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Hearing Preservation and Facial Nerve Outcomes in Vestibular Schwannoma Surgery: Results Using the Middle Cranial Fossa Approach

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Objective: To evaluate surgical results using the middle cranial fossa approach for hearing preservation vestibular schwannoma surgery.
Study Design: Retrospective case review.
Setting: Tertiary referral academic center.
Patients: Seventy-three consecutive patients with vestibular schwannoma operated on using the middle cranial fossa approach between February 1999 and February 2005.
Interventions: The tumors were removed via the middle cranial fossa approach with modifications to improve exposure. Standard auditory brainstem and facial nerve monitoring were used.
Main Outcome Measures: Pre- and postoperative hearing measures and facial function, tumor size, and postoperative complications. Hearing status was categorized into Classes A, B, C, and D as described by the American Academy of Otolaryngology–Head and Heck Surgery "Guidelines for the Evaluation of Hearing Preservation in Acoustic Neuroma, 1995."
Results: Thirty-four patients presented with Class A hearing preoperatively. Among patients presenting with Class A hearing, a total of 27 (80%) maintained Class A or B hearing postoperatively. Of these, 21 (62%) remained in Class A, 6 (18%) deteriorated slightly to Class B, and 7 (20%) deteriorated to Class D postoperatively. Twenty-eight patients presented with Class B hearing preoperatively. Of these, 18 (64%) remained in Class B, 3 (11%) deteriorated to Class C, and 7 (25%) deteriorated to Class D. Three patients had Class C hearing preoperatively. Of these, 2 (66%) remained in Class C and 1 (33%) deteriorated to Class D. Eight patients presented in Class D and one of these improved to Class C postoperatively. Overall, 62 patients presented with useful (Class A or B) hearing and 45 (73%) remained in Class A or B. Nineteen patients had tumors larger than 10 mm in greatest dimension and had Class A or B hearing preoperatively. Of these, 11 (58%) retained Class A or B hearing postoperatively. At 4 months or greater follow-up, facial nerve outcome were excellent in 96%: House-Brackmann Grade I in 61 (85%), Grade II in 8 (11%), and Grade III in 3 (4%). There were no Grade IV, V, or VI results on final follow-up. Six (8%) patients developed cerebrospinal fluid leaks.
Conclusion: By achieving excellent exposure and using meticulous microsurgical technique, it is possible to resect small vestibular schwannomas via the middle fossa approach, with preservation of hearing at excellent or preoperative levels in the majority of patients, with excellent or satisfactory facial nerve outcomes in 96% of patients. **Key Words:** Facial nerve—Hearing preservation—Middle cranial fossa—Outcomes—Vestibular schwannoma.
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With the advent of modern microsurgical techniques, outcomes after surgical management of vestibular schwannoma have progressively improved. Mortality and major neurologic morbidity has been reduced to almost negligible levels. Facial nerve outcomes are now excellent in over 90% of patients in virtually all published series. Hearing preservation, however, remains an area in need of improved outcomes. The widespread use of magnetic resonance imaging has resulted in the diagnosis of vestibular schwannoma much earlier than in the past, and now very small lesions with excellent hearing routinely present for treatment. In these cases, hearing conservation has now become a primary management goal.

In the past, hearing conservation has been attempted primarily with the retrosigmoid approach. Increasing use of the middle cranial fossa (MCF) approach, as initially described by House, has resulted in substantial improvements in hearing preservation (1). As more experience has been gained with this approach, and as smaller

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tumors with better hearing have been identified, hearing preservation rates have increased. Successful hearing preservation using this approach has been reported to vary from a low of 20% to a high of 85% (2–13); however, the parameters for comparison for preservation have varied widely between studies. Inconsistency in reporting standards has rendered meaningful comparison very difficult. More recently, several groups have proposed standardized vestibular schwannoma outcomes reporting guidelines (14–16). Although not without controversy, the system proposed by the Committee on Hearing and Equilibrium of the American Academy of Otolaryngology–Head and Neck Surgery (AAO-HNS) has been widely accepted and has become the de facto standard (15).

