Surgery for vestibular schwannomas: a systematic review of complications by approach

SHAHERYAR F. ANSARI, M.D.,¹ COLIN TERRY, M.S.,² AND AARON A. COHEN-GADOL, M.D., M.S.C.¹

¹Goodman Campbell Brain and Spine, Indiana University Department of Neurological Surgery; and ²Methodist Research Institute, Indiana University Health, Indianapolis, Indiana

Object. Various studies report outcomes of vestibular schwannoma (VS) surgery, but few studies have compared outcomes across the various approaches. The authors conducted a systematic review of the available data on VS surgery, comparing the different approaches and their associated complications.

Methods. MEDLINE searches were conducted to collect studies that reported information on patients undergoing VS surgery. The authors set inclusion criteria for such studies, including the availability of follow-up data for at least 3 months, inclusion of preoperative and postoperative audiometric data, intraoperative monitoring, and reporting of results using established and standardized metrics. Data were collected on hearing loss, facial nerve dysfunction, persistent postoperative headache, CSF leak, operative mortality, residual tumor, tumor recurrence, cranial nerve (CN) dysfunction involving nerves other than CN VII or VIII, and other neurological complications. The authors reviewed data from 35 studies pertaining to 5064 patients who had undergone VS surgery.

Results. The analyses for hearing loss and facial nerve dysfunction were stratified into the following tumor categories: intracanalicular (IC), size (extrameatal diameter) < 1.5 cm, size 1.5–3.0 cm, and size > 3.0 cm. The middle cranial fossa approach was found to be superior to the retrosigmoid approach for hearing preservation in patients with tumors < 1.5 cm (hearing loss in 43.6% vs 64.3%, p < 0.001). All other size categories showed no significant difference between middle cranial fossa and retrosigmoid approaches with respect to hearing loss. The retrosigmoid approach was associated with significantly less facial nerve dysfunction in patients with IC tumors than the middle cranial fossa method was; however, neither differed significantly from the translabyrinthine corridor (4%, 16.7%, 0%, respectively, p < 0.001). The middle cranial fossa approach differed significantly from the translabyrinthine approach for patients with tumors < 1.5 cm, whereas neither differed from the retrosigmoid approach (3.3%, 11.5%, and 7.2%, respectively, p = 0.001). The retrosigmoid approach involved less facial nerve dysfunction than the middle cranial fossa or translabyrinthine approaches for tumors 1.5–3.0 cm (6.1%, 17.3%, and 15.8%, respectively; p < 0.001). The retrosigmoid approach was also superior to the translabyrinthine approach for tumors > 3.0 cm (30.2% vs 42.5%, respectively, p < 0.001). Postoperative headache was significantly more likely after the retrosigmoid approach than after the translabyrinthine approach, but neither differed significantly from the middle cranial fossa approach (17.3%, 0%, and 8%, respectively; p < 0.001). The incidence of CSF leak was significantly greater after the retrosigmoid approach than after the translabyrinthine approach, but neither differed significantly from the translabyrinthine corridor (4%, 5.3%, 7.1%; p = 0.001). The incidences of residual tumor, mortality, major non-CN complications, residual tumor, tumor recurrence, and dysfunction of other cranial nerves were not significantly different across the approaches.

Conclusions. The middle cranial fossa approach seems safest for hearing preservation in patients with smaller tumors. Based on the data, the retrosigmoid approach seems to be the most versatile corridor for facial nerve preservation for most tumor sizes, but it is associated with a higher risk of postoperative pain and CSF fistula. The translabyrinthine approach is associated with complete hearing loss but may be useful for patients with large tumors and poor preoperative hearing.

