Surgical Approaches to Vestibular Schwannomas: What the Radiologist Needs to Know[1]

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TEACHING POINTS
See last page

Vestibular schwannomas account for 85% of cerebellopontine angle tumors in adults and most commonly arise from the inferior division of the vestibular nerve. Surgical and imaging techniques have evolved to offer earlier detection and the potential for hearing preservation. Three main surgical techniques are currently being used for the removal of vestibular schwannomas: middle cranial fossa, suboccipital, and translabyrinthine approaches. Each surgical approach has unique advantages and limitations. For example, the middle cranial fossa and suboccipital approaches make hearing preservation possible in selected patients, whereas the translabyrinthine approach precludes hearing preservation because it involves a labyrinthectomy. Imaging plays a key role in preoperative assessment and postoperative management in affected patients. A good understanding of the main surgical approaches, relevant anatomic considerations, surgical complications, and likelihood of tumor recurrence is essential for interpreting magnetic resonance images to the advantage of both the surgeon and the patient, particularly when hearing preservation is a consideration.

Abbreviations: CISS = constructive interference into steady state, CSF = cerebrospinal fluid, FIESTA = fast imaging employing steady-state acquisition, FLAIR = fluid-attenuated inversion recovery, GRE = gradient-echo, IAC = internal auditory canal, MCF = middle cranial fossa, SPACE = sampling perfection with application-optimized contrasts by using different flip angle evolutions, 3D = three-dimensional

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Introduction

Vestibular schwannoma accounts for approximately 85% of all cerebellopontine angle masses (1). The tumor was first described in 1777 by Eduard Sandifort, an anatomist from the Netherlands (2). Schwannomas arise within or near the vestibular ganglion, also known as the Scarpa ganglion. This ganglion lies at the porus acousticus, or just within the internal auditory canal (IAC), and contains cell bodies of primary afferent neurons, which synapse with the vestibular nuclei and receive input from hair cells in the cochlea (1). Teaching Point Schwannomas most often involve the inferior division (91.4% of cases) and, to a lesser extent, the superior division (6%) of the vestibular branch of cranial nerve VIII, often near the Obersteiner-Redlich zone (1), which marks the transition from glial cells to Schwann cells and from the central to the peripheral nervous system (Fig 1).

The first case in which a patient survived surgical resection of a vestibular schwannoma was reported in 1894. The procedure was performed by Sir Charles Balance, a British surgeon who also popularized mastoidectomy for major middle ear infections (2). Surgery was generally reserved for cases of brainstem compression, since mortality and morbidity rates were high. Contributions from surgeons such as Fedor Krause (1857–1937), Harvey Cushing (1869–1939), Walter Dandy (1886–1946), and William House have led to significant decreases in surgical mortality and morbidity. In recent decades, major advances in medical imaging have permitted earlier diagnosis, and improved surgical techniques have led to less invasive treatments with decreased morbidity. Today, surgery offers the option of hearing preservation in a number of patients, and schwannomas now have a recurrence rate that is generally less than 1% (3). Imaging plays a large role in the success of modern vestibular schwannoma management in both the pre- and postoperative setting.

In this article, we provide background information regarding surgical approaches to vestibular schwannomas and discuss and illustrate these approaches in terms of imaging and surgical techniques, anatomic variants, and complications (early complications, postoperative hearing loss, delayed complications, tumor recurrence).

Background

Surgical techniques and imaging of vestibular schwannomas have undergone a concurrent evolution. Before the advent of cross-sectional imaging, diagnosis was suggested by clinical presentation (ipsilateral hearing loss, vertigo, facial palsy, and signs of brainstem compression and hydrocephalus) and confirmed with pneumencephalography and angiography. Intervention was undertaken primarily to alleviate brainstem compression.

Advances in diagnostic imaging, beginning with computed tomography (CT) and later joined by magnetic resonance (MR) imaging, have permitted detection of much smaller lesions. The development of microsurgical techniques now allows treatment much earlier in the course of the tumor's natural history and can often provide a chance for hearing preservation. Stereotactic radiosurgery has also emerged as a minimally invasive treatment option with the potential for tumor control and hearing preservation (4). Retrospective reviews, case series, and case-control and prospective cohort studies have demonstrated the efficacy of radiosurgery; to our knowledge, however, no randomized trials have compared radiosurgery with microsurgery (5). Therefore, in this article we focus on surgical management, which at least for now remains the definitive therapy for vestibular schwannoma.

With the advent of the surgical microscope, precision drills, and high-resolution imaging, three main surgical approaches are now generally accepted: middle cranial fossa (MCF), suboccipital, and translabyrinthine. Each technique has its own unique advantages and disadvantages. For example, the MCF and suboccipital approaches offer the option of hearing preservation, whereas the translabyrinthine approach traverses the inner ear structures and generally eliminates the possibility of functional hearing.

The selection of surgical approach is based on multiple factors, including pure tone thresholds, speech discrimination score, auditory-evoked responses, tumor size, hearing status of both ears, and patient age and preference. Surgery practices vary in degree of experience and preferred techniques (6). Despite these differences, however, imaging directs preoperative management by addressing tumor size, extent of IAC penetration, cerebellopontine angle involvement, relationship of the tumor to cranial nerves, and relevant anatomic variants (7). Preoperative MR imaging is generally considered the standard procedure unless contraindications exist.

Postoperative management is also highly influenced by imaging. The timing of postoperative imaging is debated and highly variable. Algorithms

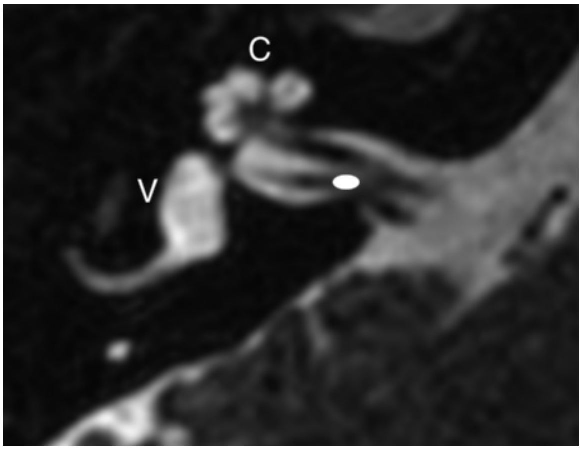


Figure 1. Axial three-dimensional (3D) T2-weighted sampling perfection with application-optimized contrasts by using different flip angle evolutions (SPACE) image shows the vestibular nerve complex. The vestibular (Scarpa) ganglion lies within the shaded oval, where neurons receive input from cochlear hair cells. This region also approximates the location of the Obersteiner-Redlich zone, the transition from the central to the peripheral nervous system. *C* = cochlea, *V* = vestibule.

for appropriate imaging are currently being developed but are not yet standardized (8). The primary goals of postsurgical imaging include monitoring for tumor recurrence; assessing the extent of residual tumor if less than total resection was performed; and looking for a variety of postoperative complications such as cerebrospinal fluid (CSF) leak, meningitis, parenchymal injury, vascular insults, and labyrinthine disruption.

A working knowledge of these surgical approaches, their indications, and their limitations can enable the radiologist to provide a more detailed and clinically relevant imaging assessment for the surgeon in both the pre- and postoperative setting.

Imaging Technique

Pre- and postoperative imaging of the IACs, labyrinth, and vestibulocochlear nerves is best achieved with high-resolution MR imaging, which can routinely be performed at 1.5 T despite greater signal-to-noise ratio and improved resolution with 3.0-T systems (9). Factors besides field strength that have a significant impact on image quality include coil selection and pulse sequences used.

