Surgery is cost-effective treatment for young patients with vestibular schwannomas: decision tree modeling of surgery, radiation, and observation

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Object. Vestibular schwannomas (VSs) are managed in 3 ways: observation (“wait and scan”); Gamma Knife surgery (GKS); or microsurgery. Whereas there is considerable literature regarding which management approach is superior, there are only a few studies addressing the cost of treating VSs, and there are no cost-utility analyses in the US to date.

Methods. In this study, the authors used the University of California at San Francisco medical record and hospital accounting databases to determine total hospital charges and costs for 33 patients who underwent open surgery, 42 patients who had GKS, and 12 patients who were observed between 2010 and 2013. The authors then performed decision-tree analysis to determine which treatment paradigm produces the highest quality-adjusted life years and to calculate the incremental cost-effectiveness ratio, depending on the patient’s age at VS diagnosis.

Results. The average total hospital cost over a 3-year period for surgically treated patients was \$80,074 ($\pm$ \$49,678) versus \$9737 ($\pm$ \$5522) for patients receiving radiosurgery and \$1746 ($\pm$ \$2792) for patients who were observed. When modeling the most debilitating symptoms and worst outcomes of VSs (vertigo and death) at different ages at diagnosis, radiation is dominant to observation at all ages up to 70 years. Surgery is cost-effective when compared with radiation (incremental cost-effectiveness ratio $<$ \$150,000) at younger ages at diagnosis ($<$ 45 years old).

Conclusions. In this model, surgery is a cost-effective alternative to radiation when VS is diagnosed in patients at $<$ 45 years. For patients $\geq$ 45 years, radiation is the most cost-effective treatment option.
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KEY WORDS • vestibular schwannoma • acoustic neuroma • surgery • cost-utility analysis

VESTIBULAR schwannomas (VSs; also known as acoustic neuromas) are benign tumors that represent approximately 10% of intracranial primary brain tumors.¹² Although they may be asymptomatic, they often present with unilateral hearing loss, tinnitus, imbalance, or vertigo. When they are discovered, VSs are managed in 3 ways: observation (the “wait and scan” approach); Gamma Knife surgery (GKS); or microsurgery. There is a significant body of literature (including many single- and multi-institution studies, as well as meta-analyses)

regarding which management approach is superior.^{10,11} One particularly nice study describes a decision-analytical model for determining which treatment option—observation, radiosurgery, or surgery—will produce the best quality of life outcome for a patient with VS.¹⁵

However, there is very little written about the cost of treating these patients. In a comprehensive PubMed search, we found only 4 studies that attempt to address the “cost” of VS surgery; however, these studies either did not use actual cost data or did not perform complete economic analyses.^{6,13,14} In one study, Sonig et al. reported the average charges per hospitalization (\$76,365.09 $\pm$ \$58,039.93) for 2589 patients who underwent surgery for VSs between 2005 and 2009, as determined from the Nationwide Inpatient Sample (NIS) database.¹³ In the second paper, Verma et al. performed a cost comparison within the Canadian single-payer health care system and reported the average cost of treating a VS with microsurgery.

Abbreviations used in this paper: CAD = Canadian dollars; GKS = Gamma Knife surgery; ICER = incremental cost-effectiveness ratio; NIS = Nationwide Inpatient Sample; NPV = net present value; OR = operating room; PT/OT/RT = physical therapy/occupational therapy/respiratory therapy; QALYs = quality-adjusted life years; UCSF = University of California at San Francisco; VS = vestibular schwannoma.

gery (CAD \$22,402) versus LINAC radiosurgery (CAD \$27,659) versus observation (CAD \$9651).¹⁴ In the third paper, Banerjee et al. calculated initial and follow-up costs for 32 radiosurgery patients (\$16,143) and 21 microsurgery patients (\$23,788) at their institution (Mayo Clinic) between 2000 and 2002.¹ Finally, a British group published the first cost-utility analysis for VS treatment using estimated, as opposed to actual, costs of care in the United Kingdom.⁶

To date, no one has performed a cost-utility analysis with actual costs of care for patients with VS under conservative and nonconservative management paradigms in the multipayer system here in the US. We therefore performed a cost-utility analysis for the treatment of VSs at University of California at San Francisco (UCSF) between 2010 and 2013 under 3 different paradigms: observation, radiosurgery, and surgery.