This report presents results using the middle cranial fossa (MCF) approach for vestibular schwannoma resection over the past 6 years. Hearing preservation, facial nerve outcomes, and other complications are discussed.

PATIENTS AND METHODS

A retrospective review was undertaken to identify patients in whom an MCF approach was used for resection of vestibular schwannoma. Seventy-four cases were identified (Appendix). All cases were jointly performed by one of three faculty neurotologists and a single neurosurgeon at an academic medical center between 1999 and 2005. One case was excluded from the analysis because of insufficient follow-up data. Pre- and postoperative hearing data were recorded using AAO-HNS criteria including the four-frequency pure-tone average (PTA) at 500 Hz, 1 kHz, 2 kHz, and 3 kHz, and the word recognition score (WRS) using NU6 word lists (25 words) presented at 40 dB hearing level (HL) or at PBmax. Hearing was assessed within a month before surgery and at 1 to 3 months or more after surgery. All testing was performed in a sound-attenuated booth using calibrated equipment (ANSI, 1969). Pre- and postoperative hearing was classified according to the guidelines published by the Committee on Hearing and Equilibrium of the AAO-HNS (Table 1). (15)

Facial nerve outcomes were determined by the attending neurotologist and graded using the House-Brackmann (H-B) scale (17). Tumor size was measured from the preoperative magnetic resonance image. The dimensions of the intracanalicular and extracanalicular portions were recorded separately. The extracanalicular portion dimensions parallel to the petrous ridge, perpendicular to the petrous ridge, and cranial-caudal were recorded. The intracanalicular portion dimensions were recorded in the planes parallel to and perpendicular to the internal auditory canal. For purposes of this analysis, the largest tumor dimension was recorded. All complications were recorded.

The MCF approach was selected on the basis of location and size of the tumor and the presence or absence of serviceable hearing. For purposes of approach selection, the presence or absence of "serviceable hearing" was decided by the patient, after careful counseling by the neurotologist and neurosurgeon. Other factors such as age, anatomy, and contralateral hearing levels were taken into consideration. Electronystagmography data suggesting nerve of origin, and degree of bony internal auditory canal erosion were not used as selection criteria. If hearing preservation was not a goal, the translabyrinthine approach was usually used. In rare cases, the retrosigmoid approach was selected for hearing preservation if the tumor was very medially located. Neither translabyrinthine nor retrosigmoid cases are included in this report.

All the MCF procedures were performed in an identical fashion. Continuous facial nerve electromyographic monitoring and auditory brainstem response (ABR) monitoring were used in all cases. The patient's head was placed in a Mayfield headrest and a low-profile Greenberg retractor system used to provide enhanced exposure. The middle meningeal artery was routinely divided and dural attachments to Meckel's cave were dissected anteriorly as needed, to allow satisfactory placement of the retractor blade over the petrous ridge. The tumor was always dissected in a medial to lateral direction (except when impossible, i.e., with tumor in the fundus of the internal auditory canal [IAC]), and sharp dissection, using microscissors or microknives, was used whenever possible. Cautery was meticulously avoided in the vicinity of the IAC. Patients were given dexamethasone 10 mg intravenously at the beginning of the procedure and continued on a tapering dose of dexamethasone over the following 3 to 5 days. In the latter years of this series, patients developing delayed postoperative facial weakness were also treated with valacyclovir, for possible herpes simplex reactivation. The tumor was completely removed in all cases. The labyrinthine portion of the facial nerve was not decompressed.

TABLE 1. *American Academy of Otolaryngology–Head and Neck Surgery hearing preservation reporting guidelines*

Class	PTA (dB HL)	WRS (%)
A	≤30	≥70
B	>30 bit ≥50	≥50
C	>50	≥50
D	Any level	<50

RESULTS

A total of 75 cases were identified in which a lesion was removed from the IAC using the MCF approach between 1999 and 2005. One was excluded because of insufficient follow-up data. One was excluded because the lesion consisted of heterotopic brain tissue in a 14-year-old girl. The remaining 73 cases consisted of surgically confirmed vestibular schwannoma. Three patients in this series had neurofibromatosis Type 2.

