Contemporary Surgical Management of Vestibular Schwannomas: Analysis of Complications and Lessons Learned Over the Past Decade

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BACKGROUND: Despite advanced microsurgical techniques, more refined instrumentation, and expert team management, there is still a significant incidence of complications in vestibular schwannoma surgery.

OBJECTIVE: To analyze complications from the microsurgical treatment of vestibular schwannoma by an expert surgical team and to propose strategies for minimizing such complications.

METHODS: Surgical outcomes and complications were evaluated in a consecutive series of 410 unilateral vestibular schwannomas treated from 2000 to 2009. Clinical status and complications were assessed postoperatively (within 7 days) and at the time of follow-up (range, 1-116 months; mean, 32.7 months).

RESULTS: Follow-up data were available for 357 of the 410 patients (87.1%). Microsurgical tumor resection was performed through a retrosigmoid approach in 70.7% of cases. Thirty-three patients (8%) had intrameatal tumors and 204 (49.8%) had tumors that were <20 mm. Gross total resection was performed in 306 patients (74.6%). Hearing preservation surgery was attempted in 170 patients with tumors <20 mm, and good hearing was preserved in 74.1%. The main neurological complication was facial palsy (House-Brackmann grade III-VI), observed in 14% of patients (56 cases) postoperatively; however, 59% of them improved during the follow-up period. Other neurological complications were disequilibrium in 6.3%, facial numbness in 2.2%, and lower cranial nerve deficit in 0.5%. Nonneurological complications included cerebrospinal fluid leaks in 7.6%, wound infection in 2.2%, and meningitis in 1.7%.

CONCLUSION: Many of these complications are avoidable through further refinement of operative technique, and strategies for avoiding complications are proposed.

KEY WORDS: Acoustic neuroma, Facial nerve palsy, Hearing preservation, Postoperative complications, Vestibular schwannoma

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Surgery of vestibular schwannoma (VS) remains a challenging procedure. The goal of VS surgery is radical tumor resection with preservation of normal facial nerve (FN) function and hearing preservation, if indicated, without postoperative complications. In recent years, surgical management of VS has benefitted from earlier diagnosis, advanced skull base techniques, a skull base expert team approach, and better intraoperative monitoring.[1-5] However, despite these advances, recent reported series still document a significant incidence of cranial nerve (CN) deficits and surgical complications.[6-28]

The purpose of the present study is to critically review outcomes and to elucidate complications of VS surgery in a consecutive series of 410 patients treated surgically over the past 10 years at Duke and to identify strategies for avoiding complications.

ABBREVIATIONS: ABR, auditory brainstem response; **AICA,** anterior inferior cerebellar artery; **CN,** cranial nerve; **CPA,** cerebellopontine angle; **FN,** facial nerve; **GTR,** gloss total resection; **H-B,** House-Brackmann; **HPS,** hearing preservation surgery; **NTR,** near-total resection; **SRT,** stereotactic radiation therapy; **STR,** subtotal resection; **VAFE,** vascular, adherent, fibrous, and engulfing; **VS,** vestibular schwannoma

PATIENTS AND METHODS

Patient Population

There were 410 consecutive unilateral VSs (excluding neurofibromatosis type II cases) surgically treated by the senior authors between January 2000 and December 2009 at Duke University Medical Center and Duke Raleigh Hospital. Patient charts were reviewed retrospectively for clinical status, operative findings, radiological results, and clinical outcomes. The data were analyzed with respect to tumor size, surgical approach, extent of resection, surgical results, and complications. Patient characteristics are summarized in Table 1. The patients' ages ranged from 13 to 82 years (mean age, 49.7 years). There were 179 male (43.7%) and 231 female (56.3%) patients.

Classification of Tumor Size

Tumor size was categorized according to the international criteria using the largest extrameatal tumor diameter on the postcontrast axial magnetic resonance image (MRI; Table 2).[29] Grade 0 is for intrameatal tumors without extension into the posterior fossa; grade 1 is for small tumors ≤10 mm; grade 2 is for medium tumors extending 11 to 20 mm; grade 3 is for moderately large tumors from 21 to 30 mm; grade 4 is for large tumors 31 to 40 mm; and grade 5 is for giant tumors >40 mm in the cerebellopontine angle (CPA).

TABLE 1. Characteristics in 410 Patients With Vestibular Schwannomas[a]

Characteristics	
Age, y	
Range	13-82
Average	49.7
Sex, n (%)	
Male	179 (43.7)
Female	231 (56.3)
Size of tumors, n (%)	
Intracanal	33 (8.0)
Small (≤10 mm)	56 (13.7)
Medium	148 (36.1)
Moderately large (21-30 mm)	111 (27.1)
Large (31-40 mm)	33 (8.0)
Giant (≥41 mm)	29 (7.1)
Surgical approaches, n (%)	
RS approach	290 (70.7)
TL approach	103 (25.1)
MF approach	17 (4.2)
Extent of tumor resection, n (%)	
GTR	306 (74.6)
NTR	77 (18.8)
STR	27 (6.6)
Follow-up range, mo	1-116
Average	32.7
Availability (cases)	357 (87.1)
HPS attempted (cases), n (%)	170 (41.5)
Previous surgery (cases), n (%)	25 (6.1)
Previous radiosurgery, n (%)	8 (1.9)

[a]GTR, gross total resection; HPS, hearing preservation surgery; MF, middle fossa; NTR, near-total resection; RS, retrosigmoid; STR, subtotal resection; TL, translabyrinthine.

TABLE 2. International Grading of Size of Vestibular Schwannomas[a]

Grade		Size, mm
0	Intrameatal tumor	No extension out of the IAC
1	Small	≤ 10
2	Medium	11-20
3	Moderately large	21-30
4	Large	31-40
5	Giant	≥41

[a]IAC, internal auditory canal.

Classification of Hearing Function

Preoperative and postoperative hearing function was classified according to the Sanna-Fukushima international classification system (Table 3).[5,3,30] In this system, pure tone average and speech discrimination score are used to categorize hearing as normal, good, fair, serviceable, measurable, and deaf as listed in Table 3. Tumor size and hearing classification according to this system were used to select candidates for hearing preservation surgery (HPS). Patients with tumors <20 mm (grade 0-2) and hearing level within class A, B, or C were offered HPS. If the tumor was >2 cm, HPS was attempted only if the patient had hearing in the class A or B range and had an identifiable wave 5 on auditory brainstem response (ABR).

Evaluation of FN Function

FN function was evaluated according to the House-Brackmann (H-B) FN function grading scale immediately after surgery and at the time of last follow-up.[31] We classified FN function into 3 categories: good (H-B I+II), fair (H-B III), and poor (H-B IV+V+VI).

Surgical Approaches

In this series, 3 surgical approaches were used. The majority of small to medium tumors and all HPS cases were treated with the standard retrosigmoid approach.[18] In patients with hearing loss and in cases with otologist participation, the translabyrinthine approach was used.[32] In general, there was a preference for the translabyrinthine approach in patients with large tumors and hearing loss. The middle fossa approach was used in some cases of intrameatal tumor.[20]

TABLE 3. Sanna-Fukushima Classification of Hearing Level[a]

Class	PTA, dB	SDS, %	Definition
A	0-20	80-100	Normal
B	21-30	70-79	Good
C	31-40	60-69	Fair
D	41-60	50-59	Serviceable
E	61-80	40-49	Measurable
F	≥81	0-39	Deaf

[a]PTA, pure tone average; SDS, speech discrimination score.