Methods

We searched the UCSF neurosurgery database for all patients with the diagnosis of VS (ICD-9 code 225.1) who were treated at UCSF between 2010 and 2013. These were consecutively treated patients, and no patients were excluded. This time frame was selected because it is the period for which we have accessible UCSF cost data. After approval from our internal review board, we carefully reviewed the medical records to confirm the VS diagnosis, and then we divided up our patients into those who were observed, those who were treated with GKS, and those who received surgical treatment. Surgical patients had the diagnosis confirmed with pathological investigation, whereas patients in the GKS and observation groups had MRI findings consistent with VS.

Cost data were obtained from the UCSF hospital cost accounting database for our selected patient cohort. Both hospital charges and total costs (direct and indirect, as calculated in the UCSF financial accounting databases) were obtained for each separate patient encounter (i.e., hospitalization, office visit, and so on) and summed for each patient. The intent was to capture the entire cost of care associated with the VS, not just the index hospitalization. Averages are expressed as $\pm$ SD. Cost data manipulation was performed using Matlab scripts. Each inpatient cost item was classified into different categories: operating room (OR) including OR time, anesthesia, and all equipment/supplies; hospital room; diagnostic tests/labs; imaging; medications/blood; physical therapy/occupational therapy/respiratory therapy (PT/OT/RT); and other. Each outpatient cost item was classified into separate categories: diagnostic tests/labs; imaging; medications/blood; radiation-oncology (including direct and indirect costs of running the Gamma Knife machine, as well as nonphysician personnel costs for radiation planning); and outpatient clinic. Of note, the hospital cost accounting database did not include physician fees, so the physician fees (specifically, physician reimbursements) for the neurosurgery, otolaryngology head and neck surgery, and radiation-oncology departments were obtained from separate databases and added to the total hospital costs. Of note, non-UCSF costs incurred in the care of a patient with VS (e.g., inpatient rehabilitation stay after

discharge, outpatient PT/OT) are not available in our database and are therefore not included in our calculations.

We then created a decision-tree model in Microsoft Excel of the 2 most debilitating VS symptoms and worst outcomes (vertigo and death) to analyze the cost-effectiveness of our 3 treatment options by using outcomes information from the largest VS meta-analysis.¹⁵ Health utility indexes, which are preference-based measures of health-related quality of life (based on patients' ratings of the following domains: vision, hearing, speech, ambulation, dexterity, emotion, cognition, and pain), were taken from the published literature (0 for death, 0.62 for vertigo, 1 for perfect health).⁹ We selected these 2 outcomes because they are more disabling (i.e., associated with lower health utility index scores) than other symptoms of VSs, including facial paralysis (0.79)⁷ and unilateral hearing loss (0.82).³ We created separate models for each decade of diagnosis (20, 30, 40, 50, 60, or 70 years old). Average life expectancies, rounded to the nearest year, contingent on current age, were determined from Centers for Disease Control tables (approximately 59 years at age 20, 50 years at age 30, 40 years at age 40, 31 years at age 50, 23 years at age 60, 16 years at age 70).⁸

For patients in the observation group, we estimated a cost of \$750 per year, based on our actual costs for one MRI study (approximately \$500) and one clinic visit per year. For surgery patients, we estimated a total cost of \$82,250, with approximately \$80,000 for surgery (from our actual cost data) and \$750 per year for 3 years of follow-up. Therefore, the estimated costs are not restricted to the index hospitalization during which the surgery occurred, but rather the entire care. This includes pre- and postoperative visits, imaging, and immediate readmissions for complications such as CSF leak and wound infection. For patients in the radiation group, we estimated a cost of \$10,000 for radiation treatment (from our actual cost data) and \$750 per year for 5 years of follow-up. Note that patients who underwent radiation need longer follow-up because patients are not immediately cured with radiosurgery, as they often are with surgery.