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Key Words • vestibular schwannoma • neurosurgical procedure • complication • facial nerve weakness • hearing loss

The first operation for VS removal was performed by Sir Charles Ballance in 1894. At the time, intracranial operations carried mortality rates as high as 84%,¹⁴ so when Harvey Cushing wrote his 1917 monograph on tumors of the acoustic nerve, he advocated a subtotal resection to decrease mortality and morbidity.¹⁴,²¹ Over the ensuing years, the goal of VS surgery evolved from preservation of life to preservation of facial function,²⁷ and now to conservation of hearing.³⁹,⁶¹ In modern studies, mortality rates as low as 0.4% have been documented,¹⁶ with rates of anatomical preservation of the facial nerve approaching 100%.⁴³,¹⁴,⁴⁸,⁵⁷,⁷⁶ Moving forward, the primary goal in VS therapy will likely become early detection and complete removal or near-complete removal in combination with radiosurgery, with optimal preservation of hearing and facial nerve function when possible.³⁷,⁵⁵,⁹⁷ Currently, there are 3 options for managing cases of...
Three different approaches are generally considered when planning VS surgery, and opinions abound about when to use a particular approach. To this end, some criteria have been consistently established in the literature, and factors for consideration have been named: tumor size, patient age and overall health status, anatomy of the vestibule and CPA, involvement of the brainstem and facial nerve, and extent of involvement of the IAC. One group suggested the surgeon’s comfort as one of the main determinants of this choice.45 Anderson et al.2 suggested a combined trans labyrinthine and retrosigmoid approach for very large tumors (diameter > 3 cm), as this allows better proximal and distal identification of the facial nerve. Each approach has associated advantages and disadvantages.

The middle cranial fossa approach offers some of the highest historical hearing preservation rates, but it places the facial nerve between the surgeon and the tumor (which results in the need for blind dissection in some cases), and it places some degree of retraction on the temporal lobe (which entails a risk of postoperative seizures and speech disturbances), while providing a limited view of the CPA.47 Satar et al.81 believe that facial nerve dysfunction following the middle cranial fossa approach is transient and that the long-term outcome is the same as with the other approaches. This approach may be poorly tolerated by the elderly, as extradural dissection of the adherent dura may be difficult.55 The middle cranial fossa corridor is suggested for younger patients with smaller tumors in the IAC with less involvement of the CPA, specifically the tumors that involve the fundus of the IAC, a location to which access and visualization are restricted during the retrosigmoid approach. This route is also indicated for patients with useful preoperative hearing (although the definition of “useful” is still open to debate).25,80,93

The retrosigmoid approach is well known to neurosurgeons and allows a panoramic visualization of the CPA. Opponents of this approach quote cerebellar retraction as a risk for postoperative ataxia and maintain that this approach carries a higher incidence of postoperative headache. The retrosigmoid corridor may also provide a limited visualization of the fundus of the IAC, which may necessitate blind dissection to remove the entire tumor.43 The retrosigmoid approach is a versatile route for tumors of any size regardless of the preoperative hearing status.24

The translabyrinthine approach precludes the possibility of hearing preservation but allows removal of a tumor of almost any size, with early identification of the facial nerve, and some argue that the translabyrinthine approach permits good preservation of all CNs. It also provides very good visualization of the lateral IAC and fundus, whereas the exposure of these in the retrosigmoid approach is limited due to the risk of damaging the vestibule and cochlea; therefore the translabyrinthine approach may allow for a more complete removal of tumor from these areas. Indications for the translabyrinthine approach include larger tumors and the preoperative lack of serviceable hearing.

Because no single study to date includes a large enough number of patients, and a randomized trial would not be feasible to compare the value of different operative approaches, we attempted to conduct a systematic review of the available outcome data.

Methods

Inclusion Criteria

We defined inclusion criteria for the studies included in this review to ensure a relatively homogeneous patient population while maintaining the largest possible group size. To be included in the final analysis, studies had to fit the following criteria: the authors must have included follow-up data of at least 3 months, provided preoperative and postoperative audiometric data, used intraoperative monitoring for facial and cochlear nerves, and reported facial nerve results using the House-Brackmann scale.46 In addition, we required reporting on hearing preservation using the AAO-HNS Committee on Hearing and Equilibrium classification (or its equivalent) — studies providing raw audiometric data were also included, as were studies using the Gardner-Robertson classification.44 Studies that included patients who underwent repeat operations, radiosurgery, or endoscopic surgery were excluded.