We prefer to use bilateral surface coils, either alone or in combination with a volume head coil, to produce the highest signal-to-noise ratio at the level of the IACs (10). All IAC examinations should include a 3D T2-weighted acquisition with a 16-cm (or smaller) field of view and a partition size of less than 1 mm. These sequences, commonly referred to as MR cisternography or hydrography, may be gradient-echo (GRE)–based (3D phase-contrast fast imaging employing steady-state acquisition [FIESTA], 3D constructive interference into steady state [CISS] imaging) or spin-echo based (3D fast recovery fast spin-echo or 3D turbo spin-echo imaging). Both allow multiplanar reformation and provide excellent depiction of the cisternal and intracanalicular segments of the vestibulocochlear and facial nerves (11). GRE-based sequences are often degraded by susceptibility artifact, which can be reduced by acquiring at least two off-resonance volumes and creating a maximum-intensity-projection image. Most vendors offer this as an automated postprocessing feature that significantly reduces but does not eliminate susceptibility artifact, which appears as dark bands coursing through portions of the labyrinth or, less commonly, through the IAC. Spin-echo-based sequences are often degraded by the blurring artifact inherent in longer echo trains. Recent advances have led to the development of fast spin-echo techniques with a variable flip angle (3D extended echo-train acquisition, 3D SPACE) to reduce image blurring (11). This has become our preferred cisternographic technique for delineating the IAC and labyrinthine structures.

Thin-section T1-weighted imaging through the IACs performed before and after contrast material administration has also become part of most routine IAC MR imaging protocols since the development of MR imaging contrast media. Because fat grafts are often used with specific surgical techniques (discussed later), fat saturation is usually preferred for the postoperative evaluation of residual or recurrent tumor. Spin-echo T1-weighted sequences performed with a section thickness of 2–3 mm are the most common. More recently, 3D GRE-based T1-weighted sequences (volumetric interpolated breath-hold examination) have been gaining popularity for cranial nerve imaging because of the submillimeter section thickness, reformation capabilities, and diminished posterior fossa vascular pulsation artifact inherent in spin-echo techniques (Fig 2) (12).

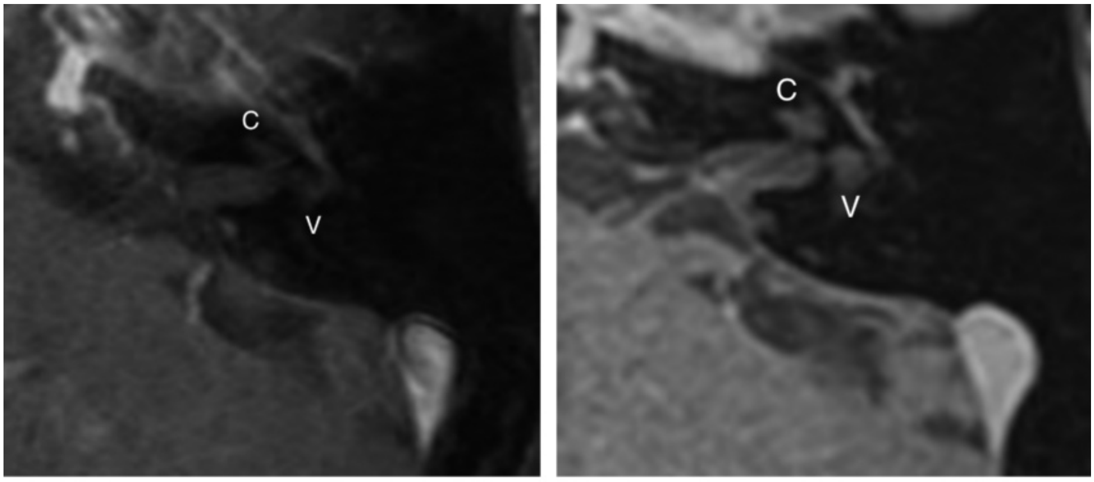


Figure 2. **(a)** Standard axial fat-suppressed T1-weighted MR image does not clearly depict the cochlea *(C)* and vestibule *(V)*. **(b)** On an axial contrast material–enhanced image (volumetric interpolated breath-hold examination), the resolution of the cochlea *(C)* and vestibule *(V)* has improved dramatically.

Surgical Techniques

MCF Approach

Teaching Point

The MCF approach is generally reserved for small tumors, which are mainly intracanalicular and have less than 1 cm of cerebellopontine angle extension, and for patients with good hearing. This is the only technique that allows complete access to the IAC without violating inner ear structures (7). However, exposure of the cerebellopontine angle cistern is limited, and tumors with a large cerebellopontine angle component cannot be easily and safely addressed with this method.

This procedure begins with a preauricular skin incision and temporal craniotomy. The middle meningeal artery may require division. The dura mater over the petrous ridge and adjacent MCF floor is dissected to allow placement of a retractor over the petrous ridge. The temporal lobe is then elevated (Fig 3). Exposure is limited due to the risk of temporal lobe injury if retraction is too aggressive. The bone around the IAC is decompressed mediolaterally from the porus acousticus up to the labyrinthine segment of the facial nerve, using anatomic landmarks such as the arcuate eminence of the superior semicircular canal, the superior petrosal sinus, and the greater superficial petrosal nerve (13). Bone drilling is performed in the extradural space to open the roof of the IAC. After the tumor has been removed, a thin fat graft or fascial graft is generally placed over the IAC dural defect and MCF floor prior to closure so as to prevent CSF leak. The graft is easily recognized at MR imaging (Fig 4).

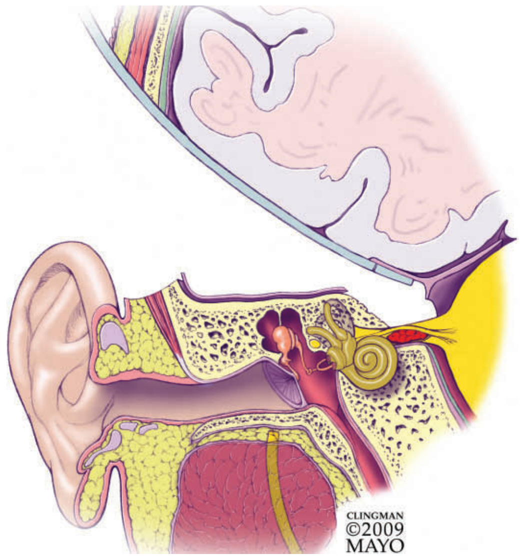
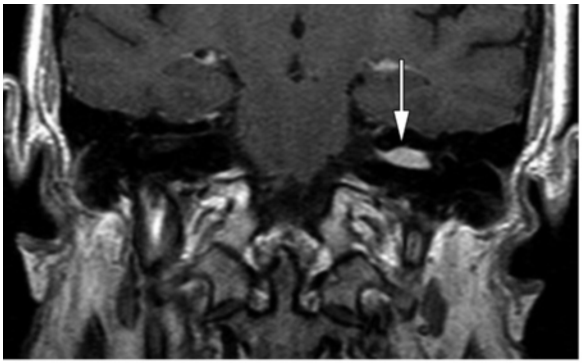
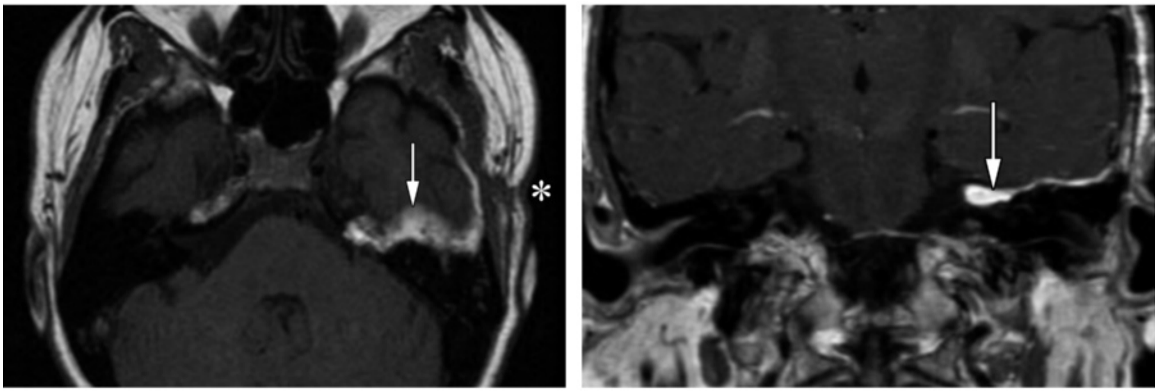


Figure 3. Drawing illustrates the MCF technique. After the dura mater is dissected off the cranial floor, the temporal lobe is retracted. The roof of the IAC is removed by drilling in a mediolateral direction in the extradural space. (Reprinted with permission from Mayo Clinic, Rochester, Minn.)