Intraoperative Monitoring

FN monitoring was used for all cases, with a preference for the NIM-Response 2.0 or 3.0 Patient Stimulator (Medtronic Xomed, Inc, Jacksonville, Florida). Continuous ABR was used for all HPS cases.

Extent of Tumor Resection

The extent of tumor resection was divided into 3 categories. Category 1, gross total resection (GTR), means a microscopically total removal by the surgeon's determination with no residual tumor detected on postoperative contrasted MRI. Category 2, near-total resection (NTR), means a small trace (<0.5 mm) of the tumor capsule remains on the thinned and stretched CN VII or VIII or on the surface of the brainstem. Postoperative MRI shows a thin line of enhancement (<1%-2% of original mass). Category 3, subtotal resection (STR), means a tumor capsule of a few millimeters' thickness is left with CN VII or VIII or on the brainstem. Postoperative MRI shows a residual mass approximately 5% to 10% of the original volume.

Analysis of Postoperative Complications

Postoperative complications were evaluated immediately perioperatively (within 1 week) and at the time of last follow-up (long-term or persistent complications). FN palsy, disequilibrium, tinnitus, facial numbness, and lower CN deficits were categorized as neurological complications. Nonneurological complications included cerebrospinal fluid (CSF) leak, wound infection, meningitis, deep vein thrombosis, and hydrocephalus. Follow-up examination was obtained in 357 of the 410 patients (87.1%). The follow-up period ranged from 1 to 116 months (mean, 32.7 months). Twenty-six percent of patients had <12 months of postoperative follow-up, 43% had 12 to 60 months of follow-up, and 18.3% had >60 months of follow-up.

RESULTS

Tumor Size and Extent of Resection

Extent of tumor resection as a function of tumor size is depicted in Figure 1. In 33 cases of grade 0 or intrameatal tumor, GTR was achieved in 100% of cases. In 56 cases of grade 1 (small) tumor, GTR was achieved in 98.2%, and only 1 case (1.8%) had NTR. In 148 cases of grade 2 (medium) tumor, 115 (77.7%) had GTR, 29 cases (19.6%) had NTR, and 4 cases (2.7%) had STR. In 111 cases of grade 3 (moderately large), 75 cases (67.6%) had GTR, 26 cases (23.4%) had NTR, and 10 cases (9%) had STR. In 33 cases of grade 4 (large) tumor, 15 cases (45.5%) had GTR, 13 cases (39.4%) had NTR, and 5 cases (15.5%) had STR. In 29 cases of grade 5 (giant) tumor, 13 (44.8%) had GTR, 8 (27.6%) had NTR, and 8 (27.6%) had STR. The retrosigmoid approach was performed in 290 cases (70.7%), for the majority of small to medium tumors, and for hearing preservation. The translabyrinthine approach was used in 103 cases (25.1%), and the middle fossa approach was used in 17 cases (4.2%).

Long-term Tumor Control

Tumor recurrence/regrowth was defined as increasing tumor size noted in at least 2 sequential follow-up MRIs. At the last follow-up, radiographic tumor regrowth was detected in 11 of 357 patients (3.1%), yielding a long-term control/cure rate of 96.9%. Of 357

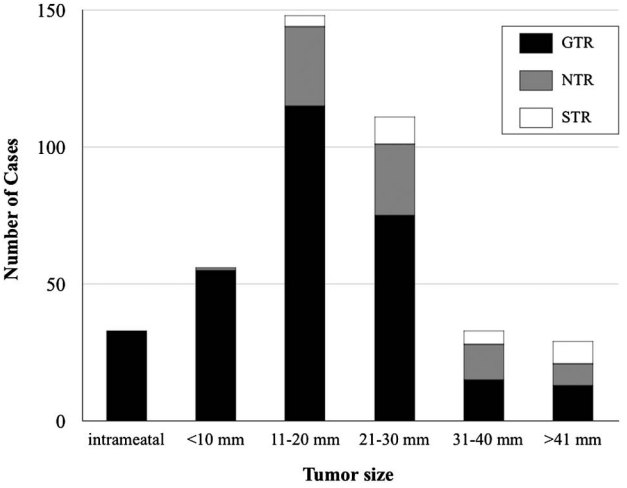

FIGURE 1. *Bar graph demonstrating the distribution of tumors by size with extent of resection in 410 cases. GTR, gross total resection; NTR, near-total resection; STR, subtotal resection.*

patients who were followed up, there were 266 patients with GTR, 67 with NTR, and 24 with STR. In the recurrent group, there were 3 male and 8 female patients, with an age range of 24 to 66 years (mean, 43 years). Time to recurrence ranged between 13 and 84 months (mean, 48 months). Six cases of small recurrence were found in the 266 patients with GTR (2.3%). For these patients, recurrence was detected at 22 to 84 months (mean, 53.8 months). In the NTR group, regrowth was detected in 2 of 67 patients (2.9%). For these patients, regrowth was detected at 19 to 70 months (mean, 44.5 months). In the 24 patients in the STR group, there were 3 cases of regrowth (12.5%). Regrowth was detected at 13 to 61 months (mean, 38.7 months). When some of the patients with shorter follow-up (<12 months) were excluded, the recurrence rates were raised to 3.2%, 4.2%, and 21.4% in GTR, NTR, and STR, respectively.

In the 11 patients with recurrent/regrowing tumors, FN function had been stable when the tumor regrowth was detected (H-B I, 8; II, 1; III, 1; and IV, 1). Only 4 patients had useful hearing function after the initial surgery, and one of them lost hearing during tumor regrowth. In these patients, reoperation was required in 3 patients (0.8%) because of the size of the mass, and stereotactic radiation was used in 2 patients with recurrence/regrowth by patient request (0.5%). In the 3 patients who required reoperation, all of them kept preoperative FN function (H-B I, 2; III, 1) after surgery, whereas none of them had useful hearing function at the time of the initial surgery. The other 6 patients (55%) with recurrent tumors have been stable under observation with annual MRI examination.

Preservation of Hearing Function (Perioperative Outcome)

HPS was attempted in 170 patients (41.5%) with small to medium (<2 cm) tumors. There were 28 intrameatal tumors

(grade 0), 40 small tumors (grade 1), and 102 medium tumors (grade 2). Overall, in 129 cases (75.9%), useful postoperative hearing was preserved (Figure 2). Of 28 patients with intrameatal tumors, 24 (85.7%) retained normal to fair hearing. Of 40 patients with small tumors, 32 (80%) had good hearing. Of 102 patients with medium-sized tumors, 73 (71.6%) kept useful hearing. Of these 170 patients, GTR was performed in 150 (88.2%; Table 4). The hearing preservation rate in cases of GTR was 75.3%. In the same way, the hearing preservation rates in cases of NTR and STR were 82.4% and 66.7%, respectively.