Normal facial nerve function was defined as House-Brackmann Grade I or II. Hearing loss was defined as any AAO-HNS classification below B, a pure-tone audiometry score of more than 50 dB, or a speech discrimination score of less than 50%.44

Literature Search

A literature search was conducted using PubMed and the search terms “acoustic neuroma surgery,” “acoustic neuroma outcomes,” “acoustic neuroma approach,” “vestibular schwannoma surgery,” “vestibular schwannoma approach,” and “vestibular schwannoma outcomes.” This yielded approximately 6800 articles, which were then screened by title and abstract. The initial screening process selected 180 articles, which were again screened for relevance to the inquiry and usable data. Eighty articles were found to offer data helpful to the analysis. Of these, 45 were excluded for reasons including inadequate follow-up and data not reported in standard metrics, as well as the other exclusion criteria mentioned above. Bibliographies of certain articles were also searched for further studies. The final quantitative analysis included 35
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articles. See Fig. 1 for a flowchart outlining this selection process.

The search included studies published during January 1992 through December 2010 to allow for review of the cases in which modern microsurgical techniques, including intraoperative CN monitoring, had been used. Finally, this review included data on 5064 patients who underwent VS surgery and who were included in the above-mentioned studies.

Review

Data were summarized across all studies using counts (percentages). Comparisons across groups were performed using Fisher exact tests. Pairwise comparisons between treatment methods were also performed using Fisher exact tests with significance levels adjusted using the Bonferroni correction. Pairwise comparisons were considered significant only if the p value was less than 0.017. Statistical tests were performed using R for Windows (version 2.10.1).

Initially, comparisons were made across all 3 approaches. When significant differences were detected, pairwise comparisons were performed, as needed, to test for differences among individual groups. Pairwise comparisons are noted in Table 1 with superscript letters “a” and “b.” Two cells that contain the same superscript letter are not significantly different. Conversely, 2 cells with different superscript letters are significantly different. Data for facial nerve dysfunction and hearing loss were stratified based on tumor size because tumor size has been shown to be the most important predictive factor for outcome related to these variables.17,28,42,64,66,77 Tumors were stratified as entirely IC (no extrameatal extension) or based on their extrameatal diameter (< 1.5 cm, 1.5–3.0 cm, or > 3.0 cm into the CPA).

Results

Hearing Loss

Table 1 summarizes the results for different clinical variables based on surgical approach. For patients harboring tumors less than 1.5 cm in diameter, the proportion of patients experiencing hearing loss was significantly lower among those who underwent surgery via a middle cranial fossa approach than those who were treated via the retrosigmoid route (43.6% vs 64.3%; p < 0.001). Among patients with tumors 1.5–3.0 cm in diameter, 82.7% of those treated with a middle cranial fossa approach experienced hearing loss, whereas 71.6% of those treated with a retrosigmoid approach suffered from this complication (p = 0.051). Finally, among the patients with intracanalicular tumors, 40.6% and 44.3% of the patients who underwent middle cranial fossa and retrosigmoid surgery, respectively, experienced hearing loss (p = 0.492).

Facial Nerve Dysfunction

Considered to be the most important complication of VS surgery,2,10,18,47 facial nerve dysfunction was defined as House-Brackmann Grade III or higher at last follow-up. In the group of patients with tumors less than 1.5 cm in diameter, 3.3% of those treated with a middle cranial fossa approach, 7.2% of those treated with a retrosigmoid approach, and 11.5% of those treated with a translabyrinthine approach suffered facial nerve dysfunction postoperatively (p = 0.001). The middle cranial fossa approach was associated with significantly lower rates of facial nerve dysfunction than the translabyrinthine approach; there was no significant difference between the retrosigmoid approach and either of the other 2 approaches with respect to rates of facial nerve dysfunction.