The advantages of the MCF approach include hearing preservation and superior exposure of the IAC fundus. Functional hearing rates with the MCF approach have been reported to range from 33% to 76% (8), with rates dropping as tumor size increases. Of importance to the surgeon is the lateral depth of tumor penetration in the IAC. A far lateral tumor impacting the fundus with extension above and below the transverse crest of the IAC complicates tumor removal and



a.



b. c.

Figure 4. Fat graft from an MCF approach. **(a)** Coronal contrast-enhanced T1-weighted MR image obtained prior to resection shows an intracanalicular schwannoma filling the left IAC (arrow). **(b)** Axial unenhanced T1-weighted MR image shows changes from an MCF approach, with a fat graft overlying the petrous bone (arrow) and a preauricular scar (*). **(c)** On a coronal contrast-enhanced T1-weighted MR image obtained following removal of the IAC roof, the fat graft (arrow) herniates slightly into the IAC.

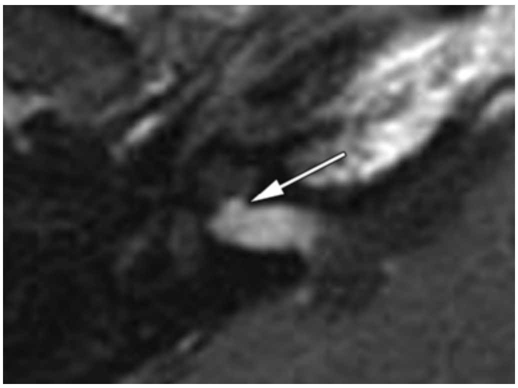


Figure 5. Tumor extending into the base of the modiolus. Axial contrast-enhanced fat-suppressed T1-weighted MR image (magnified view of the right petrous bone) shows an enhancing schwannoma at the fundus of the right IAC that extends into the base of the modiolus (arrow). Far lateral tumors complicate cochlear nerve dissection with all hearing preservation techniques—particularly the suboccipital approach, which involves limited lateral IAC exposure.

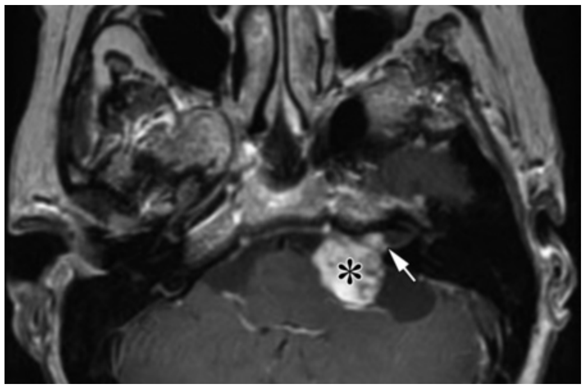
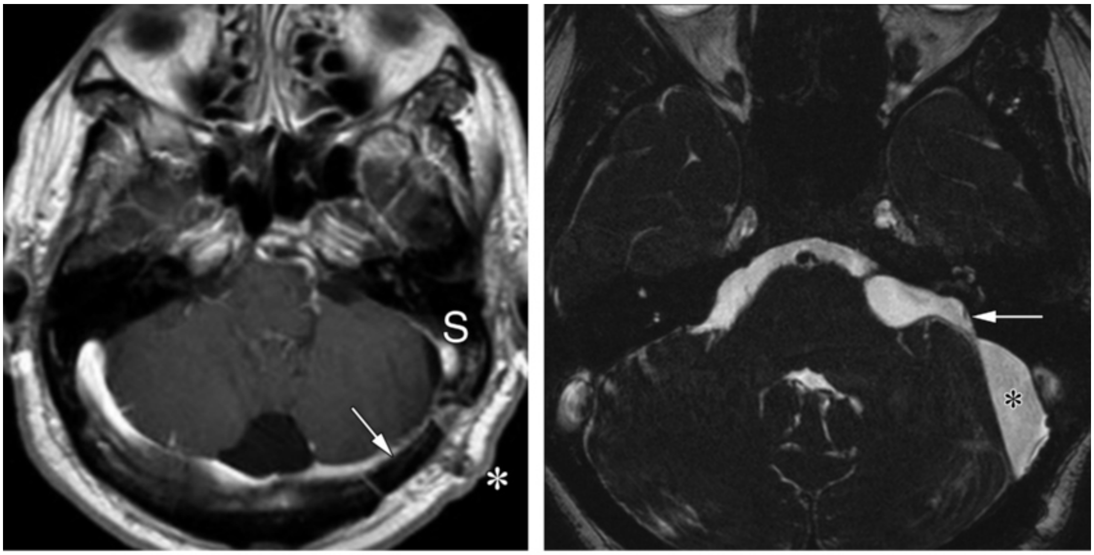


Figure 6. Tumor with a large cerebellopontine angle component. Axial contrast-enhanced fat-suppressed T1-weighted MR image shows a vestibular schwannoma that fills half the IAC (arrow) and has a large cerebellopontine angle component (*), for which the MCF approach is inadequate.

decreases the chances of hearing preservation. Tumors extending under the transverse crest and into the base of the modiolus (Fig 5) require blind dissection, increasing the risk of leaving residual tumor, and manipulation in this area puts the delicate cochlear nerve fibers as they enter the inner ear at risk for traction injury.

An important disadvantage of the MCF approach is limited cerebellopontine angle exposure, which may not be adequate for tumors with a large cerebellopontine angle component (Fig 6). The



a. b.

Figure 7. Suboccipital approach. **(a)** Axial contrast-enhanced fat-suppressed T1-weighted MR image shows suboccipital resection changes, including a craniotomy defect (arrow) behind the sigmoid sinus *(S)* and a postauricular scar (*). **(b)** Axial 3D T2-weighted SPACE image shows absence of the posterior IAC wall (arrow), which is inherent in the suboccipital technique. An extraaxial fluid collection (*) is often present and exerts a variable mass effect on the cerebellum.

frequency with which facial nerve palsy occurs is also slightly increased with this approach, particularly if the tumor arises from the inferior vestibular nerve branch (14). The facial nerve will lie unfavorably between the surgeon and the tumor in this case. Other complications include temporal lobe atrophy or gliosis and a small risk of resultant seizures. Schick et al (15) found temporal lobe gliosis in 22 of 32 patients with prior MCF resection of vestibular schwannoma but failed to find a statistically significant difference in functional outcomes with neuropsychologic testing.

Suboccipital (Retrosigmoid) Approach

Teaching Point

The suboccipital approach affords greater access to the cerebellopontine angle while maintaining the option of hearing preservation. The benefit of cerebellopontine angle exposure is countered by limited access to the lateral IAC, complicating dissection of far lateral tumors and presenting a greater challenge to the surgeon (16). Additional advantages and limitations unique to this approach are discussed later in this section.

Unlike with the MCF approach, a postauricular incision is made (Fig 7a). A bone flap over the ipsilateral cerebellar hemisphere is removed up to the edge of the transverse sinus superiorly and the sigmoid sinus anteriorly. Posterior mastoid air cells are often entered and sealed promptly with bone wax to prevent CSF leak. The dura mater is incised. The arachnoidea mater encephali is opened and CSF is allowed to drain from the cerebellopontine angle cistern. The cerebellum is then retracted (Fig 8). After removal of the intracranial portion of the tumor, the posterior wall of the IAC is removed from medial to lateral. The absence of the posterior wall is readily apparent at imaging (Fig 7b). The endolymphatic duct is often identifiable and serves as a reference point for the inner ear. In general, approximately the medial two-thirds of the IAC can be exposed before violating the inner ear, particularly the posterior semicircular canal, in contrast to the MCF approach (7,16). If hearing preservation is not a goal, bone can be removed all the way to the fundus, thereby allowing full direct visualization of the lateral IAC tumor.

The advantages of the suboccipital approach include no tumor size limitation; wide exposure of the cerebellopontine angle; the possibility of hearing preservation (achieved in 22%–58% of cases) (8); and a favorable position of the facial nerve, which is most often deep to the tumor from the surgeon's viewpoint.