HPS was attempted in 29 patients with tumors >21 mm whose preoperative hearing function was classified as A or B. Twenty-four of 29 patients (82.8%) retained useful or serviceable hearing postoperatively. GTR, NTR, and STR were performed in 11 (37.9%), 12 (41.4%), and 6 (20.7%) of these 29 patients, respectively. The hearing preservation rate was 63.6% in GTR, 100% in NTR, and 83.3% in STR.

TABLE 4. Hearing Preservation Rate Relative to Extent of Tumor in 170 Patients[a]

Extent of Tumor	HPS Attempted	Preserved	Success Rate, %
GTR	150	113	75.3
NTR	17	14	82.4
STR	3	2	66.7

[a]GTR, gross total resection; HPS, hearing preservation surgery; NTR, near-total resection; STR, subtotal resection. All tumors were <20 mm in size (grade 0-2).

FN Function

Of 410 cases, 10 patients had preexisting FN palsy resulting from prior surgery elsewhere, radiation therapy, or stroke. These patients were excluded from analysis. Immediately after surgery, good (H-B grade I or II) FN function was seen in 344 cases (86.0%; H-B I, 276; II, 68), fair (H-B grade III) FN function was seen in 27 patients (6.8%), and poor FN function (H-B grade IV-VI) was seen in 29 patients (14.0%; H-B IV, 16 [4.0%]; V, 3 [0.7%]; VI, 10 [2.5%]).

The relationship between extent of tumor resection is summarized in Figure 3. In 300 cases of the GTR group, 267 (89.0%) had good FN function (H-B I, 217; II, 50), 15 patients (5%) had fair FN function, and 18 (6%; H-B IV, 8; V, 2; VI, 8) had poor results. In 74 cases of NTR, 57 patients (77.0%) had good results, 8 patients (10.8%) had fair results, and 9 patients (12.2%) had poor outcome. In 26 patients with STR, 20 patients (76.9%) had good FN function, 4 patients (15.4%) had fair FN function, and 2 patients (7.7%) had poor outcome.

Relative to tumor size, intrameatal tumors (32 cases) were associated with 100% good facial function; of grade 1 small tumors (56 cases), 96.4% had good FN function; for grade 2 medium tumors (142 cases), 92.3% had good results; of 110 cases of grade 3 moderately large tumors, 79.1% had good results; of grade 4 tumors (33 cases), 60.6% good outcomes; and in grade 5 giant tumors (29 cases), 74.1% had good outcomes (Figure 4).

Anatomic preservation of the FN was achieved in 404 of 410 cases (98.5%). In 1 case, the FN was very thin with decreased electric response, and then the nerve was sacrificed and repaired with an FN to hypoglossal nerve end-to-side anastomosis. In another 5 patients, 3 cases of extremely stretched and elongated transparent FNs and 2 cases of tumor engulfed FNs were observed. In three of these patients, an end-to-end anastomosis was performed, and a sural nerve graft was used in 2 cases.

Postoperative delayed FN palsy occurred at 2 to 26 days in 6 cases (1.5%; H-B II, 2; III, 2; IV, 1; V, 1). Of 56 cases of FN palsy (H-B III, 27; IV-VI, 29), 33 patients (58.9%) recovered good or fair (H-B I-III) FN function, 12 patients normalized, 15 patients improved to grade II, and 6 improved to grade III. Of 68 patients

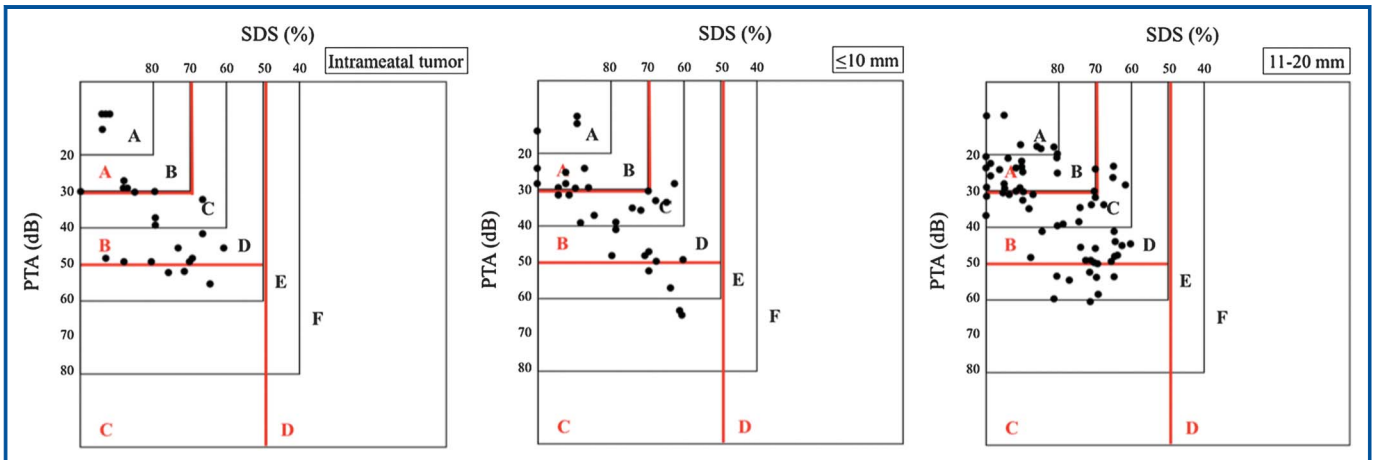

FIGURE 2. *Scatterplot demonstrating postoperative hearing: American Academy of Otolaryngology–Head and Neck Surgery (AAO-HNS) criteria (red) and Sanna-Fukushima international criteria (black). A better speech discrimination score (SDS) class than the pure tone average (PTA) class makes the category of the patient 1 class better.*

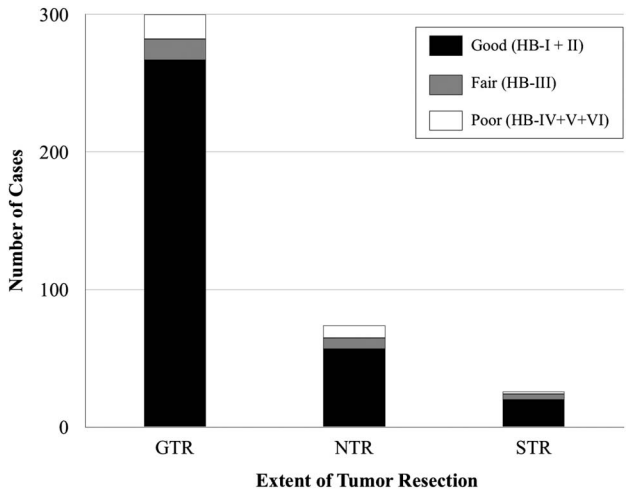

FIGURE 3. *Bar graph demonstrating perioperative facial nerve outcomes relative to extent of resection in 400 cases. Ten cases of preexisting facial nerve palsy (House-Brackmann [HB]-II, 3; III, 4; V, 3) were excluded. GTR, gross total resection; NTR, near-total resection; STR, subtotal resection.*

with grade II slight weakness, 37 (54.4%) improved to normal FN function.