Among patients with 1.5- to 3.0-cm tumors, 17.3% of those treated with a middle cranial fossa approach, 6.1% of those treated with a retrosigmoid approach, and 15.8% of those treated with a translabyrinthine approach had facial nerve dysfunction (p < 0.001). In this analysis, the retrosigmoid approach was associated with significantly less facial nerve dysfunction than either the middle cranial fossa or translabyrinthine approach. Among patients with tumors larger than 3.0 cm in diameter, 30.2% of those treated with a retrosigmoid approach and 42.5% of those treated with a translabyrinthine approach had facial nerve dysfunction (p < 0.001), and, expectedly, insufficient data were available on the patients in this tumor size group undergoing middle cranial fossa surgery. Among patients with intracanalicular tumors, 16.7% of those treated with a middle cranial fossa approach, 4.0% of those treated with a retrosigmoid approach, and 0% of those treated with a translabyrinthine approach suffered facial nerve dysfunction (p < 0.001).

Fig. 1. Flow diagram outlining the search and screening method used in this study.
Cerebrospinal Fluid Leak

Among patients treated with the middle cranial fossa approach, 5.3% experienced a CSF leak, whereas 10.3% of patients undergoing retrosigmoid surgery and 7.1% of those undergoing translabyrinthine surgery suffered from this complication (p = 0.001). Pairwise comparisons indicated that the middle cranial fossa and translabyrinthine approaches were associated with significantly lower rates of CSF leak than the retrosigmoid approach.

Postoperative Headache

Postoperative headache was found to be most prevalent among patients undergoing retrosigmoid surgery (17.3%), with significantly fewer patients undergoing translabyrinthine surgery reported to experience this complication (0%). Notably, the middle cranial fossa approach did not differ significantly from either of the other 2 groups in this regard (8.0%), but the retrosigmoid approach was associated with a significantly higher incidence of postoperative headache (p < 0.001). This analysis was likely skewed due to the lack of reporting in the translabyrinthine category. The trend in the data seems to indicate that the incidence of postoperative headache is higher with the retrosigmoid approach than with the middle cranial fossa approach.

Mortality

There was no significant difference detected in mortality rates across the 3 groups. The reported operative mortality rates were 0%, 0.3%, and 1.3% for middle cranial fossa, retrosigmoid, and translabyrinthine approaches, respectively (p = 0.346).

Major Neurological Complications

Major neurological complications included strokes (arterial and venous), seizure disorder, and persistent cerebellar dysfunction. Among patients undergoing middle cranial fossa surgery, the rate of major neurological complication was 2.4%, whereas it was 1.8% among those treated with a retrosigmoid approach and 2.6% among those treated with a translabyrinthine approach (p = 0.513).

Residual Tumor

Residual tumor was defined as any tumor visible on MRI after surgery. Cases in which subtotal resections had been planned were excluded from this analysis. Among the patients treated with a middle cranial fossa approach, 2.6% harbored residual tumor, whereas 6.0% of the those treated with a retrosigmoid approach and 5.6% of those treated with a translabyrinthine approach had some residual tumor. There was no significant difference across the 3 groups with regard to residual tumor (p = 0.107).

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TABLE 1: Results of systematic review of complications per approach*