The principal disadvantage of the suboccipital approach is the inability to expose the most

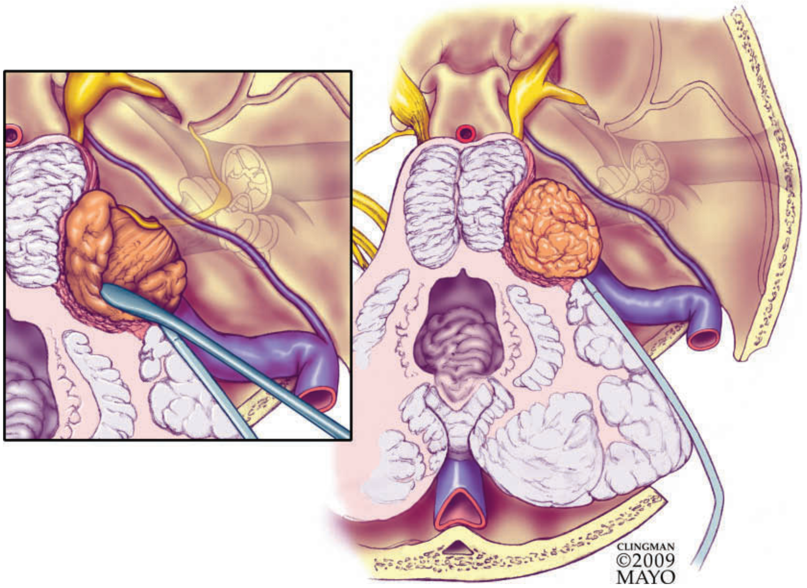


Figure 8. Drawings illustrate the suboccipital approach. Craniotomy is begun posterior to the sigmoid sinus and inferior to the transverse sinus, creating a wide view of the cerebellopontine angle. The posterior wall of the IAC is removed from medial to lateral up to the vestibular structures (left). (Reprinted with permission from Mayo Clinic, Rochester, Minn.)

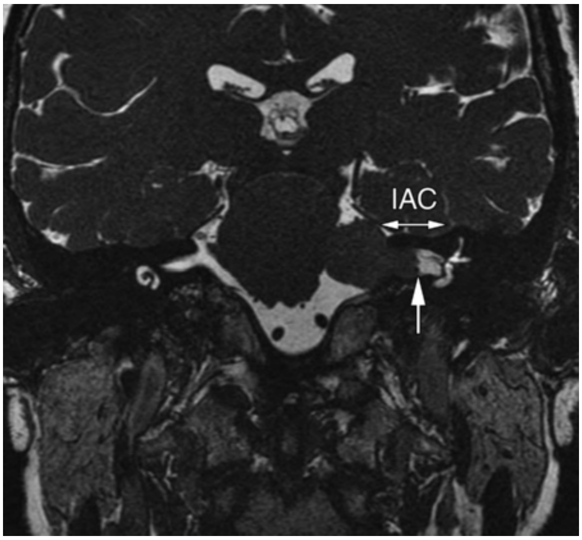


Figure 9. Schwannoma. Coronal 3D FIESTA image shows a fundal cap of CSF (single arrow) lateral to a schwannoma, which occupies one-half of the length of the left IAC (double arrow). Depth of IAC extension is essential knowledge for the surgeon, especially with a suboccipital approach. Tumors occupying more than two-thirds of the length of the IAC complicate resection because the tumor is not directly visualized and cochlear nerve dissection is more difficult.

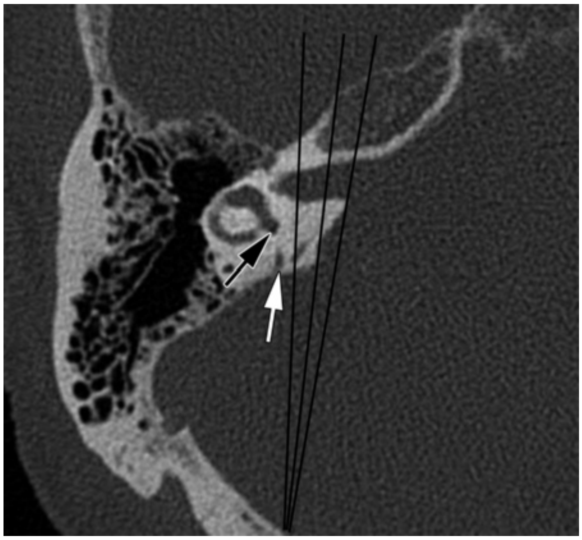


Figure 10. Axial nonenhanced CT scan (bone algorithm) shows how a line (three lines in this case for illustrative purposes) is drawn from the occipital bone 2 cm behind the sigmoid sinus to the lateral terminus of a tumor in the IAC to estimate how much of an intracanalicular tumor can be directly exposed with drilling as part of a suboccipital approach before potentially violating the endolymphatic space. Black arrow indicates the common crus; white arrow indicates the vestibular aqueduct.

lateral IAC, which increases the risk of residual tumor when a schwannoma occupies more than two-thirds of the IAC (Fig 9). Some surgeons will use angled instruments, endoscopes, and mirrors to complete tumor removal. The surgeon can estimate how much of the tumor can be directly exposed with drilling by drawing a line from the suboccipital convexity 2 cm behind the sigmoid sinus to the lateral terminus of the tumor in the IAC (Fig 10) (7). Structures that are typically at risk include the vestibule, common crus, and posterior and superior semicircular canals.

Other disadvantages include intradural bone drilling, which may increase the rate of postoperative headache, and the possibility of cerebellar atrophy from prolonged retraction (Fig 11) (7,13).

Translabyrinthine Approach

The translabyrinthine approach (Fig 12) eliminates hearing but generally results in the lowest tumor recurrence rate (17). Cerebellopontine angle exposure is adequate even for very large tumors, but an anterior sigmoid sinus or high-riding jugular bulb can make dissection of the cerebellopontine angle component more difficult compared with the suboccipital approach. Differences in retraction, resection, and wound closure unique to the translabyrinthine approach are described later and are readily apparent at MR imaging.

This approach also makes use of a postauricular incision. A complete mastoidectomy is performed, and bone over the sigmoid sinus and tegmen is skeletonized. Ossicles may or may not be removed, depending on the surgeon, to facilitate packing the middle ear to lessen the risk of CSF leak. Bone is removed from the adjacent middle and posterior fossa and from around the sigmoid sinus. The sigmoid sinus can then be retracted, unlike with a suboccipital resection. A labyrinthectomy is performed by removing the three semicircular canals and opening the vestibule after identifying the jugular bulb, which marks the inferior extent of dissection. Bone around the superior, posterior, and inferior portions of the IAC is removed, the IAC fundus lying just medial to the vestibule. After tumor removal, surgeons use a number of techniques to limit the risk of CSF leak. Some pack the middle ear with small pieces of fat, fascia, resorbable material, fibrin glue, or a combination thereof. Others may use bone wax to occlude the antrum and facial recess air cells, or may even use bone cement. Strips of abdominal fat are then cut to fill the mastoid defect. These strips often have a triangular shape at MR imaging and can undergo atrophy over time (Fig 13) (7). The fat may be compressed into the mastoid process by using titanium or resorbable mesh to reconstruct the cortex. The fat also necessitates good fat-saturation technique at contrast-enhanced MR imaging (Fig 14).

The advantages of the translabyrinthine approach include wide cerebellopontine angle exposure, extradural bone drilling (possibly limiting postoperative headache), consistent and early facial nerve identification, and relatively less cerebellar retraction. The translabyrinthine technique is also the only approach that can be used to address intralabyrinthine and intracochlear tumors (Fig 15) (7), which can be difficult to diagnose at MR imaging if they are small (18).

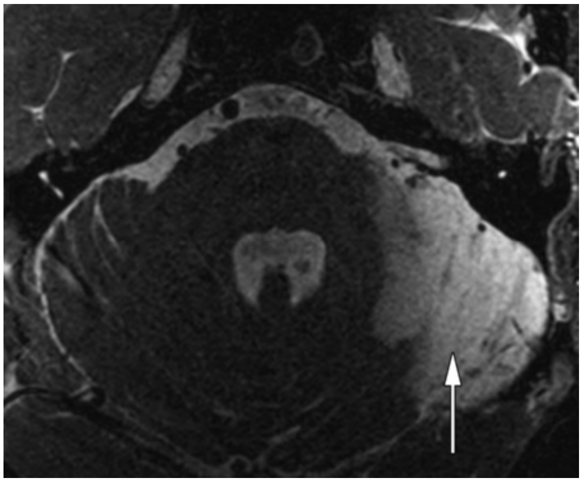


Figure 11. Cerebellar atrophy. Axial spin-echo T2-weighted MR image obtained following suboccipital resection of a schwannoma shows typical atrophy of the right cerebellar hemisphere (arrow) as a result of retraction.