Quality-adjusted life years (QALYs) are equal to Time (years) * Health (i.e., Utility). However, to capture the "real time" preference that people have (valuing events in the present more than events in the future), we used a discounting factor of 0.03 and calculated the "net present value" (NPV) for QALYs by using the following Excel formula: $NPV(0.03, \text{Range of Utility Values}) * (1 + 0.03)^{0.5}$. Incremental cost-effectiveness ratios (ICERs) = $\Delta \text{Cost} / \Delta \text{QALYs}$ were computed when appropriate.

Finally, sensitivity analyses were performed to evaluate the effect of several parameters on our model for patients diagnosed at age 40. One parameter was varied at a time. Parameters included chance of death after observation, surgery, and radiation, as well as the chance of developing vertigo after observation; ranges were chosen as the limits of the 95% confidence interval from the largest meta-analysis.¹⁵ The choices of surgery/radiation/observation after initial surgery, radiation, and observation were also varied, given all possible permutations. Finally, the costs of observation, radiation, and surgery were varied $\pm 50\%$.

Results

Total Costs for Treating Patients With VSs

We identified 87 patients with VSs seen by neurosurgeons at our institution between 2010 and 2013. Of these, 33 patients underwent open surgery, 42 had GKS, and 12 were observed. The average ($\pm$ SD) total costs (including physician fees) over the study period for patients in the surgery group were \$80,074 ($\pm$ \$49,678), versus \$9737 ($\pm$ \$5522) for patients receiving GKS and \$1746 ($\pm$ \$2792) for patients in the observation group (Table 1). Of note, the average total costs (excluding physician fees) for the index hospitalization alone (i.e., first surgery) for surgical patients was \$53,438 ($\pm$ \$31,107). The average difference of \$26,728 (between the average total cost of surgical care vs the average cost of the index hospitalization only) reflects the cost of imaging, pre- and postoperative visits, and readmissions for surgical complications such as CSF leakage and wound infection. Table 1 also shows hospital charges, which are, as expected, much higher than total costs.

Our patient cohort had a wide range of surgical costs, with the cheapest being \$35,016 and the most expensive patient in the surgery group costing \$253,601. The first patient had a routine 4-day hospitalization for an uncomplicated resection of a 1.5-cm VS, whereas the other patient had a giant VS (> 3 cm) whose postoperative course was complicated by a CSF leak causing meningitis, a second hospitalization (lasting more than 1 month), and 2 returns to the OR.

To better understand the drivers of cost, we examined the breakdown of inpatient and outpatient surgical costs. Table 2 shows that OR and hospital room costs are 43.3% and 44.6%, respectively, of total surgical inpatient costs. On the outpatient side, imaging is the biggest driver of cost, representing 45.2% of total outpatient costs. These 3 areas (OR, hospital room, and imaging) therefore represent important targets for surgical cost reduction, and we will consider this further in our *Discussion* section.

Like our surgical patients, the patients in the radiation group also had a wide cost range, from \$6499 to \$32,324. The most expensive patient required 5 fractionated treatments of GKS (as opposed to the usual 1 or 2 sessions), resulting in the higher cost. As we would expect, the majority of the cost for our radiation group patients comes from the hospital Gamma Knife costs (80.5%), with imaging costs lagging far behind, at 11% of total cost.

TABLE 1: Average total costs and hospital charges for patients with VS at UCSF*

Treatment Group	Avg Total Costs	Avg Total Hospital Charges
surgery (33)	\$80,074 $\pm$ \$49,678	\$324,933 $\pm$ \$213,384
radiation (42)	\$9737 $\pm$ \$5522	\$76,267 $\pm$ \$43,972
observation (12)	\$1746 $\pm$ \$2792	\$13,656 $\pm$ \$15,261

* The numbers in parentheses denote the number of patients in each group. Costs are expressed $\pm$ SD. Note that average total costs = average total hospital costs for entire care + physician reimbursements, per patient, from 2010 to 2013, rounded to the nearest US dollar. Avg = average.

As compared with the patients in the surgery and radiation group, the cost range for our patients in the observation group was narrower (\$477–\$1108, with one outlier at \$10,408). The major proportion of cost for these patients was imaging (62.2%), followed by clinic visits (23.5%). It is important to note, however, that these values probably represent an underestimate of true observation costs. Given the tertiary referral pattern to our neurosurgery clinic, many of the patients in the observation group received imaging and follow-up visits with local doctors; these costs are not included in the UCSF database.

