Outcomes in patients surgically treated for VS have improved dramatically over the years. In the pre-microsurgical era, even in the best hands, operative death rates of 10–20% were realized only with subtotal removal.23,24,65 Years later, House and others lowered the morbidity of VS surgery to < 10%, even with complete tumor removal.46,47,115 Further refinement of and experience with multiple surgical approaches have lowered mortality rates for VS removal to between 0.8 and 5% for all approaches.1,4,28,35,43,82,100,111,115 Within the past few decades, other factors have proven to play a significant role in predicting the likelihood of surgical morbidity and death, including unique attributes of individual patients, such as tumor size and patient age, as well as the increasing use of surgical adjuncts (that is, intraoperative monitoring).49

To date, a large volume of literature has been published on the complication and mortality rates following VS surgery. Despite these scholarly efforts, significant interpractitioner variability in approaches remains. Most of the studies have involved small to modest case series, frequently from single institutions, and thus lack the statistical power and freedom from a single surgeon’s bias to guide a new practitioner in developing his or her own approach in the management of these tumors. Further complicating
the interpretation of existing literature is the marked variability in the reported complication rates; for example, individual studies have quoted rates of non-CN VII or VIII neuropathy ranging from 1.6% to 72% to 22%.102

Here we have evaluated the published nonaudiofacial morbidity and mortality rates in patients surgically treated for VS. We excluded CN VII or VIII complications to focus on what has been an understated issue in VS surgery, namely nonaudiofacial morbidities. Our goal was to summarize these reported morbidities separately from CN VII or VIII complications.

Methods

Article Selection

Articles were identified via a PubMed search using the key words “vestibular schwannoma,” “microsurgery,” “facial nerve function,” “acoustic neuroma,” “surgery,” “morbidity,” “mortality,” “complication,” and “hearing preservation,” alone and in combination. We then searched all references in these papers. This inquiry revealed 254 papers describing > 50,000 patients, from which all data regarding patients treated with microsurgical removal were assessed.

An article was included in our analysis if morbidity and/or mortality rates had been reported specifically for VS, without the inclusion of other schwannomas or other posterior fossa tumors in the data set. Patients with neurofibromatosis Type 2 were also considered. All radiotherapy and radiosurgery cases were excluded.

Data Extraction

Data from individual and aggregated cases were extracted from each paper as follows. For studies that did not specifically state the morbidity rate, the complication rate was used. The loss of facial nerve or hearing function was not included in the calculations of morbidity for the purposes of our analysis. Data were analyzed as a whole and were divided into 2 subgroups. In the first analysis we separated data according to the surgical approach: MCFA, TLA, and RSA. In a second subgroup analysis we divided the data based on tumor size. Group 1 included patients with tumor sizes ≤ 25 mm, and Group 2 included patients in whom the average tumor size was > 25 mm. These measurements were taken from the largest diameter of the tumor, including the intracanalicular component. For purposes of analysis, “vascular morbidity” was defined as any ischemic injury or intracranial hemorrhage that was attributed to the surgical procedure. “Neurological morbidity” was defined as any postoperative neurological symptoms other than facial nerve palsy or hearing loss that was not explicitly stated to have been present preoperatively. “Short-term neurological morbidity” referred to morbidity that resolved within 3 months of surgery. Any morbidity persisting beyond 3 months postoperatively was considered to be long term.

Statistical Analysis

Comparisons of between-group rates of complications were made using the Pearson chi-square test. Correlation analysis between the date of study publication or study size and complication rates was performed using simple linear regression. For all tests, the p value was considered significant at the 5% level, that is, p < 0.05.

Results

Results of the Literature Search

One hundred articles describing 32,870 patients provided some usable data and were included in estimates of the overall incidence of complications. One hundred articles describing > 50,000 patients, from which all data could be meaningfully analyzed. Seven thousand six hundred sixty-seven patients had a tumor size of ≤ 25 mm, whereas 6251 patients had a tumor size > 25 mm. The median age at diagnosis was 48.8 years. The mean duration of the postoperative follow-up was 15.7 months (range 2.3–132 months).