Postoperative Complications

There was no mortality or any major complications in this series. Perioperative neurological complications included disequilibrium in 42 (10.2%), bothersome tinnitus in 9 (2.2%), facial numbness in 5 (1.2%), taste disturbance in 3 (0.7%), and lower CN deficits in 2 (0.5%) patients. Nonneurological complications included CSF leak in 31 (7.6%; revision required in 13 patients), wound infections in 9 (2.2%; revision required in 2 patients), meningitis in 7 (1.7%), brain swelling in 5 (temporal lobe, 2 patients; cerebellum, 3 patients), deep vein thrombosis in 2 (0.5%), gastric ulcer in 1 (0.2%), and pneumothorax in 1 patient. Meningitis, brain swelling, deep vein thrombosis, gastric ulcer, and pneumothorax resolved with standard medical treatment. Acute hydrocephalus was noted in 3 patients, each of whom required a ventriculoperitoneal shunt.

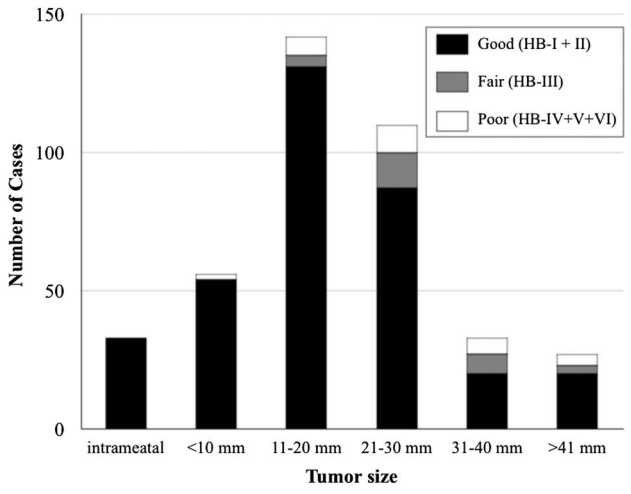

FIGURE 4. *Bar graph demonstrating perioperative facial nerve outcomes relative to tumor size in 400 cases. Ten cases of preexisting facial nerve palsy (House-Brackmann [HB]-II, 3; III, 4; IV, 3) were excluded.*

The incidence of postoperative CSF leak was much higher than expected in this series. CSF leak was characterized by rhinorrhea (8 cases; 2%), otorrhea (3 cases; 0.7%), and leakage from the operative wound (20 cases; 4.9%). Of these 31 cases, 16 cases of wound leaks regressed spontaneously with a pressure dressing (with or without lumbar drainage); 2 patients (1 patient with rhinorrhea and 1 patient with otorrhea) improved by several days of lumbar drainage only. Thirteen patients (3.2%) who did not respond to lumber drainage (7 case of rhinorrhea, 1 case of otorrhea, and 4 cases of wound leaks) required revision surgery. Revision surgeries were performed with waxing for bone defects and patching a fascial graft on the leaking area of the dura. Twenty-three cases of CSF leaks occurred in the retrosigmoid approach, and another 8 cases were seen in the translabyrinthine approach. No CSF leaks were seen in the middle fossa approach. There were 6 cases of wound infection related to CSF leaks. Four patients responded to antibiotics, and 2 patients required surgical treatment.

There were significant differences in the incidence of CSF leakage according to surgeons. When dural closure was performed by residents, the incidence of CSF leak was 13.9%. When closure was performed by faculty, the rate of CSF leak was 5.5%.

Complications at Follow-up

Postoperative initial follow-up was scheduled 2 weeks after discharge from hospital. Any remaining deficits or symptoms after 12 to 24 months of follow-up were considered persistent deficits or complications. These complications included hearing loss in 44 (24.6%), FN palsies in 29 (7.3%; H-B III, 16 [4%]; IV-VI, 13 [3%]), disequilibrium in 26 (6.3%), bothersome tinnitus in 9 (2.2%), facial numbness in 9, chronic headache in 8 (2.0%), taste disturbance in 5 (1.2%), hydrocephalus in 4 (0.9%), cosmetic deformity that required cranioplasty in 4, facial synkinesis in 4, scar pain in 3 (0.7%), blepharospasm in 1 (0.2%), hemifacial spasm in 1, facial pain in 1, and tongue numbness in 1 (Table 5) patient.

Previously Operated or Irradiated Cases

The majority of tumors in this series were primary resections; however, 25 cases (6.0%) were redo operations for recurrence previously operated on somewhere else. Three of these 25 patients had undergone GTR, 1 had STR, and 4 had partial resections elsewhere. The extent of tumor resection was unknown in another 17 cases. The period for recurrence ranged from 24 to 180 months (mean, 71.1 months). In the GTR group, the period for recurrence

TABLE 5. Persistent or Long-term Complications in 410 Patients[a]

Type of Complication	Patients, n (%)
Neurological complications	
Hearing loss	44 (24.6) (44/170)[b]
FN palsy (H-B III-VI)	29 (7.3) (29/400)[c]
Disequilibrium	26 (6.3)
Bothersome tinnitus	9 (2.2)
Facial numbness	9
Taste disturbance	5 (1.2)
Facial synkinesis	4 (0.9)
Blepharospasm	1 (0.2)
Hemifacial spasm	1
Facial pain	1
Tongue numbness	1
Nonneurological complications	
Chronic headache	8 (2.0)
Delayed hydrocephalus	4 (0.9)
Cosmetic deformity	4
Scar pain	3 (0.7)

[a]FN, facial nerve; H-B, House-Brackmann facial nerve grading system.
[b]Hearing preservation surgery was attempted in 170 cases.
[c]Ten preexisting cases of FN palsies were excluded.

ranged from 36 to 72 months (mean, 59.3 months); in the primary resection group, it ranged from 36 to 72 months (mean, 56.0 months). Another 8 cases (2%) recurred after stereotactic radiation. The period for recurrence after irradiation ranged from 36 to 120 months (mean, 57.0 months).

DISCUSSION

In recent years, the goal of VS surgery has been total tumor resection with normal FN function and hearing preservation if indicated. Our review of a large case series of VS surgery published in the last decade and a half (Table 6) demonstrated a significant incidence of FN palsy in 8% to 68.6% (mean, 34.0%), disequilibrium in 2.6% to 35% (mean, 20.7%), meningitis in 0% to 8% (mean, 2.9%), CSF leak in 2% to 15% (mean, 8.2%), lower CN deficits in 0.14% to 12.6% (mean, 3.3%), and mortality in 0% to 6% (mean, 1.0%) of cases.[7-9,12,14,16,17,21-27]

Extent of Tumor Resection

This review demonstrated a correlation between tumor size and the extent of resection. The success rate of GTR declined in parallel with tumor size; GTR was achieved in 100% of intrameatal tumors, 98.2% of small tumors, 77.7% of medium tumors, 67.5% of moderately large tumors, 45.4% of large tumors, and 44.8% of giant tumors. Likewise, NTR and STR rates increased with increasing tumor size. NTR was achieved in 19.6% of medium, 23.4% of moderately large, 39.4% of large, and 27.6% of giant tumors. STR was achieved in 2.7% of medium tumors, 9% of moderately large tumors, 15.2% of large tumors, and 27.6% of giant tumors. The major reason for NTR or STR was fibrous adhesion between the tumor capsule and the brainstem or the CNs. Additionally, hypervascularity or fibrous nature of the tumor tissue hampered radical resection.