Characteristics and Outcomes of Patients With VS

Table 3 shows the clinical characteristics of the patients with VS in our cohort. Although there is a trend toward more males in the radiation group (as compared with the observation group: 40% vs 25%), this was not statistically significant ($p > 0.3$). The average age of our patients in the radiation group, however, was significantly higher than the average age of our surgical patients (59 versus 49 years old; $p < 0.01$). The average tumor size in the patients in the surgery group was significantly higher than the average tumor size of the patients in the radiation and observation groups (largest diameter 2.8 cm versus 1.9 and 1.3 cm, respectively; $p < 0.01$). Another important difference between these groups is that the surgical patients had a significantly higher percentage of individuals with neurological deficits at the time of diagnosis (84% in surgical group, vs 56% in radiation group and 18% in observation group; $p < 0.01$). This underscores the fact that the surgical, radiation, and observation groups represent different cohorts of patients. Specifically, our surgical treatment group has younger patients with larger, more symptomatic VSs. It is important to note, however, that we do not see a statistically significant difference in outcomes of our surgical versus radiation group patients ($p > 0.1$; Table 3).

Decision-Tree Model of Patients With VS

Figure 1 demonstrates our decision-tree model for the 3 basic treatment options for VSs (observation, radiosurgery, and surgery). The chance frequencies for vertigo and death after each treatment option are derived from the largest VS decision-modeling meta-analysis.¹⁵ More specifically, observation comes with the highest chance of death (2.4%, vs 1% with radiation and 0.4% with surgery). Similarly, observation is associated with the highest rates of vertigo in the patients with VS (22%), versus 5.7% in patients in the radiosurgery group and 0.8% in patients in the surgery group.¹⁵

Cost-Utility Analysis for VS

Using this decision-tree model, we first perform a cost-utility analysis to determine total lifetime cost and QALYs if a VS is diagnosed in a patient at age 40. Estimates for total lifetime cost for patients in the observation group assumed an annual cost of \$750 (associated with yearly MRIs and clinic visits). Surgical and radiation costs were estimated from our UCSF calculated costs (see *Methods*).

TABLE 2: Categorical breakdown of inpatient and outpatient hospital costs for surgical, radiation, and observation groups of patients with VS treated between 2010 and 2013*

Cost Category	Avg Surgical Costs (%)	Avg Radiation Costs (%)	Avg Observation Costs (%)
inpatient			
hospital room	\$30,420 (44.6%)	\$0	\$0
OR	\$29,520 (43.3%)	\$0	\$0
medications/blood	\$2477 (3.6%)	\$0	\$0
PT/OT/RT	\$1922 (2.8%)	\$0	\$0
imaging	\$1783 (2.6%)	\$0	\$0
diagnostic tests/labs	\$1715 (2.5%)	\$0	\$0
other	\$334 (0.5%)	\$0	\$0
outpatient			
radiation	\$0 (0%)	\$6958 (80.5%)	\$0 (0%)
imaging	\$986 (45.2%)	\$949 (11.0%)	\$1087 (62.2%)
diagnostic tests/labs	\$214 (9.8%)	\$48 (0.6%)	\$250 (14.3%)
clinic	\$245 (11.2%)	\$669 (7.7%)	\$410 (23.5%)
other	\$736 (33.8%)	\$1 (<0.5%)	\$0 (0%)
physician reimbursements	\$6292	\$1214	\$0

* Note that (%) indicates percentage of total inpatient or outpatient cost. Surgical costs include the total surgical care, not just the index hospitalization.

Table 4 shows that surgical patients have the highest estimated lifetime cost (\$82,527), followed by observation (\$34,251) and then radiation (\$15,714). The highest QALY is associated with surgery (23.30), followed by radiation (22.81) and then observation (21.40). Radiation is there-

fore a dominant treatment to observation, in that it is both cheaper in the long term (lower cost) and produces better outcomes (higher QALY). Table 4 also demonstrates that surgery is a cost-effective treatment as compared with radiation, with an ICER of \$137,747. In the US, ICERs <

TABLE 3: Characteristics and outcomes of patients in the surgery versus radiation versus observation groups in the UCSF cohort*

