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Long-term Hearing Preservation After Resection of Vestibular Schwannoma: a Systematic Review and Meta-analysis

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Objective: The objective is to perform a systematic review and meta-analysis of the literature on the long-term results of hearing preservation after vestibular schwannoma resection.
Data Sources: Ovid/Medline, PubMed, Embase, and the Cochrane library from January 1980 to January 2015.
Study Selection: Inclusion criteria: age ≥18 years, minimum 10 patients in the treatment group, hearing preserving microsurgery, no previous radiation treatment, serviceable hearing at immediate postop follow-up, hearing outcomes reported using Gardner Robinson or the American Academy of Otolaryngology-Head and Neck Surgeons hearing grading scales, and average follow-up of 5 years. Preoperative, immediate postoperative, and last follow-up audiograms were required. Exclusion criteria included neurofibromatosis type 2 patients and surgery for salvage therapy or decompression.
Data Extraction: Quality evaluated using Methodological Index for Non-Randomized Studies.
Data Synthesis: Meta-analysis was performed using R v3.2.2, Metafor package v 1.9-7. Cohen's D was used to determine effect size. Ten reports had at least 5-year follow-up and used standardized hearing grading scales. The systematic review found that if hearing was preserved at Class A or B at early postop visit, the chance of preserving hearing at 5 years was excellent. Those who maintained speech discrimination score ≥ 89% at the early postoperative follow-up had better long-term hearing preservation. The meta-analysis reveals that only preoperative and postoperative pure-tone average was associated with long-term hearing preservation.
Conclusion: Long-term (>5 yr) hearing durability rates are generally very good. Most studies do not report patient and tumor characteristics, therefore precluding combining studies for meta-analysis. Only preoperative and postoperative postoperative pure-tone average was associated with long-term hearing durability. **Key Words:** Acoustic neuroma—Hearing preservation—Long-term hearing preservation—Vestibular schwannoma.

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Surgical treatment of vestibular schwannoma (VS) has evolved from a significantly morbid undertaking with high mortality to one in which the contemporary surgeon aims to remove the tumor as well as reduce loss of hearing, balance, and facial function. VS often presents with hearing loss and tinnitus. Since the onset of earlier use of magnetic resonance imaging for detection of VS, more small tumors (<2 cm) have been detected and thus more patients present with near normal to serviceable hearing (1,2). The best therapeutic outcome for small tumors is still under much debate and study. The options for treatment include watchful waiting, stereotactic radiosurgery, and microsurgical resection. For small tumors, there is significant effort to preserve hearing during surgical resection via the middle cranial fossa (MCF) or retrosigmoid (RS) approaches.

If surgical treatment for hearing preservation is selected after appropriate counseling, the MCF approach is often used for tumors confined to the internal auditory canal (IAC) with a small portion extending into the cerebellopontine angle. The RS approach is used for larger tumors that are mostly confined to the cerebellopontine angle with partial extension into the IAC (2). The largest series by Brackmann et al. (3) reported preoperative hearing preservation levels in 59% of patients who underwent MCF resection. Hillman et al. (4) reported that the MCF approach led to better hearing preservation than the RS approach (59 versus 38.5%); tumors were slightly larger in the RS than MCF group (14 versus 8 mm). However, in a series of 125 patients (Sameshema et al. (5)), usable hearing preservation (defined as American Academy of Otolaryngology—Head and Neck Surgeons [AAO—HNS] Class A and B) was similar using the MCF or RS approach (76.7 versus 73.2%). The mean tumor size in the MCF group was 8.9 versus 12.4 mm in the RS group. No tumors were larger than 1.5 cm (5). In general, microsurgical resection of vestibular schwannoma leads

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to immediate postop hearing preservation rates of 50 to 70% (3,6–10).

Few studies have reported long-term data on hearing preservation after hearing preservation microsurgery (11,12). These were retrospective reviews of their respective experiences over a 5-year (Friedman et al. (11)) and 10-year (Meyer et al. (12)) period. However, they only looked at MCF approaches for VS resection. In addition, the study by Friedman et al. did not evaluate any specific variables to predict preservation of hearing due to missing data. Meanwhile, Meyer et al. (12) attempted to evaluate which characteristics may predict hearing preservation. However, this study only statistically evaluated word recognition score (WRS) to determine long-term hearing preservation using multiple regression. Recent data on watchful waiting revealed progressive hearing loss even with minimal to no growth of the tumor (13). Currently, surgeons can give patients some idea of whether there is a chance of hearing preservation based on size of tumor, location, and certain radiological features such as presence of cerebrospinal fluid in the fundus of the IAC. The studies available are limited in their scope that limits using their findings to counsel patients considering hearing preservation surgery. Thus, it would be helpful if surgeons had predictive information on the durability of postoperative serviceable hearing; therefore, a systematic review and meta-analysis was performed of the literature evaluating the long-term hearing preservation rate after hearing preservation surgery for VS. Specifically, we wanted to evaluate which characteristics are associated with long-term (≥5 yr) hearing preservation after VS surgery and compare to the results with radiotherapy.