<table>
<thead>
<tr>
<th>Variable</th>
<th>MCF</th>
<th>RS</th>
<th>TL</th>
<th>p Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>hearing loss</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>tumor size &lt;1.5 cm</td>
<td>72/165 (43.6)</td>
<td>137/213 (64.3)</td>
<td>NA</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>tumor size 1.5 cm–3.0 cm</td>
<td>62/75 (82.7)</td>
<td>214/299 (71.6)</td>
<td>NA</td>
<td>0.051</td>
</tr>
<tr>
<td>tumor size &gt;3.0 cm</td>
<td>NA</td>
<td>9/127 (7.1)</td>
<td>NA</td>
<td></td>
</tr>
<tr>
<td>intracanalicular tumors</td>
<td>95/234 (40.6)</td>
<td>86/194 (44.3)</td>
<td>NA</td>
<td>0.492</td>
</tr>
<tr>
<td>CN VII dysfunction</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>tumor size &lt;1.5 cm</td>
<td>8/240 (3.3)</td>
<td>20/279 (7.2)</td>
<td>38/331 (11.5)</td>
<td>0.001</td>
</tr>
<tr>
<td>tumor size 1.5 cm–3.0 cm</td>
<td>9/52 (17.3)</td>
<td>28/456 (6.1)</td>
<td>65/412 (15.8)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>tumor size &gt;3.0 cm</td>
<td>NA</td>
<td>134/444 (30.2)</td>
<td>144/339 (42.5)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>intracanalicular tumors</td>
<td>41/245 (16.7)</td>
<td>8/200 (4.0)</td>
<td>0/11 (0.0)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>CSF leak</td>
<td>23/436 (5.3)</td>
<td>110/1067 (10.3)</td>
<td>116/1623 (7.1)</td>
<td>0.001</td>
</tr>
<tr>
<td>post-op headache</td>
<td>4/50 (8.0)</td>
<td>127/732 (17.3)</td>
<td>0/40 (0.0)</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>mortality</td>
<td>0/42 (0.0)</td>
<td>2/772 (0.3)</td>
<td>1/75 (1.3)</td>
<td>0.346</td>
</tr>
<tr>
<td>major neural compl</td>
<td>1/42 (2.4)</td>
<td>12/655 (1.8)</td>
<td>13/500 (2.6)</td>
<td>0.513</td>
</tr>
<tr>
<td>residual tumor</td>
<td>6/231 (2.6)</td>
<td>44/735 (6.0)</td>
<td>48/857 (5.6)</td>
<td>0.107</td>
</tr>
<tr>
<td>other CN dysfunction</td>
<td>0/35 (0.0)</td>
<td>17/607 (2.8)</td>
<td>2/167 (1.2)</td>
<td>0.457</td>
</tr>
<tr>
<td>recurrence</td>
<td>1/91 (1.1)</td>
<td>31/501 (6.2)</td>
<td>NA</td>
<td>0.045</td>
</tr>
</tbody>
</table>

* Values represent numbers of patients (%). Data were summarized across all studies using counts (%). Tumor size refers to extrameatal diameter (extension into the CPA). Comparisons across groups were performed using Fisher exact tests. Pairwise comparisons between treatment methods were also performed using Fisher exact tests with significance levels adjusted using the Bonferroni correction. Pairwise comparisons were considered significant only if p < 0.017. Statistical tests were performed using R (version 2.10.1). Abbreviations: compl = complications; MCF = middle cranial fossa; NA = data not available; neurol = neurological; RS = retrosigmoid; TL = translabyrinthine.

Pairwise comparisons are notated by superscript letters (a and b). Two cells that contain the same letter are not significantly different. Conversely, 2 cells with different letters are significantly different.
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Tumor Recurrence

Based on the investigators’ reports, tumor recurrence was diagnosed in 1.1% of patients treated with a middle cranial fossa approach and 6.2% of those treated with a retrosigmoid approach. Insufficient data were available to analyze this variable among patients treated with a translabyrinthine approach. The difference between the retrosigmoid and middle cranial fossa groups approached significance (p = 0.045).

Follow-Up Duration

We found 33 studies with information regarding the duration of follow-up as well as facial nerve function. The mean duration of follow-up was 23 months.