Variable	Surgery	Radiation	Observation
characteristic			
male	11 (33%)	17 (40%)	3 (25%)
female	22 (67%)	25 (60%)	9 (75%)
age in yrs	49 ± 15.3†	59 ± 11.1†	52 ± 16.7
tumor size in cm	2.8 ± 1.5†	1.9 ± 1.2†	1.3 ± 1.3†
preintervention status			
no deficit	4 (13%)	17 (42%)	9 (82%)
minor deficit	26 (84%)†	23 (56%)†	2 (18%)†
major deficit	1 (3%)	1 (2%)	0 (0%)
outcome			
postintervention status			
no deficit	5 (16.1%)	5 (33%)	NA
minor deficit	24 (77.4%)	10 (67%)	NA
major deficit	2 (6.5%)	0 (0%)	NA
disposition			
home	22 (71%)	NA	NA
SNF, rehabilitation	9 (29%)	NA	NA

* Age is average age at diagnosis, and tumor size is largest diameter in centimeters; both values are expressed ± SD. Subtotals vary because some data were not available in the electronic medical records. NA = not applicable; SNF = skilled nursing facility.

† Statistically significant difference between groups ($p < 0.01$). Minor deficits include mild dizziness and facial nerve dysfunction; major deficits include hemiparesis and coma.

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Fig. 1. Decision-tree model of VS treatment options. Squares indicate decision nodes, circles are chance nodes. Chance frequencies are derived from Whitmore et al., *J Neurosurg* 114:400–413, 2011.

\$150,000 are typically considered cost-effective, because this represents 3 times our gross domestic product per capita (www.who.int/choice/costs/CER_thresholds/en/).

We then perform similar cost-utility analyses for different ages at diagnosis, ranging from 20 to 70 years old. Table 5 shows that radiation is superior to observation (in that it is cheaper and has a higher QALY) at all ages of diagnosis through 70 years. The ICER for surgery (as compared with radiation) is < \$150,000 for ages at diagnosis of 20–40 years. For ages at diagnosis ≥ 50 years, the ICER is > \$150,000 and increases up to \$307,070 for patients diagnosed at age 70. The cutoff at which surgery is no longer cost-effective (ICER < \$150,000) is closest to 45 years old, at which the ICER is \$151,429.

Sensitivity Analysis

To assess the robustness of our results, we performed several sensitivity analyses. We first varied the chance of

death after observation, radiation, and surgery, using the 95% confidence intervals reported in the largest meta-analysis.¹⁵ With all variations, radiation remained dominant to observation (i.e., both cheaper and with higher QALY), and the ICER for surgery remained < \$150,000, except when the surgical death rate increased to 0.6% (ICER = \$152,367) and the radiation death rate decreased to 0.3% (ICER = \$206,881). Next, we varied the chance of vertigo after observation, radiation, and surgery, once again using the 95% confidence intervals from the Whitmore et al. meta-analysis. With all variations, radiation remained dominant to observation, and the ICER for surgery remained < \$150,000, except when the surgical vertigo rate increased to 5%, at which point the ICER (for surgery vs radiation) rose dramatically to \$362,468 (Table 6).

For all permutations of surgery/radiation/observation after initial observation, radiation, or surgery, our results were constant, with radiation dominant to observation, and

TABLE 4: Cost-utility model if VS is diagnosed at age 40*

Treatment	Cost	ΔCost	QALYs	ΔQALYs	ICER
radiation	\$15,714		22.81		
observation	\$34,251	\$18,538	21.40	−1.41	†
surgery	\$82,527	\$66,814	23.30	0.49	\$137,747

* Total costs estimated over life expectancy of 40 additional years.

† Observation is dominated by radiation treatment because it is more expensive and has a lower QALY than radiation.

TABLE 5: Results of cost-utility analysis if VS is diagnosed at various ages

Age (yrs) at Diagnosis	ICER (radiation vs observation)*	ICER (surgery vs radiation)
20	dominant	\$111,117
30	dominant	\$121,553
40	dominant	\$137,747
50	dominant	\$163,108
60	dominant	\$202,584
70	dominant	\$307,070

* "Dominant" indicates that no ICER can be calculated because radiation is dominant to observation; i.e., it is both cheaper and has a higher QALY.