Preoperative and postoperative hearing data using AAO-HNS criteria are plotted in Figures 1 and 2 and shown numerically in Table 2. Pre- versus postoperative word recognition scores are shown in Figure 3, and pre- versus postoperative pure-tone averages are shown in Figure 4. Thirty-four patients had Class A hearing preoperatively. Of these, 21 (62%) were Class A, 6 (18%) were Class B, 0 were Class C, and 7 (20%) were Class D postoperatively. Twenty-eight patients had Class B hearing preoperatively. Of these, none improved to Class A, 18 (64%) remained Class B, 3 (11%) were

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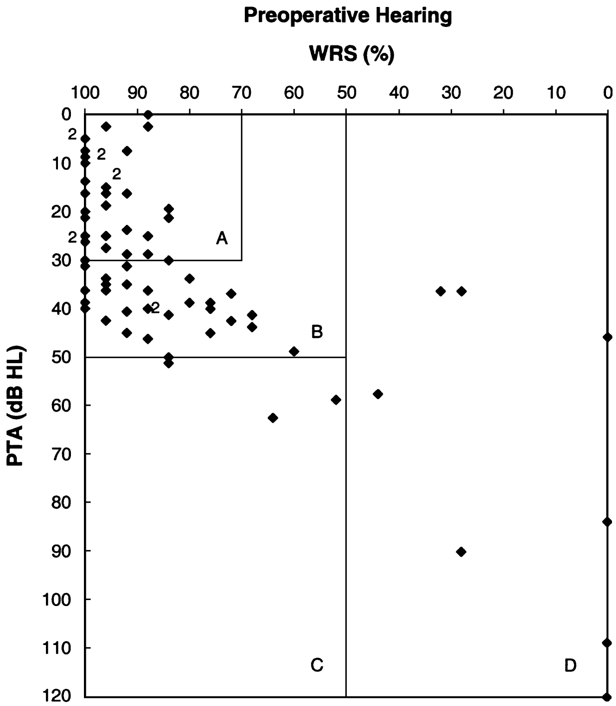

FIG. 1. Preoperative hearing status plotted in accordance with AAO-HNS guidelines. The small numbers near some data points denote the number of multiple points at one location.

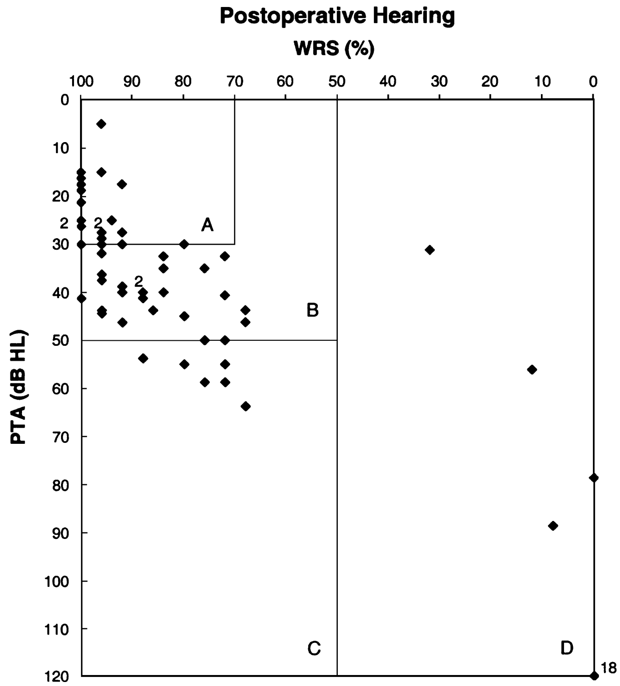

FIG. 2. Postoperative hearing status plotted in accordance with AAO-HNS guidelines. The small numbers near some data points denote the number of multiple points at one location.