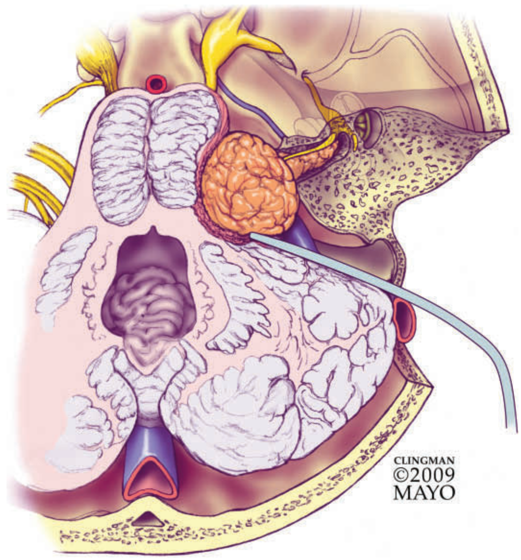
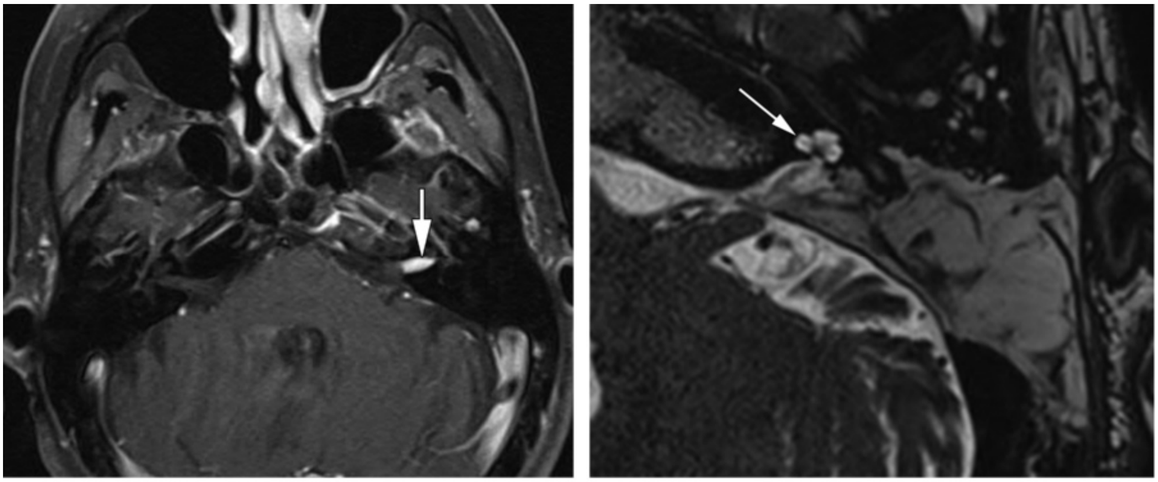
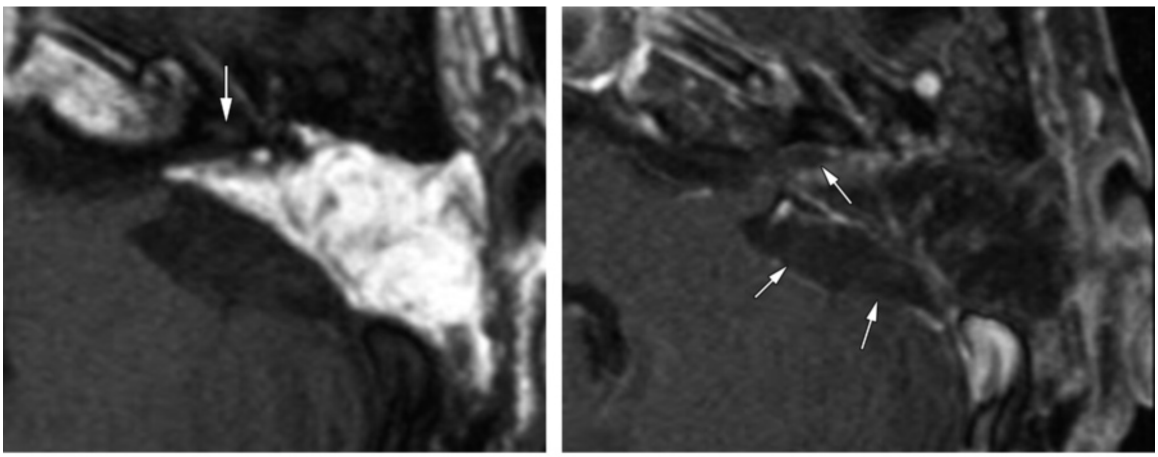


Figure 12. Drawing illustrates the translabyrinthine approach. A mastoidectomy is followed by a labyrinthectomy. The sigmoid sinus and cerebellum can be retracted to a lesser degree than with the suboccipital approach. The tumor is exposed in its entirety, and intralabyrinthine components of the tumor can also be addressed. (Reprinted with permission from Mayo Clinic, Rochester, Minn.)



a. b.

Figure 13. Translabyrinthine approach. **(a)** Axial fat-saturated T1-weighted MR image obtained prior to translabyrinthine resection shows a left intracanalicular schwannoma (arrow). A translabyrinthine approach was chosen because the patient had no useful hearing. **(b)** Axial 3D T2-weighted SPACE image obtained following left translabyrinthine resection shows the typical placement of a fat graft, which usually has a triangular shape and can undergo atrophy over time. The cochlea is intact (arrow).



a. b.

Figure 14. Translabyrinthine fat graft. **(a)** Axial nonenhanced spin-echo T1-weighted MR image shows the typical appearance of a translabyrinthine fat graft. The cochlea is intact (arrow). The inherent high T1 signal of the fat can be problematic on contrast-enhanced images. Fat-saturated images are usually needed to distinguish fat from residual tumor in patients who have undergone translabyrinthine resection. **(b)** Axial contrast-enhanced fat-saturated T1-weighted MR image of the fat graft shows faint enhancement along the graft margins (arrows), which represents a normal postoperative finding.

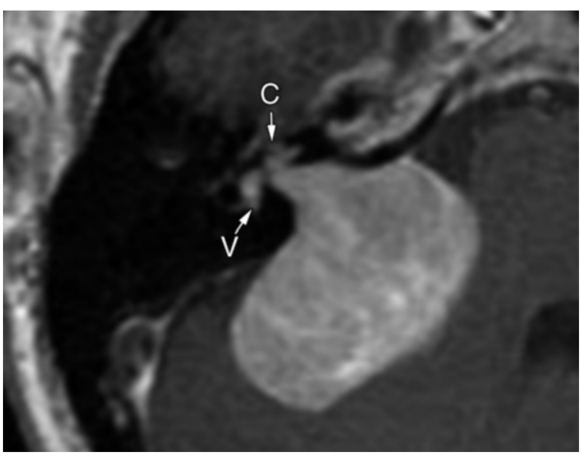


Figure 15. Vestibulocochlear schwannoma. Axial fat-saturated T1-weighted MR image shows a schwannoma that extends into the cochlea *(C)* and vestibule *(V)*. In such a case, the schwannoma can be addressed only with a translabyrinthine approach.

Postsurgical MR Imaging Findings, Advantages, and Limitations of Surgical Approaches to Vestibular Schwannomas

Approach	Postsurgical MR Imaging Findings	Advantages	Limitations
MCF	Preauricular incision, temporal craniotomy, IAC roof removed, fat or fascia graft over IAC	Hearing preservation, full IAC exposure	Poor CP angle exposure, CP angle extension ≤1cm, temporal lobe atrophy or gliosis, slightly increased prevalence of facial nerve palsy
Suboccipital	Postauricular incision, suboccipital craniotomy, posterior IAC wall removed	Hearing preservation, wide CP angle exposure, no tumor size limitation	Limited lateral IAC exposure, increased prevalence of CSF leaks, cerebellar atrophy, higher prevalence of aseptic meningitis
Translabyrinthine	Postauricular incision, complete mastoidectomy, labyrinthectomy, triangular mastoid fat graft	Wide CP angle exposure, lowest recurrence rate, addresses tumor in cochlea or labyrinth	Hearing eliminated, cerebellar atrophy, fat graft harvesting complications

Note.—CP = cerebellopontine.