Morbidity and Death Following VS Surgery

The overall mortality rate was 0.2% (95% CI 0.1–0.3%). The overall rate of experiencing at least 1 significant complication was 22% (95% CI 21–23%). Cerebrospinal fluid leakage was the most frequent morbidity, whereas the leading cause of death was AICA hemorrhage. Neurological complications occurred in 9% of cases (2829 patients), vascular complications occurred in 1% (337 patients), and infections complicated 2% of cases (523 patients) postoperatively (Table 1).

Cerebrospinal Fluid Leakage

Cerebrospinal fluid leakage was diagnosed in 2804 patients (8.5%, 95% CI 6.9–10.0%). Of patients with CSF leaks, 890 (32%) required only conservative treatment. Of the 1914 refractory leaks (68%) requiring additional treatment, 673 (35%) were resolved with a lumbar drain alone, whereas 52 (2.7%) were resolved with a CSF diversion procedure. One thousand one hundred eighty-nine patients with CSF leakage underwent open surgical dural repair to treat the leak. In the remaining cases, the exact method used to treat the leak was not stated.

Effect of Approach on CSF Leakage Rates. Among the 1632 patients who underwent the MCFA, 114 cases (7%, 95% CI 5.1–8.9%) of CSF leakage were reported. Among the RSA group, CSF leakage was diagnosed in 244 (6%) of 3757 patients (95% CI 4.8–7.2%). The MCFA
and RSA were clearly superior to the TLA in this regard. Seven hundred ninety-six (27%) of 2909 patients undergoing the TLA approach experienced a CSF leak (95% CI 24–29%; MCFA vs TLA, p < 0.0001; RSA vs TLA, p < 0.0001). There was no difference in the rates of CSF leaks when the MCFA was compared with the RSA (p = NS). A comparison of complication rates across the 3 approaches is depicted in Fig. 1.

**Effect of Tumor Size on CSF Leakage Rates.** Among the 7667 patients who had tumors ≤ 25 mm, 460 (6%) were reported to have a CSF leak (95 CI 6.1–7.6%). There were 352 cases (5.6%, 95% CI 4.7–6.4%) of CSF leakage in the group of patients with tumors > 25 mm. There was no difference in the rate of CSF leakage between these groups (≤ vs > 25 mm, p = NS). A comparison of complication rates between large and small tumors is depicted in Fig. 2.

**Vascular Complications**

Vascular complications occurred in 337 patients (1%, 95% CI 0.75–1.2%). Two hundred eighty-one of these vascular complications (83%) were hemorrhagic and 44 were ischemic (13%); in 12 cases (4%) the vascular complication was not specified. Patients with vascular complications had a mortality rate of 19%.

**Effect of Approach on Vascular Complication Rates.** In the group of patients that underwent the MCFA (1632 patients), there were 17 cases (1%, 95% CI 0.3–1.7%) of reported vascular complications. Among the 2909 patients who underwent a TLA, 26 patients (0.9%, 95% CI 0.4–1.4%) had vascular complications. In the RSA group of 3757 patients, 99 cases (2.6%, 95% CI 1.8–3.4%) had vascular complications. The MCFA and TLA demonstrated a better risk profile for vascular complications over the RSA (MCFA vs RSA, p < 0.0001; TLA vs RSA, p < 0.0001). There was no statistically significant difference in vascular complications occurring with the MCFA and the TLA (Fig. 1).

**Effect of Size on Vascular Complication Rates.** Fifty-six surgeries (0.7%, 95% CI 0.4–0.9%) were complicated by vascular events in the group of 7667 patients with tumors ≤ 25 mm. In the group of patients with tumor sizes > 25 mm, the vascular complication rate was 1.3% (95% CI 1.0–1.7%). Larger tumors were more likely to be associated with vascular complications (≤ vs > 25 mm, p < 0.0001; Fig. 2).

**Neurological Complications**

Two thousand eight hundred twenty-nine (8.6%, 95% CI 7.9–9.3%) of 32,870 patients experienced nonaudiofa-
onal neurological complications as a result of VS surgery. The most frequent postoperative neurological morbidity was CN neuropathy, which was present in 425 patients (15%), whereas the most common long-term complication was balance disturbance, which was observed in 325 patients (11%). In 1736 of these patients (61%), these deficits were short term and resolved within 3 months. Long-term neurological complications were observed in 1082 patients (38%). The mortality rate among patients with neurological morbidity was 0.39% (11 cases), and all deaths were attributable to aspiration pneumonia caused by lower CN palsy.