An important relationship demonstrated in this study is the correlation between the extent of resection and long-term tumor control. Follow-up radiographic examination demonstrated 11 cases of tumor recurrence in 357 patients (3.1%). Six cases of small regrowth were detected in the 306 GTR patients, mostly grade 0 and 1 HPS cases. In the 73 patients with NTR, recurrence was detected in 2 patients (2.7%). There were 3 cases of recurrence in the 31 patients who had STR (9.7%). In this series, there is not a substantial difference in tumor control rates among GTR, NTR, and STR. Therefore, to accomplish excellent FN outcome and hearing preservation, surgeons should consider more cases of NTR or STR in the face of difficult dissection. This decision of leaving some residual tumor capsule should be made before a decrease in FN response or ABR (auditory brainstem response).

Neurological Complications

Hearing Preservation

Preservation of good, fair, or serviceable hearing was also correlated with tumor size and extent of resection. Success rate for HPS was 85.7% for intrameatal tumors, 80% for small tumors, and 71.6% for medium tumors in 170 cases. Of these, GTR was achieved in 150 (88.2%), NTR in 17 (10%), and STR in 3 (1.7%) cases.

HPS was also attempted in 29 cases of larger (>21 mm) tumors with class A or B level of hearing function. Of these, 24 patients (82.8%) maintained good hearing. We previously reported HPS in large VSs with an overall success rate of 53.7% in 54 patients who had preoperative hearing of A, B, C, or D in the Sanna-Fukushima system.[5] We achieved a better rate of hearing preservation in the present series. The reasons for better results in the present series were more conservative patient selection criteria for HPS and a more conservative resection (NTR or STR in 62% of patients vs 76% rate of GTR in the previous series). Again, this suggests the advantage of deciding for NTR or STR early before significant changes in amplitude or latency of ABR.

Our analysis of our operative records suggests that the causes of hearing loss in patients whose cochlear nerve was anatomically preserved at surgery included severe adhesion between tumor capsule and nerve, excessive nerve retraction at CPA, nerve ischemia resulting from coagulation of the small vessels, overheating or mechanical damage of the nerve, and opening of the labyrinth during internal auditory canal drilling.

FN Preservation

There was a surprising lack of correlation between the extent of tumor resection and the success rate of FN preservation (GTR, 89.0%; NTR, 77.0%; STR, 76.9%). In NTR or STR, some portion of the tumor capsule was left attached to the thin, adherent FN or on the brainstem with the expectation of better FN function. It stands to reason that leaving more residual tumor

TABLE 6. Surgical Complication Rates in the Recent Large Series of Vestibular Schwannoma (Acoustic Neuroma) Surgeries[a]

	Patients, n		Approaches			Preservation Rate, %		Complications, %				
Authors and Year	Total	NF-II	RS	TL	MF	Hearing	FN (H-B I+II)	CSF Leak	Balance Problem	Meningitis	CN IX-XI Deficits	Mortality
Sterkers et al,[26] 1994	572[b]	N/D	52	492	27	36.5	47.6	N/D	N/D	N/D	2.1	N/D
Gormley et al,[14] 1997	179	4	157	8	22[c]	48	77	15	N/D	3	2	1
Samii and Matthies,[22] 1997[d]	962	82	962	0	0	49.8	63.5	9.2	35	1.2	5.5	1.1
Lanman et al,[17] 1999[e]	190	N/D	0	190	0	N/A	52.6	14.2	12.6	3.7	12.6	0
Briggs et al,[7] 2000	132	11	27	80	10	54.1	90.6	6.5	2.6	1.6	0.8	0
Slattery et al,[25] 2001	1687	N/D	(0.8%)	(72.5%)	(25.7%)	N/D	N/D	9.4	N/D	1.5	N/D	0.1
Enée et al,[12] 2003	348	N/D	42	195	111[c]	N/D	40.8	6.3	30	6.3	N/D	0.85
Sanna et al,[23] 2004	707	N/D	38	600	54	N/D	N/D	2.8	N/D	0.14	0.14	0.14
Darrouzet et al,[9] 2004	400	N/D	42	229	129[c]	58	70.7	8.2	30	5.5	0.7	0.5
Jain et al,[16] 2005	259	11	259	0	0	29.6	31.4[f]	4	N/D	8.0	6.8	6
Samii et al,[21] 2006	200	N/D	200	0	0	51	81	2	N/D	0	N/D	0
Sekhar et al,[24] 2006	219[g]	8	191	11	26[c]	42	79	14	N/D	2	1	1.4
Charpiot et al,[8] 2010[h]	123	0	0	123	0	N/A	92	6.5	13.8	1.6	1.6	0.8
Sughrue et al,[27] 2011[i]	32 870	N/D	3757	2909	1632	N/D	N/D	8.5	11	3.0	15[j]	0.2
Present series[k]	410	0	290	103	17	74.1	92.8	7.6	6.3	1.7	0.5	0

[a]CN, cranial nerve; CSF, cerebrospinal fluid; FN, facial nerve; H-B, House-Brackmann facial nerve grading system; MF, middle fossa approach; N/A, not applicable; NF-II, neurofibromatosis type II; N/D, not described; RS, retrosigmoid approach; TL, translabyrinthine approach.
[b]Data extracted from "series i" of their categories.
[c]Other different approaches.
[d]Total number of resected tumors was 1000.
[e]Outcomes for large (> 3 cm) tumors.
[f]Calculated value according to Table 3 in the article.
[g]A total of 228 operations were performed on 219 patients.
[h]Outcomes for large or giant (> 4 cm) tumors.
[i]Comprehensive search of the English language literature.
[j]Cranial neuropathy.
[k]Data described as overall rate.

would translate into less FN injury. This notion is not supported by our data. Reviewing the operative records demonstrated that in most cases, the surgeon aimed for maximal tumor resection but decided to stop dissecting tumor from the nerve after observing a decrease in FN response. This may explain the higher-than-expected rate of FN palsy in the STR group. Again, this observation highlights the importance of deciding whether to perform NTR or STR before there is a significant change in electrophysiological monitoring.