Class C, and 7 (25%) were Class D postoperatively. If postoperative Class A and B patients are combined (considered "successful" results), 27 (80%) of the original 34 patients with Class A hearing preoperatively had useful hearing preserved postoperatively. If all of the preoperative Class A and B patients are combined (62 patients), 45 (73%) of them had Class A or B hearing postoperatively. Three patients had Class C hearing preoperatively. Two (66%) of these retained Class C and 1 (33%) had Class D hearing postoperatively.

Eight patients had Class D hearing preoperatively. Two of the Class D patients underwent MCF procedures for technical reasons. One had a large tumor with extensive IAC involvement, with an extremely high jugular bulb. The MCF approach was performed as a second-stage procedure to completely excise the IAC portion of the tumor. The other presented with an intracochlear tumor with extension to the IAC. The remaining six Class D patients presented with some degree of residual hearing (ranging from PTA of 30–90 dB HL and WRS of 0–44%), which the patient elected to attempt to preserve. Of these six, four had retained or improved PTA postoperatively, two of whom also had improved WRS (from 44% to 72%, and from 0% to 12%) postoperatively. Therefore, of the six patients presenting with measurable Class D hearing, one improved to Class C and three were Class D but were improved or preserved. Finally, if we consider the entire group as a whole and consider as preserved the Class A and B patients who remained Class A or B, the Class C patients who remained Class C, and the preserved or improved Class D (excluding the two cases performed for technical reasons), 51 (72%) of 71 patients can reasonably be considered to have preserved hearing.

The average tumor size (largest dimension as measured on preoperative magnetic resonance imaging) was 8.9 mm, with a range of 3 to 18 mm (median, 8 mm; standard deviation, 3.9 mm). The relationship between tumor size and hearing (WRS and PTA) is shown in Figures 5 and 6.

Adequate facial nerve outcome data were available in 72 of the 73 patients in this series. Early and final outcomes are shown in Table 3. The lone case with missing data is a patient who had H-B Grade I function immediately postoperatively but then developed H-B Grade III function at 1 week postoperatively. This patient was subsequently lost to follow-up. Final facial nerve outcome in the remaining 72 patients was Grade I

TABLE 2. *Hearing results by American Academy of Otolaryngology–Head and Neck Surgery classification*

Postoperative class	Preoperative class				Total	%
	A	B	C	D		
A	21	0	0	0	21	29
B	6	18	0	0	24	33
C	0	3	2	1	6	8
D	7	7	1	7	22	30
Total	34	28	3	8	73	—
%	47	38	4	11	—	100

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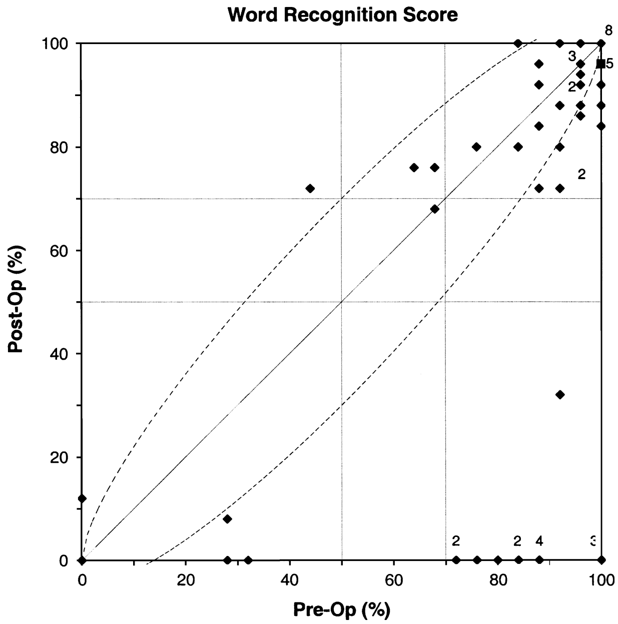

FIG. 3. Pre- versus postoperative word recognition scores. *Curved dotted lines* denote ±2 standard deviations for the word recognition score modeled as a binomial variable with n = 25 (where n represents the number of words in the word list presented). The *vertical* and *horizontal lines* denote the dividing lines for the different AAO-HNS word recognition categories. The small numbers near some data points denote the number of multiple points at one location.