ICER for surgery versus radiation < \$150,000. Finally, we found that our results remained the same when increasing and decreasing the cost of observation or radiation by 50% (Table 7). When we increased the cost of surgery by 50%, our ICER for surgery rose to \$221,300, and when we decreased the cost of surgery by 50%, our ICER for surgery became much more cost-effective, at \$54,195.

Discussion

Our study is one of the only reports on the total cost

of treating VS patients in the US. Our surgical costs (average \$80,074) are higher than the only other reported costs from the US (\$23,788 for surgery at Mayo Clinic between 2000 and 2002¹), which may reflect institutional differences as well as the rising cost of health care over the past decade. Interestingly, however, our average radiosurgery costs (\$9737) are lower than those reported in the Mayo Clinic study (\$16,413), perhaps due to decreasing radiosurgery costs with improving technology over time. Similarly, our surgical costs in the multipayer system here in the US are higher than those reported in Canada (\$80,074 in our study vs \$22,402 in Canada¹⁴), which is consistent with other studies showing similar cost discrepancies between the 2 countries for cardiac bypass surgery.⁴

One of the strengths of our study is that we calculate hospital costs, as compared with charges (i.e., what the hospital bills the insurance company), which were reported in the study by Sonig et al. in which the NIS database was used.¹³ Several recent studies show that hospital charges (or billing) bear little resemblance to economic cost,² and use of hospital charges as a proxy for cost may lead researchers to draw unwarranted conclusions.⁵ The best measure of cost is actual resource utilization,⁵ which can be extremely difficult to calculate. We believe that by combining our direct cost data from the hospital accounting database with actual physician reimbursements, we have calculated the closest and most accurate proxy for the true cost of care for patients with VS that has been published to date. Although we appreciate that physician reimbursements may not accurately reflect the true "cost"

TABLE 6: Sensitivity analysis for cost-utility model at age 40

Parameter (base case value)*	Radiation vs Observation†		Surgery vs Radiation		
	ΔCost	ΔQALYs	ΔCost	ΔQALYs	ICER
base case	-\$18,538	1.41	\$66,814	0.49	\$137,747
death after observation (0.024)					
0.02	-\$18,675	1.33	\$66,814	0.49	\$137,747
0.03	-\$18,332	1.55	\$66,814	0.49	\$137,747
death after surgery (0.004)					
0.002	-\$18,538	1.41	\$66,814	0.53	\$125,687
0.006	-\$18,538	1.41	\$66,814	0.44	\$152,367
death after radiation (0.01)					
0.003	-\$18,524	1.57	\$66,800	0.32	\$206,881
0.013	-\$18,544	1.35	\$66,819	0.55	\$120,496
vertigo after observation (0.22)					
0.16	-\$17,378	0.99	\$66,814	0.49	\$137,747
0.26	-\$19,311	1.69	\$66,814	0.49	\$137,747
vertigo after radiation (0.057)					
0.055	-\$18,607	1.43	\$66,882	0.47	\$142,034
0.059	-\$18,469	1.40	\$66,745	0.50	\$133,701
vertigo after surgery (0.008)					
0	-\$18,538	1.41	\$66,536	0.54	\$122,947
0.05	-\$18,538	1.42	\$68,269	0.19	\$362,468

* Each parameter is varied independently; parameter ranges represent 95% confidence interval from the meta-analysis by Whitmore et al.

† Radiation dominant to observation; no ICER can be calculated.

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TABLE 7: Sensitivity analysis for cost-utility model at age 40

Parameter (base case value)*	Radiation vs Observation†		Surgery vs Radiation		
	ΔCost	ΔQALYs	ΔCost	ΔQALYs	ICER
base case	−\$18,538	1.41	\$66,814	0.49	\$137,747
cost of observation (\$750/yr)					
\$1,125/yr	−\$32,402	1.41	\$66,668	0.49	\$137,747
\$375/yr	−\$2825	1.41	\$66,978	0.49	\$138,087
cost of radiation (\$13,750)					
\$20,625	−\$11,989	1.41	\$59,839	0.49	\$123,367
\$6,875	−\$25,086	1.41	\$73,788	0.49	\$152,127
cost of surgical care (\$82,250)					
\$123,375	−\$20,491	1.41	\$107,340	0.49	\$221,300
\$41,125	−\$16,585	1.41	\$26,286	0.49	\$54,195

* Each cost parameter is varied independently $\pm 50\%$.