Within 2 years of follow-up observation, perioperative FN weakness (H-B II, 68; III, 27; IV, 16; V, 3; VI, 10) improved in 75 of 124 cases (60.4%). Of the 68 patients with perioperative grade II weakness, 37 patients normalized. Of the 27 patients with grade III palsy, 8 patients normalized and 9 patients improved to grade II. Overall, 63% of patients with grade III palsy showed some improvement. Of the 16 patients with grade IV palsy, 4 patients normalized, 6 patients improved to grade II, and 1 patient improved to grade III. Overall, 31% of patients with grade IV palsy remained at grade IV. Of the 13 patients with grade V and VI palsies, no patient improved to grade I or II, 5 patients improved to grade III, and another 5 patients improved to grade IV. Therefore, 23% of patients with grade V or VI palsy showed little or no improvement. The improvement in FN palsies from grade VI to III in 2 of 4 patients was the result of an end-to-end anastomosis of the FN after tumor resection. Two of 3 patients whose FN palsies improved from grade VI to IV had an end-to-end FN anastomosis; the third had a sural nerve graft. One case of FN palsy underwent FN to hypoglossal nerve end-to-side anastomosis and improved to grade IV.[33,34]

Overall, permanent FN palsy was seen in 29 patients (7.3%), including those who were lost to follow-up. In total, H-B grade III palsies were seen in 16 (4.0%), IV in 10 (2.5%), V in 0, and VI in 3 (0.7%) patients. Good FN function was seen in 371 patients (92.8%), fair FN function was noted in 16 patients (4.0%), and poor FN function was seen in 13 patients (3.2%). With respect to extent of tumor resection, long-term FN function was good in 282 patients (94.0%; H-B I, 252; II, 30) and poor in 10 patients (3.3%; H-B IV, 8; V, 0; VI, 2) who had GTR. In patients who had NTR, 62 (88.6%) had good and 3 (4.3%; H-B IV, 2; V, 0; VI, 1) had poor FN functions. In the STR group, 27 patients (90.0%) had good FN function and no patients had poor FN function. We identified the causes of FN palsy as extremely severe adhesion between the tumor capsule and the FN in 38 cases (65.5%), thin or elongated FN in 25 cases (43.1%), anatomically preserved but unexpectedly lost FN response during tumor resection in 4 cases (6.9%), dorsal shift of the FN (the FN was located at the dorsal side of the tumor) in 4 cases, FN engulfed by tumor in 3 cases (5.2%), delayed FN palsy in 3 cases, damage during coagulation in 2 cases (3.4%), invisible FN (the FN was too stretched and thinned to identify visually but responded to stimulator) in 2 cases, indeterminate cause (regardless of 0.05-mA response during surgery) in 1 case, and split FN in 1 case.

Delayed facial palsy occurred in 6 cases (1.5%; H-B II, 2; III, 2; IV, 1; V, 1) within 2 to 26 days of surgery. The incidence of delayed facial palsy in our series was quite low compared with published rates of between 4.8% and 29%.[35-39] Our 6 patients were treated with a tapered course of dexamethasone; 2 patients demonstrated excellent facial function recovery in a few months, 1 showed partially recovery, and the other 2 still had palsy at their last follow-up (13 and 51 months). One patient who presented with H-B IV palsy missed follow-up. The cause of delayed facial palsy is thought to be neural edema, inflammation, vasospasm, ischemia, venous outflow obstruction, nerve compression from fat packing, iatrogenic injury, fluid shifts, sterile arachnoiditis after CPA surgery, or reactivation of a latent herpesvirus.[35-44] Most delayed facial palsy cases demonstrated favorable recovery (79%-100%), and only tumor size has been shown to correlate inversely with the degree of FN recovery at 1 year.[36]

For hearing preservation, because of the extreme fragility of the nerve, the surgeon must either perform a smooth separation of the tumor or opt for NTR or STR. In contrast, the FN is more tolerant, and as long as it is anatomically preserved, postoperative FN palsy has the possibility of improvement. This is especially true for low-grade palsies. In addition, our operative records showed there were 15 patients (3.6%) with a dorsally located FN and 4 patients (1%) with an FN engulfed in a lobulated tumor or in the tumor capsule. In these cases, the risk of FN palsy is elevated, and the surgeon must use frequent stimulation to precisely determine the location of the FN at every stage of tumor resection.

Factors Influencing Nerve Preservation

A number of factors influence the results in regard to hearing or facial function preservation in patients undergoing VS surgery. These factors include adhesion of the tumor to CN VII and VIII, preoperative nerve status, tumor consistency and vascularity, tumor size, irradiated or recurrent tumor, surgical technique, surgeon experience, decision making, appropriate instrumentation, and intraoperative monitoring. Although some features of the tumor such as solid, cystic, or mixed type can be identified easily by preoperative images, other features such as vascularity, adhesion between CNs and brainstem, fibrous change, and nerve engulfment are unidentifiable. Our review of operative records demonstrated that VAFE (vascular, adherent, and fibrous and had engulfed adjacent nerves and vessels) type tumors were particularly difficult to dissect from the CNs and brainstem. Among 10 cases of H-B grade VI FN palsies, 2 cases were VAFE and another 5 cases had a combination of 2 or more of these features (vascular, adherent, and fibrous; adherent and engulfing; or adherent and fibrous). Of note, the presence of these features does not influence tumor debulking. Rather, VAFE features make separation of the tumor from the FN or brainstem extremely difficult. This is most manifest during the last 10 mm of tumor resection. In most procedures, the last 10 mm is the section of tumor on the thinned portion of the FN extending from the inferior edge of the internal auditory canal into the CPA. This is the area where FN responsiveness is most likely to disappear. Awareness of the influence of VAFE is critically important; our data suggest that the earlier decision for NTR or STR has a major influence on outcomes.

Disequilibrium

Balance disturbance was the most frequently reported symptom after VS surgery. Forty-two patients (10.2%) complained of imbalance or unsteadiness immediately after surgery. When examined according to approach, the vestibular dysfunction occurred in 12% of patients with the retrosigmoid approach, 11.7% of patients with the middle fossa approach, and 5% of patients undergoing the translabyrinthine approaches. There were 2 cases of direct damage of the vestibule while drilling the petrous bone at the posterior wall of internal auditory canal during the retrosigmoid approach. Both of these patients lost hearing and developed imbalance postoperatively. At the final follow-up, 26 of the 42 patients with immediate postoperative disequilibrium had improved. However, an additional 10 patients who had no postoperative dysfunction developed symptomatic imbalance. So, the rate of long-term disequilibrium in this series was 6.3%. Disequilibrium can be caused by cerebellar damage, brainstem injury, residual vestibular nerve dysfunction, or compromise of anterior inferior cerebellar artery (AICA) vessels. In the majority of larger tumors, meatal and cerebellar branches of the AICA are involved either in the lobules of the tumor or between the tumor and the facial or cochlear nerve. AICA vessels in these situations are very fragile, and careful separation and preservation are required. Damage to AICA may cause not only stroke but also delayed hemorrhage.

Nonneurological Complications

CSF Leak

Conceptually, a watertight dural closure is a technically simple proposition. However, postoperative CSF leak has been the most frequent serious complication in VS surgery.[45-53] Many reports have discussed different factors leading to postoperative CSF leaks. Pirouzmand et al[54] and Yasargil[53] suggested that hydrocephalus was the main cause of CSF leaks. Slattery et al[25] and Brennan et al[46] found a significant relationship between tumor size and prevalence of CSF. On the other hand, Sanna et al[23] did not demonstrate this relationship, and Hoffman[48] stated in his study that the incidence of CSF leak was not influenced by age, sex, tumor size, postoperative hydrocephalus, or the intraoperative use of autologous fibrin glue. The largest and most recent study by Sughrue et al[27] reported that the occurrence of CSF leak was markedly increased with the translabyrinthine approach but was not affected by tumor size.

