Objective: To characterize contemporary practice patterns and outcomes of vestibular schwannoma surgery.

Design: Cross-sectional analysis.

Setting: Maryland Health Service Cost Review Commission database.

Patients: The study included patients who underwent surgery for vestibular schwannoma between 1990 and 2009.

Main Outcome Measures: Temporal trends and relationships between volume and in-hospital deaths, central nervous system (CNS) complications, length of hospitalization, and costs.

Results: A total of 1177 surgical procedures were performed by 57 surgeons at 12 hospitals. Most cases were performed by high-volume surgeons (47%) at high-volume hospitals (79%). The number of cases increased from 474 in 1999-2000 to 703 in 2000-2009. Vestibular schwannoma surgery in 2000-2009 was associated with a decrease in CNS complications (odds ratio [OR] 0.4; \(P < .001\)) and an increase in cases performed by intermediate-volume (OR, 4.2; \(P = .002\)) and high-volume (OR, 3.2; \(P = .005\)) hospitals and intermediate-volume (OR, 1.9; \(P = .004\)) and high-volume (OR, 1.8; \(P = .006\)) surgeons. High-volume care was inversely related to the odds of urgent and emergent surgery (OR, 0.2; \(P < .001\)) and readmissions (OR, 0.1; \(P = .02\)). Surgeon volume accounted for 59% of the effect of hospital volume for urgent and emergent admissions and 20% for readmissions. After all other variables were controlled for, there was no significant association between hospital or surgeon volume and in-hospital mortality or CNS complications; however, surgery at high-volume hospitals was associated with significantly lower hospital-related costs (\(P < .001\)).

Conclusions: These data suggest increased centralization of vestibular schwannoma surgery, with an increase in cases performed by intermediate- and high-volume providers and meaningful differences in high-volume surgical care that are mediated by surgeon volume and are associated with reduced hospital-related costs. Further investigation is warranted.


The management of vestibular schwannoma has evolved over the past century driven by innovations in surgical philosophy, instrumentation and technique, advances in neuroradiology, and the advent of stereotactic radiosurgery.¹ Postoperative outcomes have also been aided by improvements in intraoperative neuromonitoring, neuroanesthesia, and neurologic intensive care. Two The vestibular schwannoma is a relatively uncommon condition, with an incidence of approximately 1 to 2 tumors per 100,000 population per year.³ Declining surgical volumes owing to increasing rates of observation and stereotactic radiation treatment may dilute surgical care experience, particularly in saturated health markets. The impact of these practice trends on the collective competence of multidisciplinary surgical teams, as reflected by clinical outcomes and practice efficiency, should be considered in the organization and financing of this care.

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In several surgical disciplines, practice volume is inversely associated with short- and long-term mortality for surgical procedures.⁶⁻¹⁰ Case volume has therefore been interpreted by health care purchase coalitions, such as the Leapfrog Group, as a surrogate for quality and as a factor that should determine how health care services are reimbursed.¹¹ While much of the data in this area to date have concerned cardiovascular, intra-abdominal, and intrathoracic procedures, favorable relationships between surgical volume and postoperative discharge status, complications, and hospital costs have been identified for vestibular schwannoma surgic-
A cross-sectional analysis of patients with a diagnosis of vestibular schwannoma was performed using hospital discharge data from nonfederal acute care hospitals in Maryland collected by the Maryland Health Service Cost Review Commission (HSCRC). The HSCRC database provides information regarding the index hospital admission (surgery) and is limited to 30 days of follow-up. The study population comprised all patients who underwent an ablative procedure for a vestibular schwannoma in Maryland between January 1, 1990, and July 1, 2009. International Classification of Diseases, Ninth Revision, codes for vestibular schwannoma (225.1, 237.7, 237.70, 237.71, and 237.72) and for diagnosis and excision of acoustic neurona (04.01) were used to identify the appropriate cases. Central nervous system (CNS) complications were derived from codes for complications assigned at the time of hospital discharge, including bacterial meningitis (320), meningitis not otherwise specified (322), subarachnoid hemorrhage (430), intracerebral hemorrhage (431), unspecified intracerebral hemorrhage (432), obstructive hydrocephalus (331.4), central nervous system complication (997.01), and cerebrospinal fluid otorrhea (388.61). Facial nerve paralysis and hearing loss codes were excluded because of the difficulty in determining whether paralysis or hearing loss was present before surgery and the absence of functional grading as an indicator of severity and outcome. Prior irradiation was obtained from the codes for previous exposure to therapeutic or other ionizing radiation (V13.3).