† Radiation dominant to observation; no ICER can be calculated.

of physician services, we believe that this is a better proxy than physician charges, which are often significantly inflated (to account for low reimbursement rates, for instance). Moreover, the physician reimbursement reflects the actual cost to society (in terms of dollars transferred in our economy) to pay for that physician's services. We acknowledge that a homogeneous method of calculation of cost for hospital-related care and physician services is needed so that we can better compare results across studies and organizations.

Furthermore, we provide the first published breakdown of hospital costs for these patients. In our current economic climate, price transparency is one of the first, and necessary, steps toward cost containment. As we would expect, we find that the OR and hospital stay are the most expensive aspects of hospitalization for a patient with VS. More specifically, 1 minute of OR time costs between \$53 and \$78, an ICU bed costs \$4337 per day, and a floor bed costs \$1519 per day at our institution. This suggests that reduction of OR costs and length of hospital stay could significantly impact surgical costs. For example, just a 10% reduction in surgical costs (from \$82,250 to \$74,025) results in improved ICERs and makes surgery a cost-effective option for patients who are diagnosed at age 50 (ICER \$143,255).

Although we recognize the limitations of our relatively small data set, we believe that our data and conclusions are more powerful than larger studies, such as the one by Sonig et al.,¹³ because of the accuracy of our cost data. Expanding our study to other institutions might help increase generalizability, but would also decrease confidence in our cost data and therefore introduce further sources of error. Unfortunately, none of the nationally available databases (such as the NIS or Premier databases) provide real cost data for this type of analysis. Another important limitation is our retrospective study design, and the different characteristics of our surgical, radiation, and observation groups. Specifically, our surgical group is composed of younger patients with larger, more symptomatic tumors. We acknowledge that a prospective study of all patients in whom VSs were diagnosed, controlling

for tumor size, patient age, and symptoms, would provide the best measure of cost over a variety of treatment paradigms. Such a study would also enable us to determine treatment recommendations based on age, presentation, and tumor size (for example, what is the most cost-effective treatment for a 40-year-old patient who presents with a < 1-cm asymptomatic VS?), detailed questions that we cannot fully answer with our current analysis.

Finally, our cost-utility model provides an important guideline for neurosurgical practice. Unlike the only other VS cost-utility analysis in this area,⁶ our model calculates utilities based on the chances of vertigo and death. We have selected these 2 outcomes (as opposed to the hearing loss, facial nerve dysfunction, and so on examined in Gait et al.'s study) because these are 2 of the most debilitating symptoms/complications of VSs. Patients can often continue to have a relatively normal life with unilateral hearing loss, but symptoms of vertigo that lead to dizziness, nausea, and imbalance can have a significant impact on their well-being and ability to work. These differences are reflected in published health utilities, which, for example, are lower for vertigo than for unilateral hearing loss or facial paralysis.⁹ We acknowledge that selection of these 2 outcome metrics may bias our results in favor of surgery, given that facial paralysis and hearing loss outcomes are more favorable for radiosurgery than for open surgery.

Another major improvement in our model is that we consider many decades of diagnosis (from 20 to 70 years old), whereas Gait et al. only looked at a starting age of 58 years.⁶ Our longer duration of follow-up probably explains the difference in our results, in that we find that surgery is a cost-effective option for patients < 45 years old. Lastly, we understand that patients may have staged treatments (planned surgery, followed by radiation) or may have multiple rounds of either surgery or radiation, which are not accounted for in our model. Similarly, there are many additional options, including return to emergency room, readmission for complication, and so on that we have not included. We have assumed only 2 decision points in our model to avoid this extraordinary complexity.

Conclusions

We report that the average total hospital cost over a 3-year period for surgically treated patients with VS was \$80,074 ($\pm$ \$49,678) versus \$9737 ($\pm$ \$5522) for patients receiving radiosurgery and \$1746 ($\pm$ \$2792) for patients who were observed. When modeling the most debilitating symptoms/complications of VSs (vertigo and death) at different ages at diagnosis, we find that surgery is a cost-effective alternative to radiation when VS is diagnosed in patients who are < 45 years old. For patients $\geq$ 45 years, radiation is the most cost-effective treatment option for VSs. This is the first cost-utility analysis for VSs using real cost data published in the US.