We routinely use continuous lumbar drainage for the majority of cases except for intrameatal tumors, not only to obtain intraoperative brain relaxation but also to prevent postoperative CSF leak. Our analysis demonstrated that surgeon experience influenced the occurrence of CSF leak. It is common practice for the primary surgeon not to be involved in the closure process. When we think about techniques to reduce surgical complications, the best and simplest solution is for the more experienced surgeon to review the procedure from skin incision to skin closure with the surgical team.

Intracranial Hemorrhage

Intraparenchymal hematoma was seen in 1 patient 3 weeks after surgery. This hematoma resolved without operative intervention. This patient also presented with hydrocephalus 4 weeks after surgery that required ventriculoperitoneal shunt. No postoperative intracranial hemorrhage requiring additional treatment occurred in the present series. Additionally, no case of significant postoperative cerebral edema requiring surgical decompression or placement of a ventriculostomy was seen in this series. Our policy of intraoperative lumbar drainage to maximize brain relaxation and to minimize retraction injury may have contributed to this finding.

Intracranial hemorrhage resulting from vascular injury remained one of the most serious postoperative complications. Wiet et al[28] discussed intracranial vascular complications as AICA injury, posterior fossa hemorrhage, supratentorial hemorrhage, intracerebellar hemorrhage, and cerebellar infarction with subsequent edema. The largest series reported cerebrovascular accident in 0.2% of cases.[25] Their vascular accidents were due to infarction in 3 of 4 cases. Samii and Matthies[22] also reported their acute and subacute postoperative hemorrhage cases as 2.2% and 1.5%, respectively. In 7 of 15 patients who required emergency surgical revision, the hemorrhage was of acute onset within the first 24 hours, occurred between 4 and 9 hours after surgery, and was located in the CPA in 4 patients, intrapontine in 2 patients, and epidurally in 1 patient.

Failure to recognize the symptoms of intracranial hemorrhage can lead to severe brainstem damage. Sade et al[19] concluded that the overall incidences of vascular complications, including hemorrhagic and ischemic complications, in VS surgery were similar for the retrosigmoid and translabyrinthine approaches (2.7%).

Headache

Postoperative persistent headache has not been commonly reported in patients undergoing resection of tumors via either the middle fossa or translabyrinthine approach.[55-58] In the present series, 7 of 8 patients who had persistent headache had tumor resection via the retrosigmoid approach. Ruckenstein et al[56] stated that initial discomfort after surgery is expected and related to the incision, reduced CSF pressure, dural irritation, and muscle spasm. However, the origin of postoperative headaches after the retrosigmoid approach is not yet fully understood. Schaller and Baumann[58] advocated that prevention of postoperative headache may include the replacement of bone flap, Dura Plastic instead of direct dural closure, and prevention of the use of fibrin glue or extensive drilling of the posterior wall of the internal auditory canal, which cause aseptic meningitis. They also stated that tight dural closure may result in excess tension of the dura and that dural adhesion to nuchal muscles may result in intermittent stretching and traction of the dura with head movement or straining.

Hydrocephalus

Three cases (0.7%) of acute or subacute hydrocephalus after tumor resection were improved by performing ventriculoperitoneal

shunt. The tumor was 50 mm in 2 cases and 10 mm in 1 case. Another 4 patients (0.9%) became symptomatic (headache, memory disturbance, ataxia) gradually 4 weeks after tumor resection. These cases of late hydrocephalus were confirmed by follow-up MRI and improved by performing ventriculoperitoneal shunt. None of these 7 patients had accompanying CSF leaks. The reported incidence of hydrocephalus needing treatment before and after surgery ranges from 0.4% to 3.7%.[22,25,59,60] In the series of Briggs et al,[59] 43 of 1152 patients (3.7%) had hydrocephalus with the tumor size varying from 25 to 60 mm (mean, 40 mm), and 19% of patients with tumors $\geq$ 40 mm had preoperative hydrocephalus.

Mortality

There was no mortality in this series. The mean mortality rate in the 13 largest VS surgery series is 1.0%.[7-9,12,14,16,17,21-27] Causes of death included CPA or intracranial hemorrhage (hematoma) in 7 patients, cerebral or cerebellar edema with brainstem failure in 7 patients, aspiration pneumonia or obstructive lung disease in 6 patients, myocardial infarction in 3 patients, meningitis in 3 patients, air embolism in 2 patients, and brainstem edema caused by AICA ischemia in 1 patient. No definitive cause of death could be established in 3 patients. Sughrue et al[27] analyzed 32 870 patients in 100 articles that reported morbidity and mortality after VS surgeries from 1968 to 2006. This comprehensive statistical analysis revealed that the overall mortality rate of VS surgeries was 0.2%. According to their analysis, CSF leakage was the leading cause of morbidity, whereas the leading cause of death was AICA hemorrhage.

Long-term Tumor Control

As expected, our retrospective analysis demonstrated that the rate of tumor recurrence increased and the mean duration until tumor recurrence decreased as the extent of the tumor resection decreased. Interestingly, we had tumor recurrence in 6 patients with initial GTRs. These 6 patients had all undergone HPS. These patients probably had microscopic residual tumor infiltrating along or behind the cochlear nerve or some blind spot in the fundus that could not be detected intraoperatively or on initial postoperative imaging. Perhaps, because of the emphasis on HPS, the surgeon was less aggressive in manipulating the cochlear nerve in these cases. These results also underscore the importance of continued radiographic surveillance of patients, even if there is no apparent residual tumor on initial follow-up.

Strategy for Complication Avoidance

For the best results with VS surgery, the surgical team must take a very individualized approach to each patient. The critical first question is, What is the appropriate extent of tumor resection for this patient? The answer depends on tumor size and patient age, social background, occupation, and preference. The surgeon must keep in mind that GTR is desirable but not the main goal of VS surgery. STR or NTR with no deficits provides a greater benefit to the patient than GTR with neurological dysfunction. A balance must be struck between tumor control and extent of tumor resection. In this series, there was no significant difference in the recurrence rate between the NTR and GTR groups. Therefore, especially in the VAFE cases, tailored NTR is highly recommended.

For success of HPS, it is important to decide to leave a small capsule on the nerves before wave 5 on the ABR starts to diminish. Precise determination of the anatomy of a thinned or spread-out FN both outside and inside the tumor is mandatory. Frequent use of the FN stimulator, even during intracapsular debulking of the tumor, is the first step in preserving FN function. Linear adjustment of stimulation amplitude from 1.0 to 5.0 mA can determine the precise FN location through the thinned tumor capsule. When the thinned tumor capsule starts to pulsate with the brainstem and CSF or when an FN response is found at 1 to 1.5 mA, the capsule is thin enough to attempt to dissect the tumor off of the FN.

Operative Technical Pearls for Preservation of Facial and Cochlear Nerves

The key element for successful VS surgery is paying attention to meticulous manipulation of the flattened nerves and the brainstem in a bloodless operative field with minimal use of the brain spatula.[32] Additionally, the bipolar coagulation adjacent to the nerve also must be minimized to prevent electric or thermal injury. Very short pulses of current should be used with a 0.3-mm sharp-tip bipolar forceps in a dry environment with a micro-patty protecting the nerve from current and heat spread. For hearing preservation, not only must the tumor be cleanly separated from the nerve, but also special attention must be paid to preserving the internal auditory artery, which originates from the AICA meatal branch and capillary arteries on the nerves.

