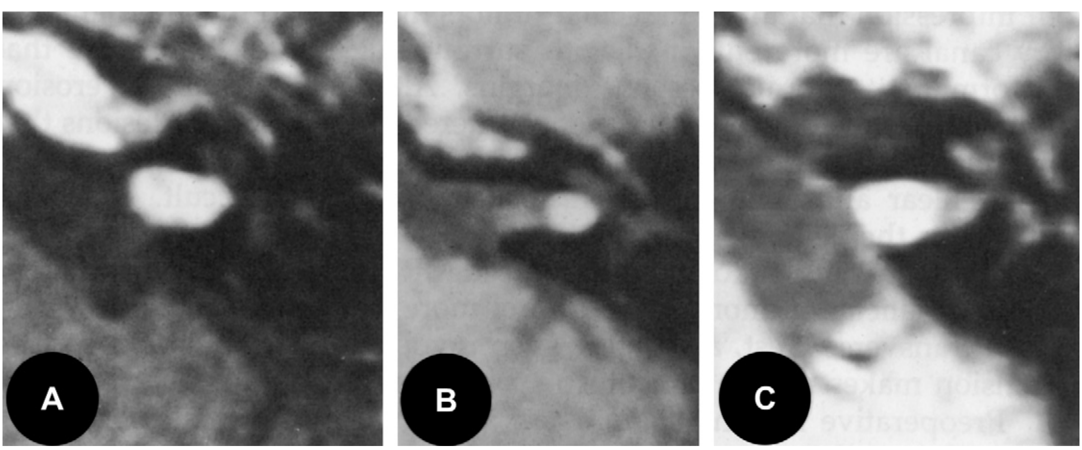

Fig. 14. Intracanalicular acoustic neuromas on gadolinium-enhanced magnetic resonance imaging scans in the axial plane. Examples include a tumor involving the entire internal auditory canal (*A*), only the lateral extremity (*B*), and only the proximal portion adjacent to the porus acusticus (*C*). The management implications of these lesions are addressed in the text.

presence of an inferior vestibular nerve tumor and predicts an unfavorable facial nerve relationship. A substantially impaired or absent caloric response does not necessarily imply favorable anatomy. Although the lesion may have originated from the superior vestibular nerve, inferior vestibular schwannomas can also impair both divisions of the nerve. When presented with these choices, most individuals with small, laterally placed intracanalicular tumors select a middle fossa hearing conservation attempt. The alternative is a translabyrinthine procedure with sacrifice of residual hearing.

The most common variety of intracanalicular tumor, in our experience, is one that involves the entire length of the internal auditory canal from the porus acusticus to its distal extremity. When good hearing persists, the middle fossa route is the only method that affords direct exposure to the entire tumor and the chance of preserving hearing. As previously discussed, however, this technique carries a higher risk of facial neurapraxia. In advising the patient as to the probability of hearing preservation and the relative degree of risk to the facial nerve, we take several factors into account in addition to those already mentioned. It has been our impression that intracanalicular rumors that expand the internal auditory canal are more entwined with surrounding nerves than those that conform to its normal osseous margins. Although most bony erosion occurs posteromedially, we have encountered intracanalicular lesions that expanded the anterior aspect of the canal. In such cases, dissection of both the cochlear and facial nerves has been unusually difficult. A second criterion is the degree of penetration of the lateral extremity of the canal by the tumor. With gadolinium-enhanced MRI scans, a surprising number of intracanalicular tumors penetrate 1 or more mm deep to the free margin of the transverse crest, and a few even involve the vestibule. Such deep extension makes it very difficult to spare hearing.

Preoperative hearing status is an important determinant of surgical approach to an intracanalicular tumor. As a general rule, the more normal the hearing, the higher the probability of success with hearing preservation. We place particular importance on the level of speech discrimination scores and the auditory brain stem response results. Selection of the optimal surgical approach in these cases is often a matter of judgment and is not easily codified into a set of rules. Of course, when hearing is normal, the canal is not expanded, and the far lateral end of the internal auditory canal is uninvolved, we strongly encourage either the suboccipital or the middle fossa approach. Similarly, when hearing is marginal, the osseous canal is substantially eroded, and deep penetration of the lateral extremity is detected, we encourage selection of the translabyrinthine technique. In essence, we present the relative degree of risk to hearing and facial function as well as the incidence of complications and the predicted postoperative recovery period and allow the patient to decide between a hearing conservation attempt (middle fossa or suboccipital) and a hearing sacrificing approach (translabyrinthine).