The primary clinical end points for analysis in this study were variables associated with high-volume care and temporal trends in vestibular schwannoma surgical care. Hospital and surgeon volume, CNS complications, in-hospital death, length of hospitalization, and cost were also examined as dependent variables. Surgeons and hospitals were included in the analysis if they were involved with at least 1 vestibular schwannoma operation during the entire study period. The average annual number of vestibular schwannoma surgical cases was obtained by calculating the mean of the number of cases performed each year for each individual provider for the years in which that surgeon or hospital performed at least 1 vestibular schwannoma operation. Annual volumes were divided into tertiles, which were categorized as low, intermediate, and high volume and were modeled as categorical variables. Based on case distributions, values for annual case volume of less than 4, 5 to 7, and 13 to 16 were used to classify surgeons by low, intermediate, and high volume.

Secondary independent variables available from the HSCRC database included age; sex; race; All Patient Refined-Diagnosis Related Group (APR-DRG) case complexity score (1-4); APR-DRG mortality risk score (1-4); payer source (commercial, health maintenance organization [HMO], Medicare or Medicaid, or self-pay); nature of admission (emergency/urgent or other); readmission; and hospital type (university or community). The APR-DRG case complexity score reflects the clinical severity of illness related to the extent of physiologic decompensation or loss of organ function experienced by the patient for either the primary diagnosis or comorbidities, while the APR-DRG mortality risk score reflects the likelihood of dying. Both scoring systems incorporate the impact and interaction of multiple secondary diagnoses. For statistical analysis of temporal trends, the study period was divided into 2 time intervals (1990-1999 and 2000-2009). Hospital-related charges for each index admission were converted to the organizational cost of providing care using cost to charge ratios for individual hospitals. Cost to charge ratios were calculated from HSCRC data by dividing the average inpatient expense by the average inpatient revenue of each hospital during each year of the study interval. This ratio was then multiplied by each patient’s charge to obtain the cost per admission. All costs were adjusted for inflation based on US Bureau of Labor Statistics indices, with results converted to 2009 US dollars. Cases with incomplete financial data were excluded from analysis.

Data were analyzed using Stata version 10 (StataCorp). Associations between variables were analyzed using cross-tabulations and multivariate regression. Age categories were created based on the results of Lowess smoothed regression analysis. The primary clinical end points were evaluated using multiple logistic regression analysis, with odds ratios (ORs) expressed relative to a reference baseline category. Multinomial logistic regression was used for analysis of dependent variables with more than 2 response levels. Generalized linear regression modeling with a log link was used to analyze costs and length of
stay because these variables were not normally distributed. To assess the relative contribution of surgeon and hospital volume to observed associations with high-volume hospital or surgeon care, the attenuation of the OR was computed as \((\text{OR}_H - \text{OR}_{HS}) / (\text{OR}_H - 1)\), where \(\text{OR}_H\) is the OR for high-volume hospital care without adjustment for surgeon volume and \(\text{OR}_{HS}\) is the OR for high-volume hospital care after adjustment for surgeon volume.11 This protocol was reviewed and approved by the institutional review board of The Johns Hopkins Medical Institutions, Baltimore, Maryland.

## RESULTS

A total of 1177 cases met study criteria (Table 1). The mean age was 50.6 years (age range, 9-85 years). Most patients were female and white, had commercial insurance, and received their care at a university hospital. Most patients had low case complexity and mortality risk scores (1 or 2) at the time of surgery. The overall rate of postoperative CNS complications was 8.7%, and the rate of in-hospital mortality was 0.5%. The average number of annual surgical cases treated increased by 53.9% in 2000-2009, with an annual average of 45.1 cases treated surgically during 1990-1999 and 69.4 cases during 2000-2009. Patients in 2000-2009 compared with 1990-1999 were more likely to be younger than 65 years, to receive their care at a community hospital, to have HMO insurance, and to have higher case complexity scores and were less likely to be admitted urgently or emergently. A history of radiation therapy was documented in only 1.2% of cases in 2000-2009 and in no cases in 1990-1999.