Discussion

Hearing Preservation

Our review suggests that the middle cranial fossa approach is preferable for hearing preservation in patients with smaller tumors (< 1.5 cm extension into the CPA). However, for tumors extending 1.5–3.0 cm into the CPA, the retrosigmoid approach may actually provide better rates of hearing preservation than the middle cranial fossa route. The middle cranial fossa approach provides a limited window into the posterior fossa, and the potentially blind dissection necessitated by the presence of the facial nerve in the surgeon’s field of view may limit the resection of larger tumors and allow damage to the cochlear portion of CN VIII and its vasculature during resection.15 The retrosigmoid approach, on the other hand, provides a more panoramic view of the portion of the tumor in the CPA cistern and its relationship to the surrounding cerebrovascular structures.

The practice of offering patients early surgery upon diagnosis of a small tumor as a method to preserve hearing has been controversial in VS surgery. 6,30,32,50,51,56,62,77,78,86,92 Glasscock and others submitted that no patient should be excluded from surgery based on tumor size alone.7,36,55,97 Several groups have supported this position, declaring that aggressive tumor removal as early as possible provides the greatest chance of hearing preservation.41,50,76,77 Consistent with previous studies,17,26,42,66,77 our analysis indicates improved hearing preservation with smaller tumors.

Facial Nerve Function

The best indicator of quality of life following VS surgery is facial nerve function.2,8,10,44 Delayed facial nerve dysfunction has been documented in many reports,2,8,11,53 potentially related to delayed ischemia, edema,2,55 or viral reactivation (Bell’s palsy).11 The timing for reanimation of the facial nerve if it is severed or damaged during surgery remains controversial.2,11 However, it is known that reconstruction of a facial nerve, no matter what method is employed, is not likely to have an excellent outcome (House-Brackmann Grade I or II).15,75

Frequently cited predictors of facial nerve function include tumor size, surgical approach, and the use of intraoperative monitoring.15,52,40,64,75 The length of contact of the tumor with the nerve has also been suggested as a potential prognostic factor.15 Samii et al.24 believe that prior surgery or radiosurgery and the presence of an intratumoral cyst are negative predictors of postoperative facial nerve function. Facial nerve function may be best preserved through the retrosigmoid corridor, according to current data.15

Our analysis points out that for tumors smaller than 1.5 cm in diameter, the middle cranial fossa approach provides better facial nerve preservation than does the translabyrinthine approach. However, the middle cranial fossa and retrosigmoid approaches do not seem to differ significantly with regard to facial nerve preservation in patients with tumors in this size category. On the other hand, for larger tumors (1.5–3.0 cm), the retrosigmoid approach provides a clear advantage. During the middle cranial fossa approach for larger tumors, the facial nerve is often located between the surgeon and the tumor; this topography places the facial nerve at a greater risk for damage.81 The retrosigmoid approach also seems to provide better outcomes for patients with intracanalicular lesions. (It should be noted, however, that the 0% incidence of facial nerve dysfunction with the translabyrinthine approach should be interpreted with caution, as it is based on a very small number of patients from a single study).60

The middle cranial fossa approach has been suggested as the approach of choice for intracanalicular tumors and for hearing preservation.41,50,52,90 The increased incidence of facial nerve dysfunction associated with this approach, as demonstrated by our analysis, has also been previously mentioned in the literature.59,81 The higher incidence of facial nerve dysfunction for all patients with tumors larger than 3.0 cm is likely related to the effect of tumor size.17,26,42,65,66,77 In summary, our analysis demonstrates the clear benefit of the retrosigmoid approach specifically for facial function among patients with tumors that are intracanalicular and 1.5–3.0 cm in size, with no difference in benefit between the middle cranial fossa and retrosigmoid approaches for patients with extrameatal tumor diameters less than 1.5 cm. For most tumor sizes, the translabyrinthine approach seems to be associated with a higher rate of facial nerve dysfunction. Our close examination of the studies that contributed patients to our review for the translabyrinthine approach (specifically, patients with tumors > 3 cm in diameter) revealed that at least half of the patients harbored tumors larger than 4 cm, which may account for the higher incidence of facial dysfunction in this group.