Medium-sized tumors (1 to 3 cm)

Tumors that are 1 to 3 cm in diameter in the cerebellopontine angle are approached by either the suboccipital or translabyrinthine approach (Fig. 15). Because all of these tumors possess a significant cisternal component, the middle fossa approach is not a viable option, in our opinion. Whenever hearing is poor, the translabyrinthine approach is employed. When there is significant residual hearing, a number of factors come into play. Tumor size influences decision making but is not a major criterion. Although it is true that the probability for success in hearing conservation drops off substantially in acoustic neuromas exceeding 2 cm in diameter in the cerebellopontine angle, hearing preservation may occasionally be achieved in larger tumors. When the hearing is especially good, we favor an attempt at saving hearing, even in tumors at the upper end of this size range. On the other hand, if the amount of residual hearing is marginal and the tumor is relatively large, we typically recommend a translabyrinthine approach.

The depth of tumor penetration within the internal auditory canal is a major determinant in selecting surgical approaches in patients with substantial residual hearing. When the tumor involves the lateral one third of the internal auditory canal, the suboccipital approach cannot expose the deepest portion of the tumor without exenterating a portion of the inner ear and thus sacrificing hearing (Figs. 16 and 17). Although it is possible to address this part of the tumor indirectly, without violating the inner ear, by using angled instruments and mirrors, this risks leaving viable tumor cells in the fundus of the internal auditory canal. The incidence of clinically significant

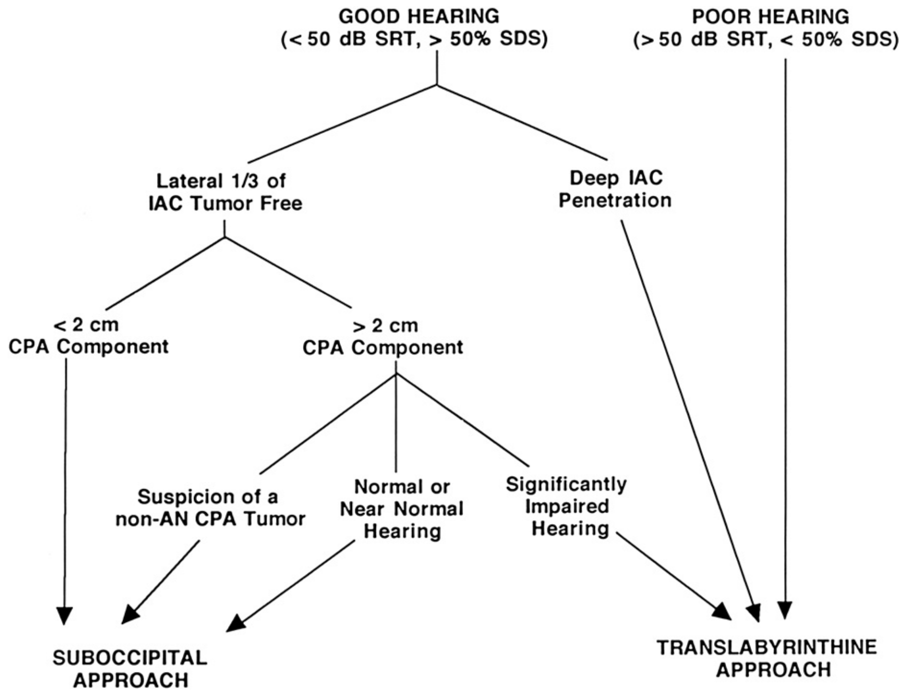

Fig. 15. Management of 1 to 3 cm acoustic neuromas.