There were 12 hospitals that cared for patients undergoing vestibular schwannoma surgery, with only 1 hospital (8%) categorized as high volume (45 cases per year).
of patients cared for by intermediate-volume hospitals (13% to 22%) and a decrease in both the number and the proportion of patients cared for by low-volume hospitals (4% to 2%). The larger number of cases at high-volume hospitals in 2000-2009 corresponded to a smaller proportion of all cases during this time period (83% to 76%) (P= .001).

Two hospitals as intermediate volume (7 cases per year), and 9 hospitals as low volume (<3 cases per year) (Figure 1A). There were only 2 university hospitals, 1 of which met the criteria for high volume. The number of low-volume hospitals decreased from 7 in 1990-1999 to 6 in 2000-2009, while the number of intermediate-volume (n=2) and high-volume (n=1) hospitals remained constant. There were 57 surgeons listed as the attending surgeon for vestibular schwannoma resection. Two surgeons were classified as high volume (13-16 cases per year), 5 as intermediate volume (5-7 cases per year), and 39 as low volume (1-3 cases per year) (Figure 1B).

Most patients received their care at a high-volume hospital and from high-volume surgeons; however, the distribution of surgical cases varied by decade (Figure 2 and Figure 3). The proportion of patients who underwent surgery at intermediate-volume hospi-

tals increased from 13% in 1990-1999 to 22% in 2000-2009, while the proportion of patients cared for at low-volume hospitals decreased from 4% to 2%, and the proportion of patients cared for at high-volume hospitals decreased from 83% to 76%. The proportion of cases performed by intermediate-volume surgeons increased from 32% in 1990-1999 to 39% in 2000-2009, whereas the proportion of cases performed by low-volume surgeons decreased from 21% to 14%. There was no change in the proportion of cases performed by high-volume surgeons.

Multinomial logistic regression analysis of variables associated with the time frame 2000-2009 compared with reference data for 1990-1999 showed a significant decrease in postoperative CNS complications and an increase in patients with HMO payer status (Table 2). After all other variables were controlled for, there was a significant increase in the total number of cases treated at intermediate-volume and high-volume hospitals and by intermediate-volume and high-volume surgeons (P <.05 for all 4 variables).

Multiple logistic regression analysis revealed that patients who received high-volume hospital care were less likely to be admitted urgently or emergently, to require readmission within 30 days of surgery, or to have HMO payer status (Table 3). Adjusting for surgeon volume attenuated these relationships so that hospital volume was no longer a significant predictor of urgent or emergent admission. High-volume surgeons were less likely to operate on patients admitted urgently or emergently, to have a patient readmitted within 30 days of surgery, or to operate on patients with HMO or Medicare/Medicaid payer status. They were also less likely to have patients with advanced mortality risk scores (Table 4). Adjusting for hospital volume had a negligible effect on the association between surgeon volume and decreased odds of urgent or emergent admission and readmission within 30 days, while the association between surgeon volume and payer status was no longer significant.

After all other variables were adjusted for, in-hospital death was significantly associated with postoperative CNS complications (OR, 8.43 [95% CI, 1.28-55.6]; P = .03) and urgent or emergent admission (OR, 9.27 [95% CI, 1.49-57.7]; P = .02). Central nervous system complications were significantly associated with advanced comorbidity status (OR, 2.51 [95% CI, 1.37-4.3]; P <.01 for mortality risk score 2; and OR, 2.97 [93%
CI, 1.16-7.60; \( P = .02 \) for mortality risk score 3). No association, however, was found between high-volume hospital or surgeon care and either in-hospital death or CNS complications.