Disclosure

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Author contributions to the study and manuscript preparation include the following. Conception and design: Zygourakis, Barani, Parsa. Acquisition of data: Zygourakis, Oh, Sun. Analysis and interpretation of data: Zygourakis, Barani, Kahn. Drafting the article: Zygourakis. Critically revising the article: Zygourakis, Oh, Sun, Barani, Kahn. Reviewed submitted version of manuscript: all authors. Approved the final version of the manuscript on behalf of all authors: Zygourakis. Statistical analysis: Zygourakis, Kahn. Study supervision: Zygourakis, Parsa.

References

- Banerjee R, Moriarty JP, Foote RL, Pollock BE: Comparison of the surgical and follow-up costs associated with microsurgical resection and stereotactic radiosurgery for vestibular schwannoma. **J Neurosurg** 108:1220–1224, 2008
- Brill S: Bitter pill: why medical bills are killing us. **Time Magazine**. April 4, 2013. pp 16–55
- de Wolf MJ, Hol MK, Mylanus EA, Snik AF, Cremers CW: Benefit and quality of life after bone-anchored hearing aid fitting in children with unilateral or bilateral hearing impairment. **Arch Otolaryngol Head Neck Surg** 137:130–138, 2011
- Eisenberg MJ, Filion KB, Azoulay A, Brox AC, Haider S, Pilote L: Outcomes and cost of coronary artery bypass graft surgery in the United States and Canada. **Arch Intern Med** 165:1506–1513, 2005
- Finkler SA: The distinction between cost and charges. **Ann Intern Med** 96:102–109, 1982
- Gait C, Frew EJ, Martin TP, Jowett S, Irving R: Conservative management, surgery and radiosurgery for treatment of vestibular schwannomas: a model-based approach to cost-effectiveness. **Clin Otolaryngol** 39:22–31, 2014
- Hernández RA, Sullivan F, Donnan P, Swan I, Vale L: Economic evaluation of early administration of prednisolone and/or aciclovir for the treatment of Bell's palsy. **Fam Pract** 26:137–144, 2009
- Hoyert DL, Xu J: **Deaths: Preliminary Data for 2011**. Centers for Disease Control and Prevention (http://www.cdc.gov/nchs/data/nvsr/nvsr61/nvsr61_06.pdf) [Accessed September 3, 2014]
- Loughran S, Gatehouse S, Kishore A, Swan IR: Does patient-perceived handicap correspond to the modified clinical test for the sensory interaction on balance? **Otol Neurotol** 27:86–91, 2006
- Maniakas A, Saliba I: Conservative management versus stereotactic radiation for vestibular schwannomas: a meta-analysis of patients with more than 5 years' follow-up. **Otol Neurotol** 33:230–238, 2012
- Maniakas A, Saliba I: Microsurgery versus stereotactic radiation for small vestibular schwannomas: a meta-analysis of patients with more than 5 years' follow-up. **Otol Neurotol** 33:1611–1620, 2012
- Schmidt RF, Boghani Z, Choudhry OJ, Eloy JA, Jyung RW, Liu JK: Incidental vestibular schwannomas: a review of prevalence, growth rate, and management challenges. **Neurosurg Focus** 33(3):E4, 2012
- Sonig A, Khan IS, Wadhwa R, Thakur JD, Nanda A: The impact of comorbidities, regional trends, and hospital factors on discharge dispositions and hospital costs after acoustic neuroma microsurgery: a United States nationwide inpatient data sample study (2005–2009). **Neurosurg Focus** 33(3):E3, 2012
- Verma S, Anthony R, Tsai V, Taplin M, Rutka J: Evaluation of cost effectiveness for conservative and active management strategies for acoustic neuroma. **Clin Otolaryngol** 34:438–446, 2009
- Whitmore RG, Urban C, Church E, Ruckenstein M, Stein SC, Lee JY: Decision analysis of treatment options for vestibular schwannoma. Clinical article. **J Neurosurg** 114:400–413, 2011

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