recurrence as a result of persistent tumor in the distal internal auditory canal is unknown, although it is most likely quite small. Nevertheless, we have treated several patients in whom this situation appeared to cause a recurrence that necessitated reoperation. Under certain circumstances, assuming this risk may be warranted. In older patients with particularly good hearing, it is reasonable to perform a suboccipital approach and indirectly address the lateral extremity of the tumor. If the cochlear division is involved by tumor or the intraoperative auditory monitoring suggests a loss of hearing during dissection, further internal auditory canal exposure can be obtained to ensure complete removal under direct vision. As a general rule, we do not favor indirect dissection of tumor from the distal internal auditory canal in younger patients, for whom total tumor removal takes priority over attempts at hearing preservation.

Large tumors (>3 cm)

We remove the majority of large tumors via the translabyrinthine approach. It is chosen for its lower incidence of cerebrospinal fluid leakage, fewer prolonged headaches, and somewhat less postoperative morbidity. The suboccipital approach is used in a few special circumstances. When preoperative imaging studies produce significant doubt that the tumor is an acoustic neuroma, we favor the suboccipital approach in certain situations. The usual rules about tumor size and hearing preservation do not apply to non–acoustic cerebellopontine angle tumors. When the hearing level associated with a meningioma or epidermoid is relatively good, we employ a suboccipital approach, even when the lesion is large. The same exception applies for the rare large acoustic neuroma that is wholly extracanalicular, although in such circumstances there is usually significant doubt on preoperative studies as to the nature of the lesion (Fig. 18). We also use the suboccipital approach when a tumor extends into the region of the jugular foramen or foramen magnum, an area not readily exposed with a translabyrinthine craniotomy. This is seldom the case with acoustic neuromas but is frequent with larger, non–acoustic neuroma cerebellopontine angle lesions, especially meningiomas.

In cases of neurofibromatosis type 2, there are often multiple tumors in the posterior fossa. The more panoramic view of the lower portion of the cerebellopontine angle afforded by the

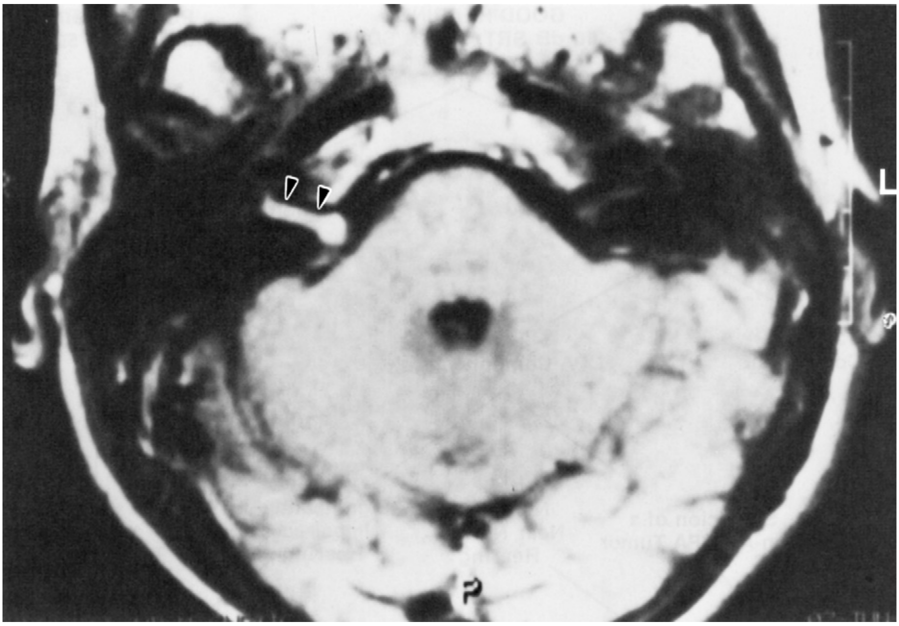

Fig. 16. Deep involvement of the internal auditory canal (*arrowheads*) by a small acoustic neuroma but only a small cisternal component as seen on an axial gadolinium-enhanced T_1 magnetic resonance imaging scan. It is difficult to save hearing with such a lesion with the suboccipital approach because exposure of the tumor requires drilling away a portion of the inner ear.