Generalized linear regression analyses of independent variables predictive of length of hospital stay and hospital-related costs are shown in Table 5. After all other variables were controlled for, high-volume hospital care was associated with a significant decrease in hospital-related costs. Advanced comorbidity scores were significantly associated with greater length of hospitalization as well as increased hospital costs, while HMO insurance status was associated with a reduction in length of hospitalization but not in hospital costs.

There has been a growing emphasis on health care quality in recent years, including an effort to align with reimbursement to incentivize quality care. Surgical quality is broadly defined as consisting of 3 principal components: structure (facilities, administration, staff, and volume), processes, and outcome.15 Of the components, volume is predominantly best categorized as a structural measure of surgeon or hospital quality.16 While surgical quality likely reflects many contributing processes of care, including patient selection, preoperative preparation, use of evidence based medicine, surgical judg-

Table 3. Multivariate Logistic Regression Analysis of Variables Associated With High-Volume Hospitals

<table>
<thead>
<tr>
<th>High-Volume Hospital</th>
<th>Unadjusted for Surgeon Volume</th>
<th>Adjusted for Surgeon Volume</th>
<th>Proportion of Effect of Hospital Volume Attributable to Surgeon Volume, %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>OR (95% CI)</td>
<td>( P ) Value</td>
<td>OR (95% CI)</td>
</tr>
<tr>
<td>Urgent/emergent admission</td>
<td>0.36 (0.19-0.68)</td>
<td>.002</td>
<td>0.74 (0.37-1.47)</td>
</tr>
<tr>
<td>Readmission</td>
<td>0.15 (0.05-0.40)</td>
<td>&lt;.001</td>
<td>0.32 (0.11-0.91)</td>
</tr>
<tr>
<td>HMO payer status</td>
<td>0.35 (0.25-0.50)</td>
<td>&lt;.001</td>
<td>0.45 (0.30-0.68)</td>
</tr>
</tbody>
</table>

Abbreviations: HMO, health maintenance organization; OR, odds ratio.

Table 4. Multivariate Logistic Regression Analysis of Variables Associated With High-Volume Surgeons

<table>
<thead>
<tr>
<th>High-Volume Surgeon</th>
<th>Unadjusted for Hospital Volume</th>
<th>Adjusted for Hospital Volume</th>
<th>Proportion of Effect of Hospital Volume Attributable to Hospital Volume, %</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>OR (95% CI)</td>
<td>( P ) Value</td>
<td>OR (95% CI)</td>
</tr>
<tr>
<td>Urgent/emergent admission</td>
<td>0.13 (0.05-0.34)</td>
<td>&lt;.001</td>
<td>0.15 (0.05-0.40)</td>
</tr>
<tr>
<td>Readmission</td>
<td>0.05 (0.01-0.41)</td>
<td>.005</td>
<td>0.07 (0.01-0.61)</td>
</tr>
<tr>
<td>HMO payer status</td>
<td>0.48 (0.35-0.65)</td>
<td>&lt;.001</td>
<td>0.74 (0.50-1.07)</td>
</tr>
<tr>
<td>Medicare/Medicaid</td>
<td>0.47 (0.24-0.91)</td>
<td>.03</td>
<td>0.52 (0.24-1.13)</td>
</tr>
<tr>
<td>Mortality risk score 4</td>
<td>0.15 (0.05-0.41)</td>
<td>&lt;.001</td>
<td>0.11 (0.04-0.33)</td>
</tr>
</tbody>
</table>

Abbreviations: HMO, health maintenance organization; OR, odds ratio.

Table 5. Generalized Linear Regression Analysis of Length of Stay and Hospital Costs