The obvious downside is the destruction of any functional hearing that may be present prior to surgery. In addition, because an abdominal fat graft is used to reconstruct the surgical defects, the abdomen is susceptible to postsurgical complications such as bleeding and infection.

The MR imaging findings, advantages, and disadvantages associated with each surgical approach are summarized in the Table.

Anatomic Variants

Specific anatomic variants in the temporal bone and posterior fossa present challenges in each procedure. Communicating relevant variants to the surgeon can limit intra- and postoperative complications.

Both the suboccipital and translabyrinthine approaches include wide removal of bone around the IAC. A high-riding jugular bulb can pose difficulty for the surgeon if it encroaches on the inferior wall of the IAC (Fig 16).

Another notable anatomic variant is pneumatization of the temporal bone, particularly around the IAC (Fig 17). The surgeon must drill through this region. If these air cells are not properly occluded with bone wax, the risk of CSF leak increases.

An unusual anterior position of the sigmoid sinus also poses a challenge to dissection with the translabyrinthine approach. In addition, a perforated tympanic membrane or chronic ear disease complicates a translabyrinthine approach because middle ear and mastoid cells may become colonized with bacteria.

Surgical Complications

Early Complications

Early postoperative complications include headache, CSF leak, meningitis, facial nerve weakness, and, occasionally, vascular injury. Headaches of varying severity occur in approximately 46% of patients and resolve within 1 year in one-half of cases (19). CSF leak often manifests as otorhinorrhea and can originate from inadequate sealing of exposed mastoid or petrous air cells, poor wound closure, or hydrocephalus (Fig 18). CSF otorhinorrhea is more common with the suboccipital approach, with a prevalence of approximately 2.2% in a recent large series (20). CSF wound leak was seen in 6% of cases in the same series (Fig 19). A larger series by Falcioni et al (21) published in 2008 reported an overall CSF leak rate of 8.3%. Severe facial nerve injury is uncommon with microscopic techniques, and most tumors are now being removed by experienced

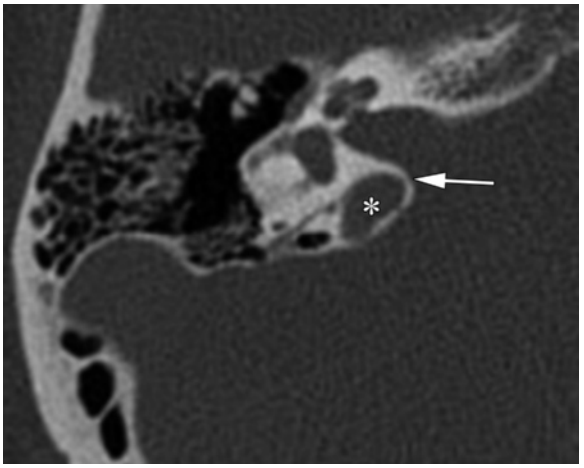


Figure 16. High-riding jugular bulb. Axial nonenhanced CT scan (bone algorithm) shows a high-riding jugular bulb (*) that lies directly adjacent to the posteroinferior wall of the IAC (arrow). A high-riding bulb complicates the drilling process and exposure, especially with a translabyrinthine approach. If necessary, the bulb can be compressed inferiorly, but not without risk of injury or thrombosis.

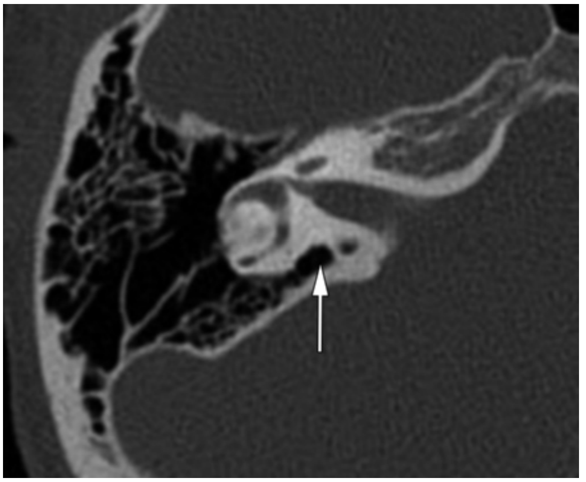


Figure 17. Pneumatization of the IAC. Axial nonenhanced CT scan (bone algorithm) shows hyperpneumatization of the posterior wall of the IAC (arrow), which increases the risk of postoperative CSF leak.

Figure 18. CSF leak. Axial nonenhanced CT scan (bone algorithm) obtained following suboccipital resection of a vestibular schwannoma shows a postoperative CSF leak. A craniotomy defect is seen traversing mastoid air cells (arrow), allowing an egress of CSF into the middle ear cavity.

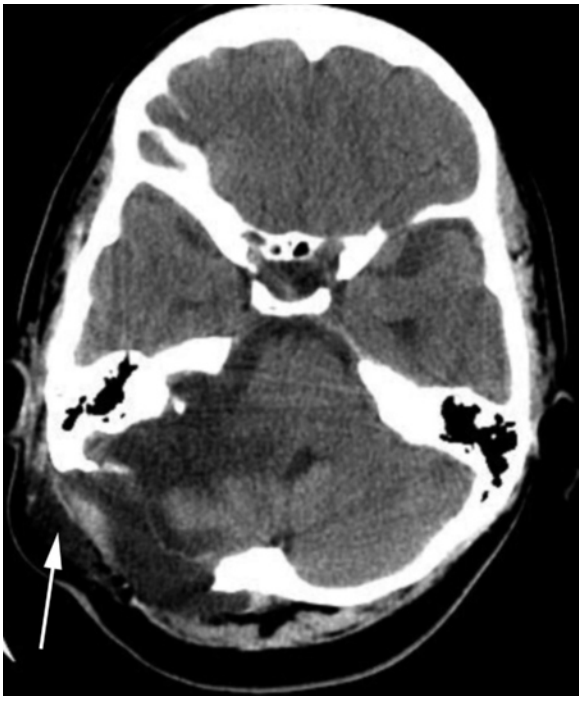


Figure 19. CSF wound leak. Axial nonenhanced CT scan shows changes from suboccipital resection, with a CSF wound leak that resulted in a pseudomeningocele (arrow).

teams of neurosurgeons and neurotologists. Transient facial nerve palsy is more common with the MCF approach as mentioned earlier. Vascular injury occurs infrequently, but the sigmoid sinus and jugular bulb can be directly compromised or may potentially thrombose after retraction, possibly with devastating consequences. It is important to assess for an intact torcula and the potential for adequate contralateral venous flow should there be injury to the sigmoid sinus or jugular bulb. In the rare case of absent flow on the contralateral side, the translabyrinthine approach would be contraindicated. Parenchymal venous injury can also occur as a result of large adherent tumors with complicated dissection (Fig 20). Arterial injuries occur rarely, with the anteroinferior cerebellar artery being most at risk.

Figure 20. Infarction following suboccipital resection of a schwannoma. Axial nonenhanced CT scan obtained following suboccipital resection of a large adherent vestibular schwannoma shows middle cerebellar peduncle infarction (arrow).

Postoperative Hearing Loss and Delayed Complications

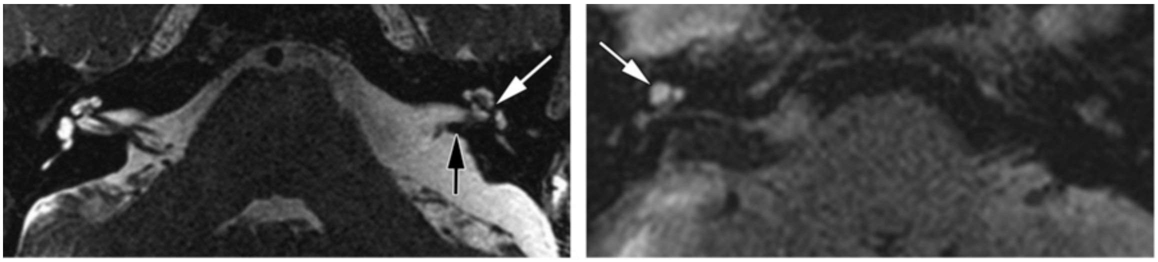
Teaching Point

A number of additional complications are possible, some of which are delayed. These complications include cerebellar or temporal lobe atrophy (as discussed earlier) and postoperative hearing loss. Hearing loss following a hearing preservation technique can result from a violation of the bone labyrinth (fenestration), microvascular injury to the cochlea, cochlear nerve damage, labyrinthitis with or without labyrinthine ossification, or tumor recurrence.