Postoperative CSF Leakage

The risk of CSF fistula formation has been considered higher for retrosigmoid surgeries due to the difficulty encountered with a watertight dural closure.19,75 Tumor size is not correlated with the risk of CSF fistula.99 Although larger tumors approached through the translabyrinthine route may be associated with a higher CSF leak rate.58,75 This could also be related to the approach itself, as meticulous dural closure is difficult, if not impossible, with this technique. The present analysis confirms the belief that the retrosigmoid approach may result in a greater risk of CSF leakage than the middle cranial fossa and translabyrinthine approaches, which we did not find to
differ significantly from each other in this respect. The confounding factor in this analysis is the different ways surgeons handle their closures to prevent a CSF leak. The retrosigmoid approach, which often violates the mastoid air cells during the craniectomy or craniotomy, may indeed place the patient at a higher risk of CSF leak.

**Postoperative Headaches**

Several causes have been suggested for the persistent postoperative headaches that seem to plague patients undergoing retrosigmoid surgery. Among these are chemical irritation from the bone dust created by drilling the IAC, and fibrous adhesions formed between the dura mater and suboccipital muscles. Cranioplasty to seal the bony defect can significantly reduce the incidence of postoperative headaches. Ruckenstein et al. pointed out that although cranioplasty reduces the incidence of headache in the long term, it does not significantly reduce the incidence of headache (compared with the incidence associated with the translabyrinthine approach) in the immediate postoperative period (within 1 year of surgery). Our analysis confirms a significantly higher rate of postoperative period (within 1 year of surgery).

Although no statistically significant difference was detected between the retrosigmoid and middle cranial fossa approaches with regard to postoperative headache, the raw data suggest that a difference may indeed exist (4 of 50 patients treated with a middle cranial fossa approach vs 127 of 732 treated with a retrosigmoid approach suffered from headache). The translabyrinthine approach seems to be associated with a small risk of postoperative headaches (0% in this analysis). However, this point should be considered carefully, as the data regarding this variable were reported only for a group of 40 patients, all in a single study.

**Residual Tumor**

Indications for subtotal resection include preservation of facial nerve integrity, development of an arrhythmia during brainstem dissection, advanced age, poor overall medical status, and previous failure of radiation therapy. Subtotal resection may be a reasonable strategy, especially if facial nerve integrity is at risk. A relatively slow rate of regrowth of residual tumor and the effectiveness of radiosurgery for controlling small tumors are justifications for this approach, and we advocate such a strategy to preserve facial nerve function. Unfortunately the studies included in this review did not provide the stratified data needed to conduct an analysis of residual tumor based on approach. This analysis indicates that the rates of residual tumor were similar for all 3 approaches, but if further investigation were carried out into the incidence of residual (and indeed, recurrent) tumor based on size, we believe there would be a clear trend toward higher incidence of residual or recurrent tumor with larger tumors.

**Tumor Recurrence**

Recurrence of tumor is documented, especially among patients undergoing less than total resection of the tumor. Reducing the volume of residual tumor as much as possible may help minimize this risk. Schomer et al. in a long-term study, found that microscopic remnants of tumor within the nerve may retain some growth potential. The present analysis points out that patients undergoing the retrosigmoid approach may have higher rates of recurrence. The higher frequency of tumor recurrence among patients treated with a retrosigmoid approach may indeed be related to the smaller size of tumors selected for the middle cranial fossa approach, as well as poor visualization of the lateral aspect of the IAC offered through the retrosigmoid approach.

**Limitations of the Study and Future Directions**

In 1993, Glasscock et al. decried the “disarray of data” in the VS literature regarding outcome reporting. Although there are available standard metrics for reporting tumor size, hearing, and facial function, some authors do not adhere to these metrics, providing nonuniform data that are difficult to compare across studies. Additionally, there are multiple standard scales for reporting hearing function, some of which do not reconcile. This fact prevents fair comparisons among institutions. The need for a new hearing classification system has also been suggested. Ideally, a universally accepted system—specifically for VS outcome classification and reporting—that considers tumor size, hearing, and facial function would be desirable and practical.