<table>
<thead>
<tr>
<th>Variable</th>
<th>Coefficient (95% CI)</th>
<th>( P ) Value</th>
<th>Mean</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length of stay, d</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Intercept</td>
<td>1.42 (1.28 to 1.55)</td>
<td>&lt;.001</td>
<td>5.6</td>
</tr>
<tr>
<td>Mortality risk score 3</td>
<td>0.30 (0.13 to 0.47)</td>
<td>.001</td>
<td>81.9</td>
</tr>
<tr>
<td>Case complexity score 2</td>
<td>0.12 (0.05 to 0.19)</td>
<td>.001</td>
<td>0.7</td>
</tr>
<tr>
<td>Case complexity score 5</td>
<td>0.37 (0.25 to 0.49)</td>
<td>&lt;.001</td>
<td>2.4</td>
</tr>
<tr>
<td>Case complexity score 4</td>
<td>1.11 (0.93 to 1.29)</td>
<td>&lt;.001</td>
<td>10.8</td>
</tr>
<tr>
<td>HMO payer status</td>
<td>-0.08 (−0.15 to −0.01)</td>
<td>.02</td>
<td>-0.5</td>
</tr>
<tr>
<td>Hospital costs (2009 US dollars)</td>
<td>10.36 (10.25 to 10.48)</td>
<td>&lt;.001</td>
<td>25560</td>
</tr>
<tr>
<td>High-volume hospital</td>
<td>-0.26 (−0.34 to −0.19)</td>
<td>&lt;.001</td>
<td>-7278</td>
</tr>
<tr>
<td>Mortality risk score 2</td>
<td>0.14 (0.06 to 0.22)</td>
<td>.001</td>
<td>3711</td>
</tr>
<tr>
<td>Mortality risk score 3</td>
<td>0.25 (0.09 to 0.40)</td>
<td>.002</td>
<td>7049</td>
</tr>
<tr>
<td>Mortality risk score 4</td>
<td>0.20 (0.05 to 0.36)</td>
<td>.01</td>
<td>5711</td>
</tr>
<tr>
<td>Case complexity score 2</td>
<td>0.14 (0.08 to 0.20)</td>
<td>&lt;.001</td>
<td>3534</td>
</tr>
<tr>
<td>Case complexity score 3</td>
<td>0.25 (0.14 to 0.36)</td>
<td>&lt;.001</td>
<td>7169</td>
</tr>
<tr>
<td>Case complexity score 4</td>
<td>0.77 (0.61 to 0.92)</td>
<td>&lt;.001</td>
<td>28579</td>
</tr>
</tbody>
</table>

Abbreviation: HMO, health maintenance organization.
ment and skill, and postoperative care, it is easier to assess and document structural measures, especially for low-volume procedures such as vestibular schwannoma surgery. As a result, volume may be a surrogate for these surgical processes.

Although associations between surgical care volume and improved postoperative outcomes have been reported for a variety of surgical procedures, there has been a relative lack of data regarding temporal trends in this relationship for neuro-otological procedures. Slater et al and Barker et al both identified favorable outcomes for high-volume providers of vestibular schwannoma surgical care over several years, including fewer CNS complications and a greater proportion of patients with routine hospital discharges. Our study demonstrated a favorable trend toward increased centralization of care for vestibular schwannoma surgery that is associated with a reduction in overall costs and suggests that there may be meaningful differences in the type of care provided by high-volume providers.

In the state of Maryland over the last 2 decades, high- and intermediate-volume hospitals and surgeons have seen an increase in the absolute number of cases, with particularly strong growth evident in the intermediate-volume centers and a decline in the low-volume hospitals. The narrowing gap in case numbers between high- and intermediate-volume hospital and surgeon categories is not associated with any differences in CNS complications or mortality. The types of patients cared for by high-volume providers, however, are different. High-volume surgical care was associated with lower odds of both urgent or emergent surgery and readmission, and a large proportion of this effect is attributable to surgeon volume. Also, high-volume surgeons were less likely to operate on patients with an advanced mortality risk score, suggesting that there are differences in the process measures used by high-volume providers in selecting patients for surgery. While the current report would suggest that in the state of Maryland patients can expect similar quality care, as indicated by complication rates, whether they are under the care of hospitals and surgeons with high- or intermediate-volume practices, other long-term quality indicators such as extent of tumor removal and long-term facial nerve function could not be determined in the current study.