Labyrinthine fenestration is a consideration in the setting of postoperative hearing loss—particularly with a suboccipital approach, in which the semicircular canals and vestibule are difficult to identify and are at risk during drilling (22). Suspected dehiscence can be evaluated with thin-section CT. As a cautionary note, the appearance of the bone labyrinth at CT does not always correlate with hearing status, as noted by Warren et al (23), who found a lack of correlation between apparent vestibular or semicircular canal dehiscence at CT and hearing status. In their study, diminished or absent T2 fluid signal (FIESTA or CISS imaging) within the labyrinth at postoperative MR imaging (Fig 21a) more accurately reflected hearing loss than apparent defects in the bone labyrinth (23). This discrepancy is likely related to a fenestration in the bone without violation of the membranous structures. Membranous violation is thought to occur more frequently with direct suctioning of a bone fenestration (24).

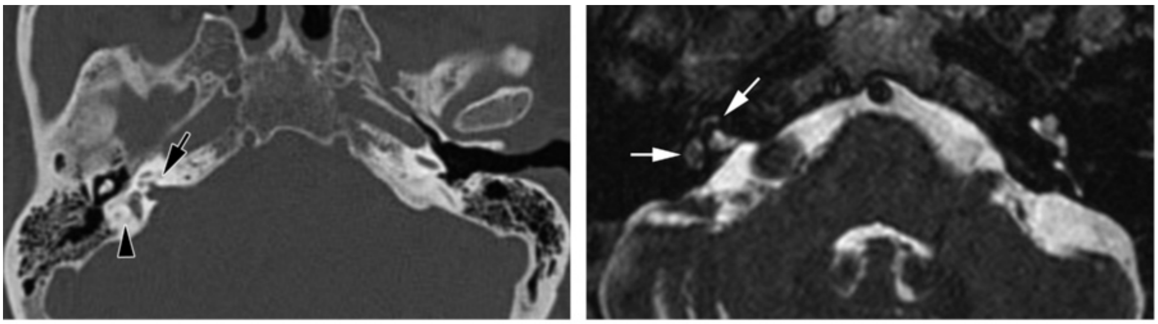
A reciprocal increase in T2 fluid-attenuated inversion recovery (FLAIR) signal after schwannoma resection can be observed in the postoperative setting as well (Fig 21b). T2-weighted FLAIR imaging tends to be more sensitive to changes in T1 and T2 relaxation times following alteration in native protein content (25), which may prove advantageous compared with standard T2-weighted or GRE techniques for detecting subtle labyrinthine signal changes.

Postoperative endolymphatic fluid signal loss may not reflect fenestration alone, however. Certainly, membranous disruption and endolymphatic leak are important considerations, but other causes include vascular injury to the cochlea, labyrinthitis, ossification (Fig 22), and, conceivably, blood products from surgery (26). Ongoing investigation and improved imaging may clarify the causes and help establish a more predictive relationship between changes in signal intensity at 3D FIESTA-CISS imaging or T2-weighted FLAIR imaging and postoperative hearing status.



a. b.

Figure 21. Alterations in endolymphatic signal. **(a)** Axial 3D T2-weighted SPACE image obtained following suboccipital resection of a schwannoma shows diminished signal intensity within the left cochlea and vestibule (white arrow) relative to the normal right side. Black arrow indicates a surgical defect in the posterior IAC wall. Loss of normal fluid signal correlates with postoperative hearing loss. **(b)** Axial 3D T2-weighted FLAIR image obtained in a different patient shows increased postoperative labyrinthine signal intensity on the right side (arrow). T2-weighted FLAIR imaging tends to be more sensitive than T2-weighted or GRE sequences for alterations in endolymphatic signal. The signal-to-noise ratio is inherently diminished, but anatomic detail is not the goal with this particular sequence.



a. b.

Figure 22. Postoperative endolymphatic fluid signal loss due to ossification. **(a)** Axial nonenhanced CT scan (bone algorithm) shows changes from suboccipital resection of a schwannoma as evidenced by an absent posterior IAC wall with subsequent development of labyrinthitis ossificans. Note the abnormal calcification in the basilar turn of the cochlea (arrow) and lateral semicircular canal (arrowhead). **(b)** Axial 3D T2-weighted SPACE image depicts the absence of fluid signal intensity in the cochlea and labyrinth (arrows) secondary to ossification.

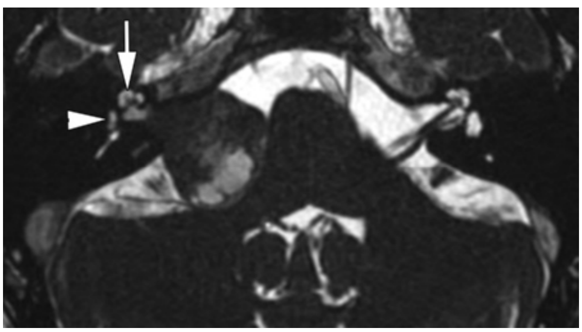


Figure 23. Diminished endolymphatic signal caused by a vestibular schwannoma. Axial 3D T2-weighted SPACE image obtained prior to resection shows a vestibular schwannoma that fills the right IAC. Endolymphatic signal intensity is diminished throughout the right cochlea (arrow) and vestibule (arrowhead) compared with the normal left side.

Careful comparison with preoperative MR imaging findings is necessary when endolymphatic signal changes are present because vestibular schwannomas can increase signal intensity at T2-weighted FLAIR imaging or decrease signal intensity at 3D FIESTA-CISS imaging in the labyrinth prior to resection (Fig 23). The proposed mechanism is an increase in endolymphatic protein content (27). The increase in protein content of the endolymphatic fluid is poorly understood, but theories include compression of the cochlear nerve with blockage of neuroaxonal transport

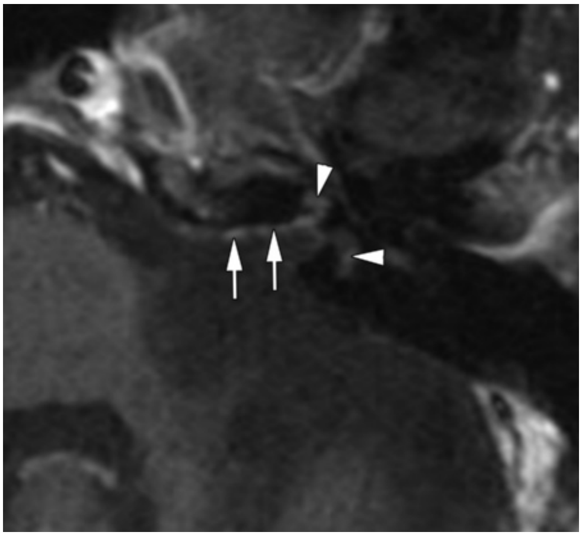


Figure 24. Linear postoperative enhancement in the IAC. Axial contrast-enhanced fat-suppressed T1-weighted MR image obtained following suboccipital resection shows linear postoperative enhancement along the remaining IAC wall (arrows). Linear enhancement is a normal finding up to 1 year following surgery. Arrowheads indicate mild enhancement in the cochlea and labyrinth, a finding that is not typically seen following surgery and may reflect the presence of inflammation, vascular injury, or labyrinthine fenestration.