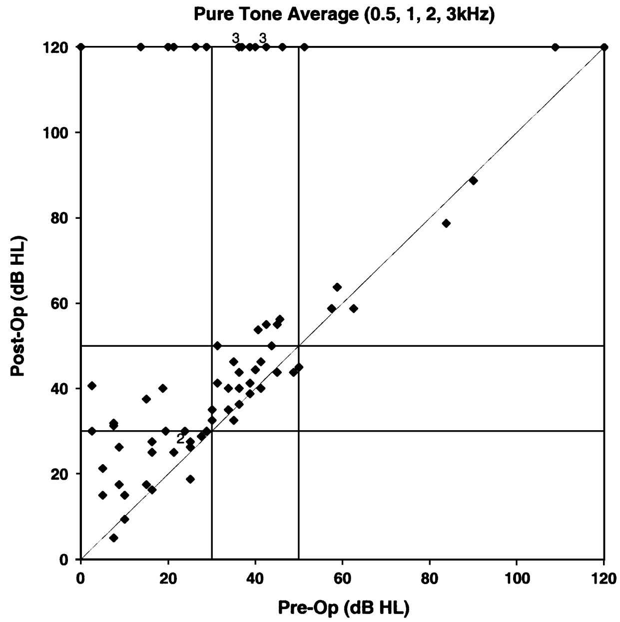

FIG. 4. Pre- versus postoperative pure-tone averages for 0.5, 1.0, 2.0, and 3.0 kHz. The *vertical* and *horizontal lines* denote the dividing lines for the different AAO-HNS pure-tone average categories. The small numbers near some data points denote the number of multiple points at one location.

in 61 (85%), Grade II in 8 (11%), and Grade III in 3 (4%). Therefore, Grade I or II results were obtained in 96% of patients. Two of the Grade 2 outcomes may improve to Grade I, as they were last evaluated at less than 6 months' follow-up. Two of the Grade III results were in larger tumors (17 and 16 mm). The other was in a patient with a small (4-mm) tumor. In this patient, undiluted papaverine was used in the IAC in an attempt to reverse a loss of ABR function. This may have produced a neurotoxic effect in the facial nerve (18).

Complications consisted of six cerebrospinal fluid leaks, all of which resolved with lumbar drainage. Four cases of aseptic meningitis resolved with steroid therapy alone. A single case of early bacterial meningitis developed that was attributed to an improperly sterilized retractor blade. This patient had an uneventful recovery after appropriate antibiotic treatment, which required 2 additional days of hospitalization. One patient developed a transient, mild expressive aphasia on the first postoperative day. This resolved completely within 6 hours without specific additional treatment. One patient developed a lower extremity deep venous thrombosis, and another developed a transient ulnar neuropathy, both of which resolved.

DISCUSSION

The outcomes reported in this study confirm that excellent facial nerve and hearing results can be expected, in experienced hands, using the MCF approach for treatment of vestibular schwannoma when tumors are small and preoperative hearing is good. Although the mean tumor size may be lower than in some series, we believe these improved results are primarily attributable to the excellent exposure achieved as a result of several technical modifications of the MCF approach, as well as extremely meticulous sharp dissection of the tumor in a medial to lateral direction. Expert intraoperative monitoring of facial electromyography plays a critical role in obtaining excellent facial nerve outcomes, and similarly, we feel that intraoperative ABR monitoring contributes to the successful hearing results. It should be noted that, in many of our cases, our hearing data reflect early postoperative results. Hearing can deteriorate with time after successful hearing preservation, and this effect was not analyzed in this study.