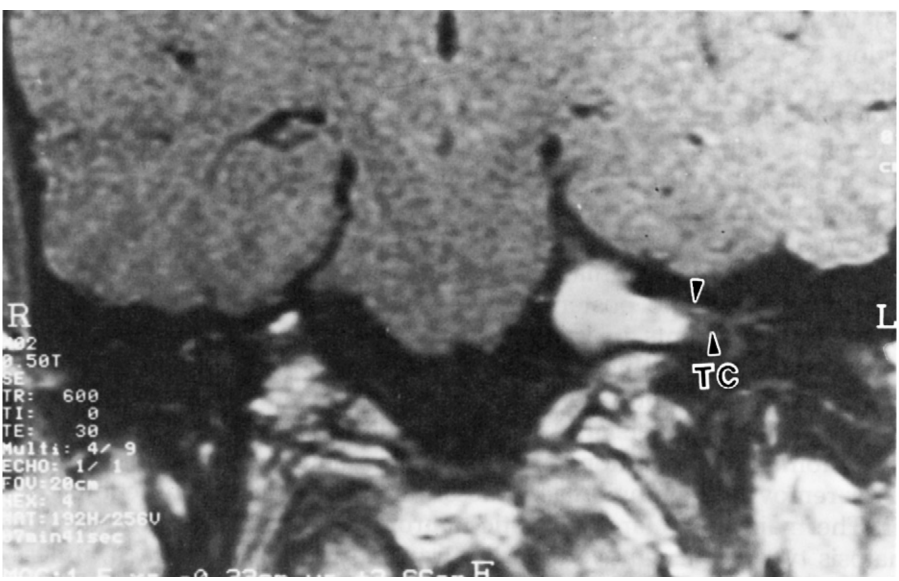

Fig. 17. Coronal gadolinium-enhanced MRI scan of an acoustic neuroma that penetrates approximately two thirds of the depth of the internal auditory canal. The cerebrospinal fluid in the distal one third of the canal can be visualized (*arrowheads*) as well as the transverse crest (TC). This tumor illustrates the maximum degree of IAC penetration that may be exposed through the suboccipital-transmeatal route.

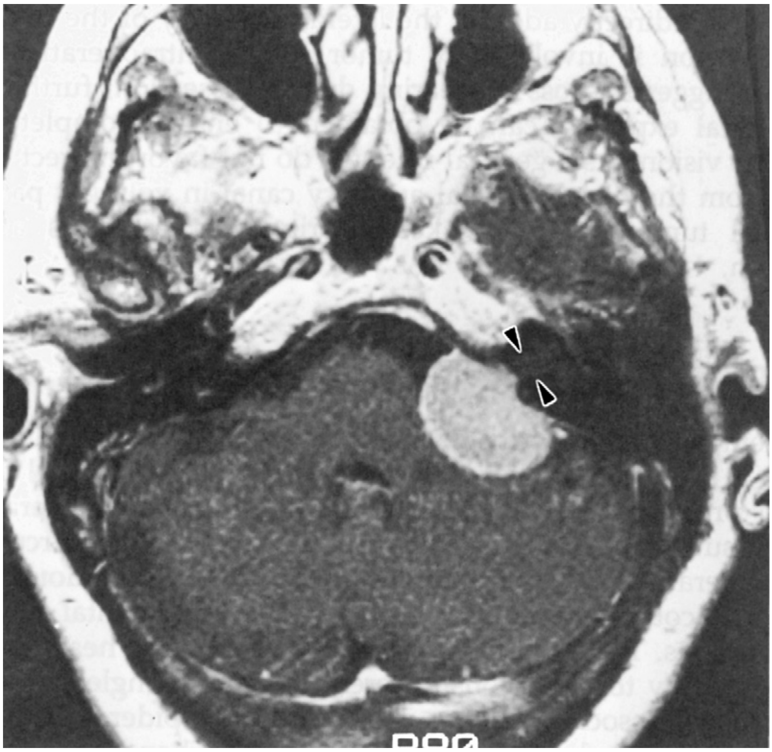

Fig. 18. An atypical medium-sized acoustic neuroma on a gadolinium-enhanced MRI scan demonstrating no extension into the internal auditory canal (*arrowheads*). When useful hearing remains in a wholly extracanalicular tumor, even though it is relatively large, the authors recommend a suboccipital hearing conservation approach.