Limitations of this review include the absence of randomized or controlled studies and bias introduced by the surgeon’s preoperative decision regarding the selection of approach. Chronology also potentially confounds our results, because the included studies were retrieved from both older and more recent series. These series have employed different techniques to maximize tumor resection. The introduction of radiosurgery has affected the decision-making process and the outcome of the recent series as compared with the old ones. Furthermore, there is a certain skew in the data, as evidenced in Table 2. Patients treated by means of a middle cranial fossa approach tend to have smaller tumors and thus may have more positive outcomes based on this fact alone. The translabyrinthine approach is well represented among patients with larger tumors, who may have worse outcomes due to the size of their tumor. There is certainly a preponderance of patients in the retrosigmoid approach group overall, but of those patients included in the final size-stratified analyses (hearing and facial nerve function), this difference is minimal, and, in fact, there are approximately 80 more patients in the translabyrinthine approach group. The composition of these populations is unfortunately out of the control of the authors, as surgeons choose approaches based on the potential benefit to each individual patient, and each approach has its advantages, disadvantages, and indications, as described above. Finally, the heterogeneity of data and lack of monitoring necessitated the exclusion of several otherwise large and potentially useful studies.

**Conclusions**

Much of the data presented here correlate with the findings in prior studies on VS surgery. Our data suggest
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<table>
<thead>
<tr>
<th>Approach &amp; Tumor Size</th>
<th>No. of Patients</th>
</tr>
</thead>
<tbody>
<tr>
<td>retrosigmoid</td>
<td>2295</td>
</tr>
<tr>
<td>intracanalicular</td>
<td>214</td>
</tr>
<tr>
<td>tumor size &lt;1.5 cm</td>
<td>525</td>
</tr>
<tr>
<td>tumor size 1.5–3.0 cm</td>
<td>487</td>
</tr>
<tr>
<td>tumor size &gt;3.0 cm</td>
<td>551</td>
</tr>
<tr>
<td>middle cranial fossa</td>
<td>814</td>
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<tr>
<td>intracanalicular</td>
<td>301</td>
</tr>
<tr>
<td>tumor size &lt;1.5 cm</td>
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<td>11</td>
</tr>
<tr>
<td>tumor size &lt;1.5 cm</td>
<td>518</td>
</tr>
<tr>
<td>tumor size 1.5–3.0 cm</td>
<td>637</td>
</tr>
<tr>
<td>tumor size &gt;3.0 cm</td>
<td>674</td>
</tr>
</tbody>
</table>

* Not all studies included data stratified by tumor size. The values listed here are based on available data.

that the retrosigmoid corridor remains a versatile approach that may be useful for preserving hearing in the case of larger tumors but carries a higher risk of postoperative CSF leakage and headache. Indeed, the middle cranial fossa approach seems to have a lower incidence of CSF leak and postoperative headache compared with the retrosigmoid approach and carries with it superior hearing preservation in the case of smaller tumors. Finally, the translabyrinthine approach may be associated with poorer facial nerve function, but the analysis was confounded by inclusion of larger tumors approached through the translabyrinthine route.

With more emphasis on hearing preservation, there is a need to standardize the classification system for hearing preservation based on a universally accepted, objective, and reproducible method of measurement. Finally, the treatment plan and surgical approach should be chosen based on careful assessment of the patient and her or his tumor, with individualized consideration and discussion of the risks to maximize the benefit to the patient.

**Disclosure**

The authors report no conflict of interest concerning the materials or methods used in this study or the findings specified in this paper.

Author contributions to the study and manuscript preparation include the following. Conception and design: all authors. Acquisition of data: all authors. Analysis and interpretation of data: all authors. Drafting the article: all authors. Critically revising the article: all authors. Reviewed submitted version of manuscript: all authors. Statistical analysis: Ansari, Terry. Study supervision: Cohen-Gadol.

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