In this series, ear, nose, and throat surgeons assisted in 43.5% of cases, especially during transmastoid translabyrinthine drilling in the translabyrinthine approach. A team approach with ear, nose, and throat surgeons may reduce total surgical time and related complications, as described by Tonn et al.[61]

Microsurgery vs Stereotactic Radiation Therapy

Stereotactic radiation therapy (SRT), including Gamma knife, Cyber knife, or other computerized linear accelerator devices, has been used as the primary treatment for VS.[62-65] After SRT, most VSs will remain the same size or will continue to grow. Only a minority of cases showed tumor shrinkage. Our unpublished experience with 55 of 1127 patients (between January 1995 and December 2011; neurofibromatosis type II patients were excluded) who failed SRT demonstrated increased rates of radiation-related side effects such as louder tinnitus, increased dizziness, hearing loss, facial palsy, facial numbness, and ataxia. These side effects are not well documented in the SRT literature. Moreover, there were some unusual surgical difficulties in the surgery of radiation failed VSs such as severe fibrous adhesions between the tumor capsule and surrounding neurovascular structures, as well as fibrous and tenacious transformation of the tumor tissue.[63,66,67]

Use of SRT may carry some uncertainties concerning long-term tumor control and potential risk of secondary malignant change even though it is low.[68-71] In contrast to the microsurgically cured patients, SRT-treated patients must have periodic surveillance MRI and physician evaluations for life.

Conservative "Wait and Scan" Policy

In recent years, several articles have been published that advocate a conservative approach to VS consisting of periodic MRI scanning in lieu of surgical resection.[65,72-78] The largest study attempting to delineate the natural history of VS is from Stangerup and colleagues[74] from Denmark published in 2006. This study had an average follow-up period of only 3.6 years. Remarkably, the authors concluded that VS growth occurs only within the first 5 years after diagnosis. There is no statistical or biological evidence that VS growth can be predicted in this fashion. A follow-up article from the same institution in February 2012 demonstrated that of 1378 consecutive patients, 419 patients were operated on soon after diagnosis, and another 161 patients were operated on because of tumor growth while under conservative management.[75] So, 798 patients remained in the conservative "wait and scan" program. Given the selection bias present in this study population, we do not feel that it is an accurate reflection of the natural history of VS.

It appears that other reports similarly are marred by selection bias, anecdotal cases of VS, and limited follow-up periods (range, 38-43.8 months) and do not reflect a statistically valid representation.[65,76,78] To determine the natural history of VS, a large study without selection bias lasting at least 10 to 20 years is required. A follow-up period of $<$ 5 years was too short an observation period for such a "slow-growing" tumor to determine growing rate and its natural history.

In many patients with VS, hearing loss is progressive over time, and it is a general experience that hearing may deteriorate to a nonserviceable level.[79] Furthermore, some "wait and scan" series have documented tumor growth in young and middle-aged patients with subsequent hearing loss during the observation period.[80] Nonetheless, these options (SRT and wait and scan) remain indisputably important in the management of selected tumors. However, in the absence of natural history evidence, we rely on our experience of the past 30 years, which has led us to the conclusion that the majority of VSs are growing neoplasms and should be treated in a curative fashion soon after detection.

CONCLUSION

Despite tremendous benefits from advanced high-tech equipment, refined microsurgical instruments, and highly developed neuroimaging technologies, our series demonstrates that there are still various and significant complications in VS surgery. The goals of VS surgery should be long-term tumor control, preservation of FN function, and preservation of cochlear nerve function (if indicated) with a complication rate of $<$ 1%. On the basis of our analysis, we propose the following strategies to achieve these goals:

1. Thorough discussion with the patient is necessary preoperatively to customize the resection strategy.
2. FN stimulation both around the tumor capsule and inside the tumor during separation and debulking should be used frequently.
3. The tumor capsule should be made as thin as possible to separate it from the nerves safely.
4. Intraoperative findings, especially with regard to VAFE features, are key in making decisions for the extent of tumor resection.
5. The decision to leave a thin tumor capsule should be made before the FN or ABR responses start to decrease.
6. HPS surgery should be tailored, and extent of resection should be modified to achieve this if it is essential.
7. Continuous lumbar drainage should be used in cases with tumor extension into the CPA to obtain intraoperative brain relaxation, to minimize retraction, to facilitate dissection, and to avoid postoperative CSF leak.
8. Dural and skin closure should be done or supervised by faculty.

We strongly believe that these are the key factors in avoiding complications in VS surgery.

Disclosures

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COMMENTS

This is a retrospective review of a large series of vestibular schwannomas operated on by an experienced team during the early years of the 21st century. Although any retrospective review has its inherent limitations, several very important points are made. First, and perhaps most important, this report describes in detail the important outcomes of treatment, including facial nerve, hearing, and complications. It is my belief that most practitioners (neurosurgeons, neuro-otologists, radiation therapists) are in the habit of quoting surgical literature that is out of date and does not accurately represent the outcomes that can be obtained today in a high-volume center with a skilled, experienced team (eg, 98.8% good facial nerve outcome in tumors <1 cm and 0% mortality in the series as a whole). Of course, this raises the question of why any patient would be operated on anywhere for a vestibular schwannoma except in a high-volume center with a skilled, experienced team.

The second important point is the description of the extent of tumor resection. The authors describe a plan of attempting gross total tumor resection but of limiting the extent of tumor resection when necessary so as not to compromise functional outcomes. In my opinion, this is the strategy that all good contemporary vestibular schwannoma surgeons have adopted.

One matter about which I disagree with the authors is their relative dismissal of stereotactic radiation and observation. I would argue that these options remain indisputably important in the management of a significant number of tumors. The decision to operate, to radiate, or to observe must be considered in its sociological context, and it is often easier and more face-saving for a treating physician to recommend against surgical resection knowing that his or her own results cannot compare to the results of other centers. In addition, given the current standard of care, there is clearly a state of clinical equipoise for many tumors, and in this situation, patient choice plays a primary role. In purely medical and scientific terms, of course, the paucity of very-long-term data leaves the best treatment for many vestibular schwannoma patients an open-ended question, the ultimate goal for these patients being to live a normal life expectancy with as few functional limitations as possible.

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This is an excellent review of a large vestibular schwannoma series by an experienced team using modern (2000-2009) technology, techniques, and thinking. These extensive reviews are essential not only for self-assessment but also for other centers to compare outcomes and techniques and to reflect on potential improvements. What I like about this article is that it reports only cases performed in the last decade. Although the case numbers are obviously lower by excluding cases done in the 1980s and 1990s, the information provided is much better and capable of setting a standard for comparison.

The excellent hearing preservation rates may lead us to rethink our management of large tumors, for which we typically prefer a translabyrinthine approach. The authors' discussion of partial and subtotal resection reflects an experienced, thoughtful, and forward-thinking skull base program.

The amount of effort, time (>10 years), and experience required to produce, study, and publish a large clinical review such as this is often underappreciated. The authors report extensive data in a usable and readable format and should be commended for this excellent work.

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