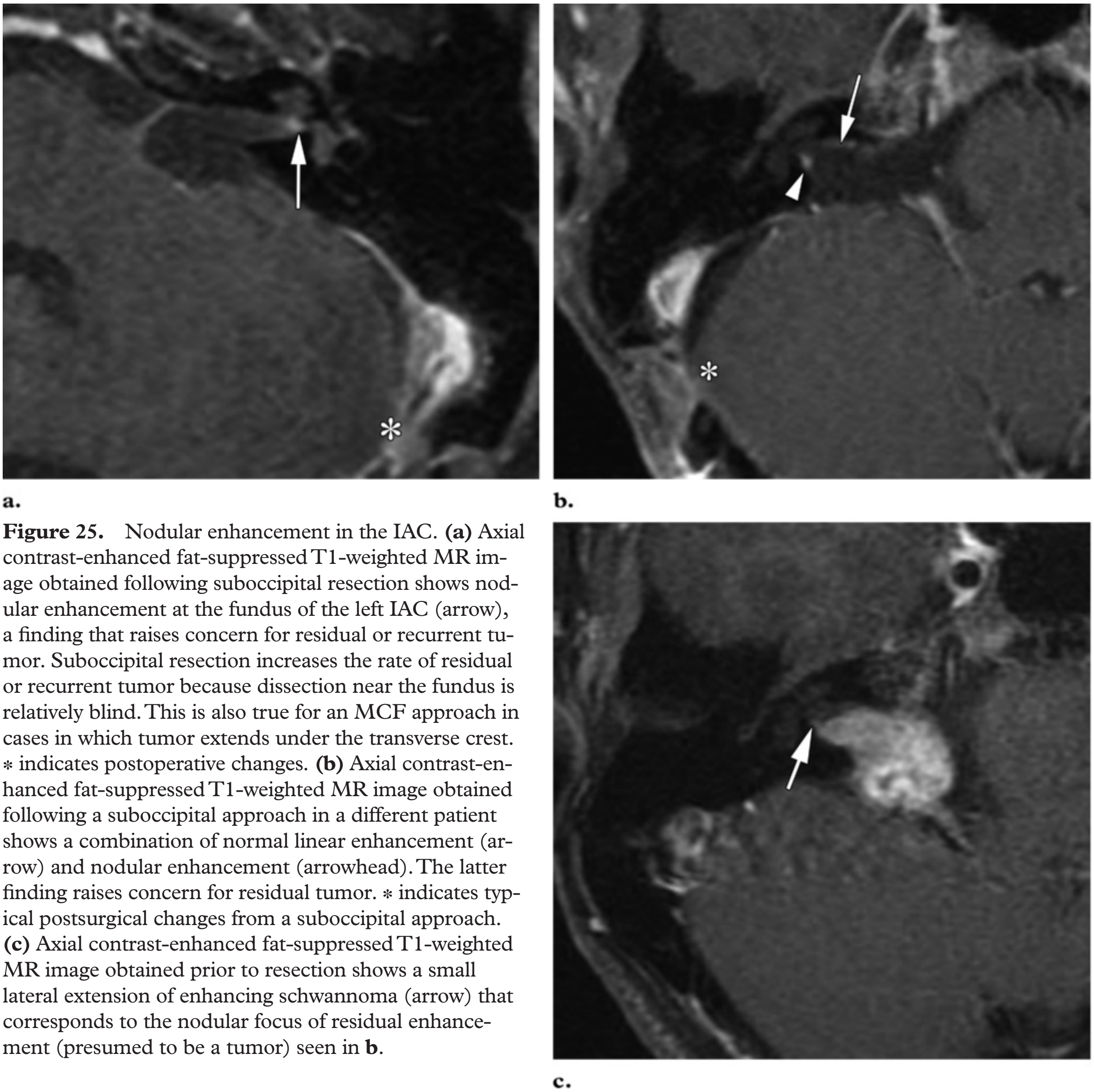


Figure 25. Nodular enhancement in the IAC. **(a)** Axial contrast-enhanced fat-suppressed T1-weighted MR image obtained following suboccipital resection shows nodular enhancement at the fundus of the left IAC (arrow), a finding that raises concern for residual or recurrent tumor. Suboccipital resection increases the rate of residual or recurrent tumor because dissection near the fundus is relatively blind. This is also true for an MCF approach in cases in which tumor extends under the transverse crest. * indicates postoperative changes. **(b)** Axial contrast-enhanced fat-suppressed T1-weighted MR image obtained following a suboccipital approach in a different patient shows a combination of normal linear enhancement (arrow) and nodular enhancement (arrowhead). The latter finding raises concern for residual tumor. * indicates typical postsurgical changes from a suboccipital approach. **(c)** Axial contrast-enhanced fat-suppressed T1-weighted MR image obtained prior to resection shows a small lateral extension of enhancing schwannoma (arrow) that corresponds to the nodular focus of residual enhancement (presumed to be a tumor) seen in **b**.

proteins, labyrinthine membrane damage from arterial stasis, and an immune reaction to the tumor (27). Venous compression is an unlikely mechanism, since venous drainage from the labyrinth more frequently occurs via the veins within the cochlear and vestibular aqueducts and much less frequently via veins in the internal auditory canal (28). Interestingly, investigators have not found a strong correlation between endolymphatic fluid signal change and preoperative hearing loss, although studies to date have been small (27).

The significance of the preoperative labyrinthine signal change, specifically as it relates to surgical outcomes in hearing preservation surgery, is also not well understood but is currently being investigated. A small series by Somers et al (28) published in 2001 found a positive correlation between normal preoperative endolymphatic fluid signal and postoperative hearing preservation. In their study, hearing was preserved in 82% of patients with normal preoperative endolymphatic fluid signal, whereas only 33% of patients with altered preoperative fluid signal retained useful hearing after resection. Further study is necessary to establish whether the observation of labyrinthine signal change might help predict outcomes in patients being considered for hearing preservation surgery.

Tumor Recurrence

The rate of tumor recurrence is generally very low, ranging from <1% to 9% (3,17,29). An increased risk of residual or recurrent tumor is seen with the suboccipital approach due to relatively blind dissection of the IAC fundus. Residual tumor is deliberately left in approximately 1%–2% of patients if dissection is complicated or vital structures such as the facial nerve are at risk for injury (22).

Postoperative imaging for recurrent or residual tumor varies among surgery practices and is debated in the literature (8). Hence, few studies have detailed the normal evolution of postoperative imaging—in particular, MR imaging.

Teaching Point

Linear postoperative enhancement in the IAC (Fig 24) is nearly universal for the first 6 months following resection but normally can be seen up to 1 year (or more) after the procedure (26,29,30). Nodular enhancement in the IAC (Fig 25) is the most likely indicator of recurrent tumor and should prompt shorter intervals between follow-up examinations (26,30). Enhancement in the cochlea or vestibule (Fig 24) is uncommon after suboccipital or MCF resection and may be indicative of postoperative labyrinthitis, vascular insult, or labyrinthine fenestration.

Conclusions

MR imaging of the inner ear for evaluation of vestibular schwannoma continues to evolve along with surgical therapies. A working knowledge of the main surgical approaches—MCF, suboccipital, and translabyrinthine, each of which has unique advantages and disadvantages—is vital, particularly when hearing preservation is a consideration, and will allow the radiologist to provide the surgeon with a more accurate imaging interpretation in both the pre- and postoperative setting.

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Surgical Approaches to Vestibular Schwannomas: What the Radiologist Needs to Know

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Page 1956
Schwannomas most often involve the inferior division (91.4% of cases) and, to a lesser extent, the superior division (6%) of the vestibular branch of cranial nerve VIII, often near the Obersteiner-Redlich zone, which marks the transition from glial cells to Schwann cells and from the central to the peripheral nervous system.

Page 1958
The MCF approach is generally reserved for small tumors, which are mainly intracanalicular and have less than 1 cm of cerebellopontine angle extension, and for patients with good hearing. This is the only technique that allows complete access to the IAC without violating inner ear structures.

Page 1960
The suboccipital approach affords greater access to the cerebellopontine angle while maintaining the option of hearing preservation. The benefit of cerebellopontine angle exposure is countered by limited access to the lateral IAC, complicating dissection of far lateral tumors and presenting a greater challenge to the surgeon.

Page 1966
A number of additional complications are possible, some of which are delayed. These complications include cerebellar or temporal lobe atrophy (as discussed earlier) and postoperative hearing loss. Hearing loss following a hearing preservation technique can result from a violation of the bone labyrinth (fenestration), microvascular injury to the cochlea, cochlear nerve damage, labyrinthitis with or without labyrinthine ossification, or tumor recurrence.

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