Although there have been several attempts to standardize reporting of hearing outcomes in vestibular schwannoma surgery, the optimal reporting scheme remains disputed. The guidelines proposed by the AAO-HNS have been most widely used. The functional groups are intuitively logical and nicely reflect the functional level of the hearing. However, using an ordinal system is problematic for outcomes near the dividing lines between categories and sacrifices potential robustness of the statistical analysis. It is possible that patients with clinically insignificant changes in hearing will be recorded as a significant degradation, and vice versa as having meaningful improvement. For example, a patient with a pure-tone average of 29 dB preoperatively might

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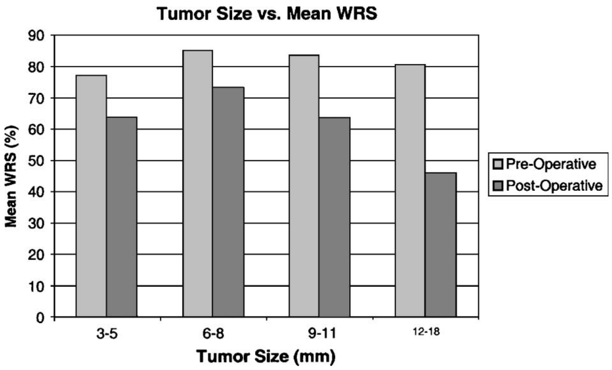

FIG. 5. Pre- and postoperative word recognition score as a function of tumor size.

drop to 31 dB postoperatively with the same WRS, based on a 5-dB shift in the threshold at a single frequency, which is certainly within the test-retest variability of a behavioral audiogram. Such a patient would be reported as a degradation of hearing from Class A to Class B. More importantly, the system is particularly insensitive to successful hearing preservation among patients presenting with more advanced hearing losses. For example, a patient with a preoperative WRS near 50% who drops just below 50% postoperatively will be recorded as a Class D outcome, which is indistinguishable from a patient with a profound postoperative hearing loss. To avoid this loss of information caused by converting continuous data into ordinal data, Rappaport et al. have recommended plotting pre- versus postoperative WRS and PTA for all patients in the report (14). Confidence intervals can be superimposed on such plots, thus enabling the interpretation of significant versus insignificant changes in hearing. They recommended modeling the WRS as a binomial distribution, as described by Thornton, from which confidence intervals can be calculated as a function of the number of words used in the word lists (19).

In the present report, we have combined Rappaport's approach with the AAO-HNS categories in Figures 3

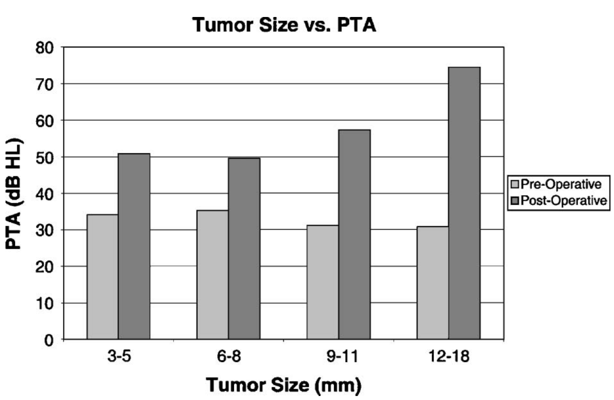

FIG. 6. Pre- and postoperative pure-tone average as a function of tumor size.

TABLE 3. *Facial nerve outcomes*

House-Brackmann grade	Immediate (%)	1 wk (%)	Final (%)
I	53 (74)	40 (56)	61 (85)
II	10 (14)	16 (22)	8 (11)
III	6 (8)	6 (8)	3 (4)
IV	0 (0)	2 (3)	0 (0)
V	3 (4)	6 (8)	0 (0)
VI	0 (0)	2 (3)	0 (0)
Total	72	72	72

and 4. Superimposing the AAO-HNS criteria on the pre- versus postoperative WRS or PTS plots provides a useful perspective. The plots are divided into quadrants on the basis of the AAO-HNS criteria for the variable being plotted. The quadrant in which a data point is located indicates whether there has been a change in criteria. This, of course, only provides information regarding the variable being plotted. For instance, a data point on the WRS plot could be in a quadrant suggesting that the patient was a preoperative Class A and a postoperative Class B. But because the WRS plot does not have threshold information, the same data point could actually be a postoperative Class C, depending on the PTA. Thus, both the WRS and the PTA plots give an incomplete picture alone but provide a useful analysis when combined with other methods of data presentation.