**Effect of Approach on Neurological Complication Rates.** The MCFA group had a neurological complication rate of 11% (95% CI 8.7–13%). The neurological complication rate following the TLA was 5% (95% CI 3.8–6.2%). Patients who underwent the RSA demonstrated a 10% neurological complication rate (95% CI 8.6–11%). Patients who underwent the TLA had a statistically lower rate of neurological complications than those who underwent either the MCFA or RSA (TLA vs MCFA, p < 0.0001; TLA vs RSA, p < 0.0001). There was no difference in neurological morbidity with the RSA compared with the MCFA (Fig. 1).

**Effect of Tumor Size on Neurological Complication Rates.** Of the 7667 patients with tumor sizes ≤ 25 mm, 355 (4.6%, 95% CI 3.9–5.3%) suffered from neurological complications. In the group with tumor sizes > 25 mm the neurological complication rate was 15% (95% CI 13–16%). Thus, not unexpectedly, the resection of smaller tumors was less likely to result in neurological complications (≤ vs > 25 mm, p < 0.0001; Fig. 2).

**Infection Rates**

Infections complicated 3.8% of cases (95% CI 3.4–4.3%). The mortality rate among patients with infection was 1.9%. Common sources of infection included meningitis (78%), wound infection (16%), and fat graft site infection (3.4%). Notably, meningitis carried a mortality rate of 1.5%.

**Effect of Approach on Infection Rates.** Seventy-three infections (4%, 95% CI 2.6–5.4%) were observed in the 1632 patients who underwent the MCFA. The TLA group had an infection rate of 1% (95% CI 0.5–1.5%), whereas the RSA group of 3757 patients had a rate of 2% (91 cases, 95% CI 1.3–2.7%). The TLA group had a small but statistically lower rate of infection as compared with the MCFA group (p < 0.0001). There was no statistical difference between the TLA and RSA or the RSA and MCFA with regard to rates of infection.

**Effect of Tumor Size on Infection Rates.** In the group of 7667 patients with tumors ≤ 25 mm, 84 cases (1%, 95% CI 0.7–1.3%) of infection were recorded. Two hundred two infections (3%, 95% CI 2.8–3.2%) were recorded in the group of 6251 patients with tumors > 25 mm. The resection of larger tumors was more likely to result in postoperative infection (≤ vs > 25 mm, p < 0.0001; Fig. 2).

**Other Complications**

Twenty-two cases of cerebellar edema, 1 case of cerebellar herniation, 3 cases of epidural air collection, 10 cases of air embolism, 5 cases of brainstem edema of unclear etiology, and 1 case of clinically significant pneumocephalus were reported in the literature.

**Relationship Among Series Size, Study Publication Year, and Complication Rates**

A relationship between surgeon experience and reduced rates of complication has been suggested in the resection of VSs. We performed a correlation analysis to study the effect of study size on complication rates. Interestingly, we found there was a minimal meaningful correlation (r < 0.2 in all cases) between the number of patients in a series and rates of nonaudiofacial neuropathy, neurological deficit, CSF leakage, infection, vascular injury, or death (Table 2).

Papers used in this study largely dated from after the introduction of the operating microscope into neurosurgical practice. During this period, MR imaging has improved significantly and image guidance techniques have entered mainstream practice. We performed a correlation analysis to study the relationship between the publication year of a study and complication rates. We found there was a minimal meaningful correlation (r < 0.2 in all cases) between the year of publication during the microsurgery era and rates of nonaudiofacial cranial neuropathy, neurological deficit, CSF leakage, infection, vascular injury, or death (Table 2).

**Discussion**

With the continuous refinement of surgical techniques, the VS operative mortality rates of 10–15% from years past have decreased to < 1%. Although the morbidity and mortality rates associated with VSs have dramatically evolved since the turn of the century, it is obvious that there is wide variation in outcome as well as in what is reported in the literature. Many investiga-

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* NS = not significant.
Morbidity and death in vestibular schwannoma surgery

tors have published their results, but to date there have been few efforts to combine these data in a comprehen-
sive fashion. In the present study, we performed a comprehensive review of the English language literature and extracted and analyzed data regarding the morbidity and mortality rates in a large population of patients who have undergone surgery for VS.