suboccipital route allows inspection of the lower cranial nerves (IX through XII) for tiny schwannomas and the dura of the posterior fossa floor for early meningiomas. With recent improvements in imaging technology, especially gadolinium-enhanced MRI scans, this advantage has become less important. In any event, whether or not to remove miniscule schwannomas from functioning nerves is controversial. As a general rule, we leave undisturbed small, asymptomatic schwannomas in neurofibromatosis type 2 patients but favor removing meningiomas, unless this would create a functional deficit. The majority of large acoustic neuromas associated with neurofibromatosis type 2 are removed via the translabyrinthine approach, unless a second tumor in the jugular foramen or foramen magnum is visualized on MRI scan.

References

[1] Cohen NL, Hammerschlag P, Berg H, et al. Acoustic neuroma surgery: An eclectic approach with emphasis on preservation of hearing. Ann Otol Rhinol Laryngol 1986;95:21–7.

[2] Glasscock ME III, Kveton JF, Jackson CG, et al. A systematic approach to the surgical management of acoustic neuroma. Laryngoscope 1986;96:1088–94.

[3] Jackler RK, Pitts LP. Acoustic neuroma. Neurosurg Clin North Am 1990;1:199–223.

[4] Long DM, Kennedy DW, Holliday MJ. Selecting a surgical approach for removal of acoustic schwannoma. Ear Nose Throat J 1986;65:163–73.

[5] DiTullio MV, Malkasian D, Rand R. A critical comparison of the neurosurgical and otolaryngological approaches to acoustic neuromas. J Neurosurg 1978;48:1–12.

[6] Bochenek Z, Kukwa A. An extended approach through the middle fossa to the internal auditory meatus and cerebellopontine angle. Acta Otolaryngol 1975;80:410–4.

[7] Kanzaki J, Kawase T, Sano K, et al. A modified extended middle fossa approach for acoustic neuroma. Arch Otorhinolaryngol 1977;217:119–21.

[8] Morrison AW, King TT. Experiences with a translabyrinthine-transtentorial approach to the cerebello-pontine angle. J Neurosurg 1973;38:382–90.

[9] Kartush JM, Telian SA, Graham MD, et al. Anatomic basis for labyrinthine preser vation during posterior fossa acoustic tumor surgery. Laryngoscope 1986;96:1024–8.
[10] McElveen JT, Wilkins RH, Erwin AC, et al. Modifying the translabyrinthine approach to preserve hearing during acoustic tumor surgery. J Laryngol Otol 1991;105:34–7.
[11] Luxford WM, House WF. Acoustic tumor. In: Pillsbury HC, Goldsmith MM, editors. Opera tive Challenges in Otolaryngology–Head and Neck Surgery. Chicago: Year Book; 1990. p. 77–83.
[12] Langman A, Jackler RK, Althaus S. Meningioma of the internal auditory canal. Am J Otol 1990;11:201–4.
[13] Jackler RK, Shapiro M, Dillon WP, et al. Gadolinium enhanced magnetic resonance imaging in acoustic tumor diagnosis. Otolaryngol Head Neck Surg 1990;102:670–7.
[14] Beatty CW, Ebersold MJ, Harner SG. Residual and recurrent acoustic neuromas. Laryn goscope 1987; 97:1168–71.
[15] Bryce GE, Nedzelski JM, Rowed DW, Rappaport JM. Cerebrospinal spinal fluid leaks and meningitis in acoustic neuroma surgery. Otolaryngol Head Neck Surg 1991;104:81–7.
[16] Mangham CA. Complications of translabyrinthine vs. suboccipital approach for acoustic tumor surgery. Otolaryngol Head Neck Surg 1988;99:396–400.