The relationship between tumor size and hearing preservation in the current study was not as strong as has been previously noted. We suspect that this is attributable to the relatively uniform size distribution in our series, with an absence of very small tumors and tumors over 18 mm. As seen in Figures 5 and 6, there is a noticeable deterioration in average hearing outcomes as tumor dimensions increase beyond 8 mm, although there is no noticeable difference in hearing outcomes between 3- to 5-mm tumors versus 6- to 8-mm tumors.

It should be noted that in our data, as would be expected, speech reception threshold (SRT) was almost always lower than the PTA (0.5, 1, 2, and 3 kHz) by at least 5 to 10 dB. In spite of the AAO-HNS guidelines specifically calling for the use of this PTA, several published studies use the SRT in place of the PTA. When our results were calculated using the SRT instead of the PTA, the outcomes were significantly better. This highlights the importance of adhering to consistent reporting guidelines and the need for inclusion of complete data sets in publications of this nature. An additional limitation of the AAO-HNS guidelines is that most audiologists do not measure the 3-kHz thresholds routinely. American Speech-Language-Hearing Association guidelines only call for measuring the 3-kHz value if there is a 20-dB or greater difference between the 2-kHz value and the 4-kHz value. Thus, the majority of our data did not have 3-kHz results. In these cases, simple linear interpolation was used to estimate the 3-kHz value, as has been previously recommended (20).

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Recent reports in the literature are primarily focused on preservation of ''useful'' or ''serviceable'' hearing. Hearing that might be considered nonserviceable for one patient, however, might be critically useful for another patient. Preservation of Class D hearing in the better or only hearing ear, for instance, would be very beneficial to the patient. Even patients with good hearing in the nontumor ear may benefit from improved sound awareness with Class D hearing postoperatively. The AAO-HNS system does not reflect these important considerations. Reporting guidelines for other otologic disorders define a degree of change in hearing that should be considered significant. We propose that any new guidelines for vestibular schwannoma do the same, to more fully describe all degrees of hearing preservation.

With regard to facial nerve outcomes, this report confirms the very high rates of excellent facial nerve outcomes that may be expected using the MCF with an experienced surgical team. We believe that one of our Grade III outcomes is related to the use of undiluted papaverine. In this case, the intraoperative ABR began diminishing partway through the tumor dissection. In an attempt to reverse this process, a piece of Gelfoam (Upjohn Co., Kalamazoo, MI, U.S.A.) soaked in full-strength papaverine (30 mg/ml) was placed in the IAC for several minutes (21). Subsequent anecdotal reports have indicated a possible neurotoxic effect of direct application of papaverine to cranial nerves (18). In this light, other authors have indicated a need to dilute the papaverine 15:1 before application (6). Two of our Grade II results have had less than 4 months' follow-up and were unremarkable cases; thus, it remains reasonably likely that they will ultimately improve to Grade I results.

CONCLUSION

Excellent outcomes with regard to hearing preservation, facial nerve function, and avoidance of complications can be obtained using the middle cranial fossa approach for small- and borderline medium-sized vestibular schwannomas. These outcomes support the continued use of early microsurgical treatment in this entity and should be given careful consideration by patients and physicians when contemplating alternate management strategies such as observation or radiotherapy. Furthermore, although current reporting standards for hearing preservation are very helpful when diligently followed up, work remains to develop the ideal standards. Currently, patients often make vestibular schwannoma treatment decisions on the basis of limited, misleading, and/or erroneous information. Consistent standards should be required by journal editors, not only in reports of surgical outcome but also in those of conservative management or radiotherapy.