In our analysis, the incidence of CSF leakage was 6–10%. This estimate markedly narrows the range that was seen in the literature, which has been quoted as 3–26.7%. Surgical approach and tumor size have been high on the list of factors associated with the occurrence of CSF leaks. One interesting finding was that the RSA did not seem to have a higher rate of CSF leakage than the MCFA. This finding contradicts a report by Sanna and colleagues indicating that the RSA poses the greatest risk for CSF leakage. The highest incidence of CSF leakage was via the TLA. Although in 2001 Slattery and colleagues reported that the resection of larger tumors results in a higher incidence of CSF leaks, our analysis did not confirm these results.

A vascular complication is the most serious morbidity that can occur in a VS case. Although many observers have reported that these complications occur at a rate of over 7%,11,12,26,29,32,39,41,57,58,62,63,88 the incidence was only 1% in our analysis. In our study, the highest incidence of vascular complications was noted via the RSA, with the TLA and MCFA being roughly equivalent in this regard. One possible reason for this finding is that in the TLA the tumor lies between the surgeon and the AICA, whereas in the RSA the surgeon must operate past the AICA to resect the tumor.

Infections have long been recognized as a significant cause of surgical morbidity and death. According to our analysis, infections occurred in 3.8% of surgeries for VS. The overwhelming majority of reported postoperative infections were related to the surgical site; however, this finding may be attributable to low rates of detection or the reporting of nonsurgical infections such as urinary tract infection or pneumonia in the existing literature. Previous estimates of the incidence of infection in the literature were wildly divergent, ranging between 1.6% for the TLA and 19% for the MCFA.

We found that study size and year of publication during the microsurgical era had no significant impact on the rates of any major class of complications. The lack of improvement with increasing sample size is counterintuitive; however, a number of potential explanations exist. First, very large studies likely represent a longitudinal section of a surgeon’s career and probably include a large number of cases from their learning curve. It is likely that studies limited to the more experienced portions of a surgeon’s career would show improvement as compared with studies from his or her earlier experience. Publication bias also probably plays a role, as small studies with high complication rates might be rejected as not representative of the larger experience.

Additionally, we found that there was minimal improvement in the rates of complications over the past 30-plus years. This result might be attributable to an improved ability to detect complications and to better follow-ups given that patients can now return to their treating surgeon more frequently when problems arise than in years past. Alternatively, this finding might reflect the minimal impact that image guidance technology has in these cases, as localization of the internal auditory canal and tumor is usually very possible by using anatomical landmarks. Moreover, important anatomical variations, such as the location of the vasculature and facial nerve, are no more evident using current imaging technology than they were in the early 1980s.

Study Limitations

We acknowledge that any aggregation of data is only as good as the composite studies and can reflect source study biases. Thus, while the greater statistical power of such an approach is appealing, the aggregation of data from different studies is not without potential problems. For example, the majority of our data set was derived from self-reported outcomes largely assessed by the treating surgeon and colleagues. It is impossible for us to assess or control for the quality of data reported in the literature or any unwillingness to report complications. Such omissions would inevitably change the rates reported in our study. Additionally, given the diverse range of data presentation, the number of variables capable of being studied and controlled for is limited. Variables that might be of interest, which are inconsistently presented across studies, cannot be analyzed. Furthermore, multivariate regression to control for the effects of important variables, such as age and initial tumor size, is impossible to perform across a large number of studies that adhere to differing formats of data presentation. Finally, an analysis of the published literature, by definition, suffers from publication bias, as unpublished data or studies rejected by searchable journals are not included. Given these limitations, while our data provide a summary of the published literature, they do not provide a predictive model of expected outcomes for an individual practitioner or a specific patient. However, as the largest aggregate of data published on this topic to date, the biases of any individual study should be minimized.

Conclusions

In this study, we provide a systematic summary of the published literature regarding complication rates following surgery for VS. By providing a more statistically powerful estimate of surgical complication rates, the arguments for and against various treatment modalities for VS can be more accurately compared.

Disclosure

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