A 50% increase in vestibular schwannoma surgery numbers belies a trend of more conservative management with serial radiological monitoring and increasing use of stereotactic radiotherapy for growth control. A decline in age at surgery in the second decade of this study. This finding is all the more remarkable given an increase in the average size of tumors that underwent surgery in many of the patients treated at the high-volume hospital during this study. This decrease in CNS complications may reflect more careful patient selection, greater comfort with monitoring tumors, and the advent of alternative treatments, including stereotactic radiotherapy for older patients and those at higher surgical risk. Surgery on younger patients is likely contributory to the favorable outcome trends. Improved standards of intraoperative care, including neuromonitoring, as well as better and more streamlined postoperative care may play a role. The lack of information regarding tumor size and specific surgical approaches, however, limits our ability to accurately correlate case volume with complications, while taking these factors into account. Such findings would be best investigated in a prospective national study.

There are several limitations to the use of hospital discharge data, which may have influenced our findings. The Maryland HSCRC database is limited to intermediate-volume centers, the incidence of postoperative CNS complications was halved in the second decade of this study. This finding is all the more remarkable given an increase in the average size of tumors that underwent surgery in many of the patients treated at the high-volume hospital during this study. Despite increasing case complexity and the diffusion of case numbers to intermediate-volume centers, the incidence of postoperative CNS complications was halved in the second decade of this study. This finding is all the more remarkable given an increase in the average size of tumors that underwent surgery in many of the patients treated at the high-volume hospital during this study. There are several limitations to the use of hospital discharge data, which may have influenced our findings. The Maryland HSCRC database is limited to follow-up data within the 30-day postoperative window and does not contain additional relevant surgical variables, such as tumor size, location, surgical approach used for resection, extent of tumor removal, or long-term facial nerve outcomes. The HSCRC database provides limited data on the use of previous surgical procedures or prior radiation therapy, which may be underreported. There may be differences in the type of patient or disease cared for at high-volume hospitals that are not adequately captured. The lower incidence of urgent and emergent admissions and readmissions seen with high-volume providers could potentially be confounded by patient instability, precluding transfer to a high-volume center. While mortality risk scores were used for risk adjustment, the ability to adequately control for case mix is limited when discharge diagnoses from administrative databases are used. This limitation is found in nearly all studies that have investigated volume and outcome associations to date. Postoperative complications may not be apparent at discharge or inadequately recorded and therefore under-
reported. Other limitations are that the cost analysis was based on hospital-related charges, was adjusted for institutional expense to revenue ratios, and did not include physician-related costs, as these data are not contained in the HSCRC database.

The Maryland vestibular schwannoma care market is dominated by a single high-volume institution that attracts a national and international clientele. Maryland HSCRC data may therefore underestimate the readmissions of patients from this facility if they occurred in other states or countries. Further investigation may benefit from exploring volume-based trends in national databases that include a broader range of high- and low-volume hospitals and surgeons. With the increasing popularity of radiation therapy, additional studies may also examine relationships between volume and outcome in vestibular schwannoma cases that are treated with stereotactic radiotherapy.

In conclusion, data from the state of Maryland suggest a temporal trend of increased centralization of vestibular schwannoma surgical care to both high- and intermediate-volume providers and a substantial decrease in the rate of postoperative CNS complications. High-volume surgical care is associated with a decrease in readmissions and reduced hospital-related costs. These findings warrant further investigation to define the process measures that yield these favorable results, particularly in an era of health care reform.

Submitted for Publication: January 31, 2012; final revision received April 2, 2012; accepted April 11, 2012.

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Author Contributions: Dr Ward had full access to all the data in the study and takes responsibility for the integrity of the data and the accuracy of the data analysis. Study concept and design: Ward and Francis. Acquisition of data: Gourin. Analysis and interpretation of data: Ward and Gourin. Drafting of the manuscript: Ward. Critical revision of the manuscript for important intellectual content: Ward, Gourin, and Francis. Statistical analysis: Gourin. Study supervision: Gourin and Francis.

Financial Disclosure: None reported.

Funding/Support: This study was funded in part by grant T32DC000027-22 from the National Institutes of Health.

Previous Presentation: This study was presented in part at the 144th Annual Spring Meeting of the American Otorhinolaryngological Society; April 30, 2011; Chicago, Illinois.

REFERENCES