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APPENDIX 1. *Patient data*

	Preoperative			Postoperative				
Subject	SRT (dB HL)	PTA (dB HL)	WRS (%)	SRT (dB HL)	PTA (dB HL)	WRS (%)	Tumor size (mm)	Final facial function (House-Brackmann grade)
1	60	90	28	55	89	8	8	1
2	25	30	100	20	33	84	11	1
3	15	25	100	10	28	92	5	1
4	30	41	92	60	54	88	5	1
5	15	15	96	25	38	96	7	1
6	30	44	68	35	50	76	8	2
7	120	109	0	120	120	0	5	1
8	25	40	88	120	120	0	8	1
9	10	19	96	30	40	92	8	1
10	15	31	92	20	50	72	5	1
11	20	20	100	120	120	0	17	3
12	10	26	100	120	120	0	4	3
13	10	19	84	30	30	100	12	1
14	40	40	76	120	120	0	8	2
15	15	28	96	20	29	96	3	1
16	90	84	0	90	79	0	5	1
17	30	25	88	25	28	96	10	1
18	25	36	96	30	44	86	10	1
19	20	16	92	20	16	100	5	1
20	55	63	64	45	59	76	8	1
21	25	29	88	30	30	92	8	1
22	30	58	44	40	59	72	5	1
23	25	46	0	35	56	12	5	1
24	120	120	0	120	120	0	12	2
25	0	9	100	20	18	100	6	1
26	25	45	76	50	55	80	16	2
27	0	3	88	25	41	72	17	1
28	30	34	96	35	40	88	4	1
29	20	21	84	120	120	0	13	1
30	10	16	96	30	25	94	4	1
31	25	39	80	120	120	0	18	1
32	25	25	96	25	26	100	8	1
33	40	24	92	25	30	80	10	1
34	20	0	88	120	120	0	12	2
35	35	36	28	120	120	0	9	2
36	10	43	72	120	120	0	10	1
37	0	8	92	20	31	32	5	1
38	20	36	88	45	40	84	12	1
39	35	46	88	120	120	0	9	1
40	40	41	68	35	46	68	7	1
41	M	36	32	120	120	0	14	1
42	45	50	84	35	45	80	8	1
43	M	31	100	25	41	88	15	1
44	25	37	72	120	120	0	14	1
45	25	49	60	25	44	68	10	1
46	25	29	92	120	120	0	13	1
47	40	40	88	120	120	0	17	1
48	25	39	76	25	39	92	8	1
49	5	16	100	20	28	96	11	1
50	35	39	100	35	41	100	8	1
51	40	40	100	45	44	96	8	1
52	10	9	100	20	26	100	5	1
53	10	5	100	5	15	96	7	1
54	20	25	100	5	19	100	16	3
55	0	8	100	0	5	96	5	1
56	15	34	80	15	35	84	12	1
57	15	35	96	30	33	72	8	1
58	40	43	96	45	55	72	5	1
59	5	5	100	20	21	100	12	1
60	L	10	L	L	9	L	8	1
61	35	51	84	120	120	0	6	1
62	20	21	100	30	25	100	5	2
63	35	45	92	35	44	96	6	1
64	5	3	96	25	30	96	10	1

APPENDIX (*Continues*)

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APPENDIX 1. (*Continued*)

Subject	Preoperative SRT (dB HL)	Preoperative PTA (dB HL)	Preoperative WRS (%)	Postoperative SRT (dB HL)	Postoperative PTA (dB HL)	Postoperative WRS (%)	Tumor size (mm)	Final facial function (House-Brackmann grade)
65	5	8	100	25	32	96	7	1
66	10	14	100	120	120	0	5	1
67	65	59	52	60	64	68	5	2
68	35	35	92	40	46	92	8	*
69	25	30	84	25	35	76	15	1
70	35	36	100	30	36	96	10	1
71	10	15	96	15	18	92	15	1
72	10	10	100	5	15	100	4	1
73	35	41	84	45	40	88	6	1

*Lost to follow-up 1 week postoperatively.

WRS, word recognition score; NU-6 word lists, 25 words, 40 dB HL or PBmax; PTA, pure-tone average (0.5, 1, 2, and 3 kHz); L, WRS not available, patient not English speaking; M, missing data.

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