METHODS

A literature search using the Preferred Reporting Items for Systematic Reviews and Meta-Analyses guidelines was performed independently by two authors (S.A. and F.H.) to identify all studies that evaluated long-term hearing preservation after VS resection (14). The subject headings ''vestibular schwannoma,'' ''hearing preservation,'' ''acoustic neuroma,'' ''hearing sparing surgery,'' ''middle cranial fossa,'' ''retro-sigmoid,'' ''suboccipital approach,'' and ''long-term hearing'' were entered in different combinations into PubMed, Ovid/Medline, and Embase search engines. The Cochrane database was also searched for relevant studies. The search was limited to English-language human studies published between January 1, 1980 and January 1, 2014. The last date of the search was in June 2015. We added Embase to our review on April 17, 2016.

Two reviewers (S.A. and F.H.) were involved in the selection of studies, data collection, and quality assessment. Any disagreement was resolved by discussion and if there was continued disagreement, a third author was asked to resolve the issues. Inclusion criteria included all study types except case reports and review articles. Further inclusion criteria included: patients aged >18 years; >10 patients in treatment group; no previous or postoperative radiation treatment; no additional surgeries on the same tumor; no neurofibromatosis type 2 patients; no decompression-only surgeries; only retrosigmoid or middle cranial fossa approach to surgical resection; hearing results reported using Gardner-Robinson (GR) or AAO-HNS grading scales; pre, post, and long-term audiogram reported; average follow-up of at least 5 years; and preserved hearing in the immediate postoperative period.

The publications' abstracts were reviewed and those fulfilling the criteria were obtained and their references reviewed to identify any relevant articles. The data were abstracted onto a form created by first author S.A. Data were entered independently after the studies were selected for review by two of the authors. SA checked the extracted data for completeness and accuracy. We recorded authors name, year of publication, sample size, surgical approach, sample size, and patient demographics. The outcome measures examined included: preoperative pure-tone average (PTA), preoperative WRS, immediate postoperative PTA, immediate postoperative WRS, tumor size, patient age, GR/AAO-HNS grade, hearing in opposite ear, and completeness of resection. We defined useable hearing preservation as AAO-HNS Class A and B or Gardner Robinson Grade 1 and 2. Hearing durability was defined for the purpose of our study as maintaining useable hearing at 5 years or more postoperatively. Hearing stability was defined as maintenance of hearing over time.

Several studies did not use these outcome measures and were not included for further analysis. Only a few of the studies used similar reporting measures that could be combined to allow a greater pool of patients for statistical analysis. The mean, standard deviation, and range were recorded for each parameter. The final analysis included all studies that fulfilled our search criteria and had clear description of preoperative, postoperative, and long-term hearing. No attempt was made to contact authors for any missing data. Each selected article was assigned a level of evidence by two of the authors (S.A. and F.H.) using guidelines published by the Oxford Centre for Evidence-Based Medicine (accessed in June 2015 and then again in April 17, 2016) (15). Any dispute in the assignment of the evidence level was resolved after discussion and mutual agreement. Quality of the studies was evaluated using the Methodological Index for Non-Randomized Studies (MINORS) (16), MINORS is a validated instrument designed to evaluate methodological quality of nonrandomized surgical studies. Seven items are used for assessment of noncomparative studies and an additional five are used for evaluating comparative studies. Each item is scored from 0 to 2 with 0 indicating that the item was not reported, 1 suggests that the item was inadequately reported and 2 suggests that it was adequately reported. The ideal global score is 16 for noncomparative studies and 24 for comparative studies (16).

Statistical Analysis

Meta-analysis was performed using R v3.2.2, Metafor package v 1.9-7. Cohen's D was used to determine effect size. Cohen's D is the standardized effect size, defined as: (Mean2−Mean1)/pooled variance. Cohen's D effect sizes are interpreted such that a one unit increase in Cohen's D is a one standard deviation increase in the variable. The effect size used in this analysis was the standardized mean difference. Using Cohen's definition (Cohen) (17) a ''small effect'' is a $d = 0.2$, a ''medium effect'' is a $d = 0.5$, and a ''large effect'' is a $d = 0.8$ or larger. The data available to us from the studies included the means and ranges on various measures for each population (hearing preserved, hearing not preserved). Thus an effect size method for two groups, mean differences, needed to be used. Analyses were computed using individual study means, estimated standard deviations (computed as range/4), and study group sample sizes. Q and I tests were used to assess for

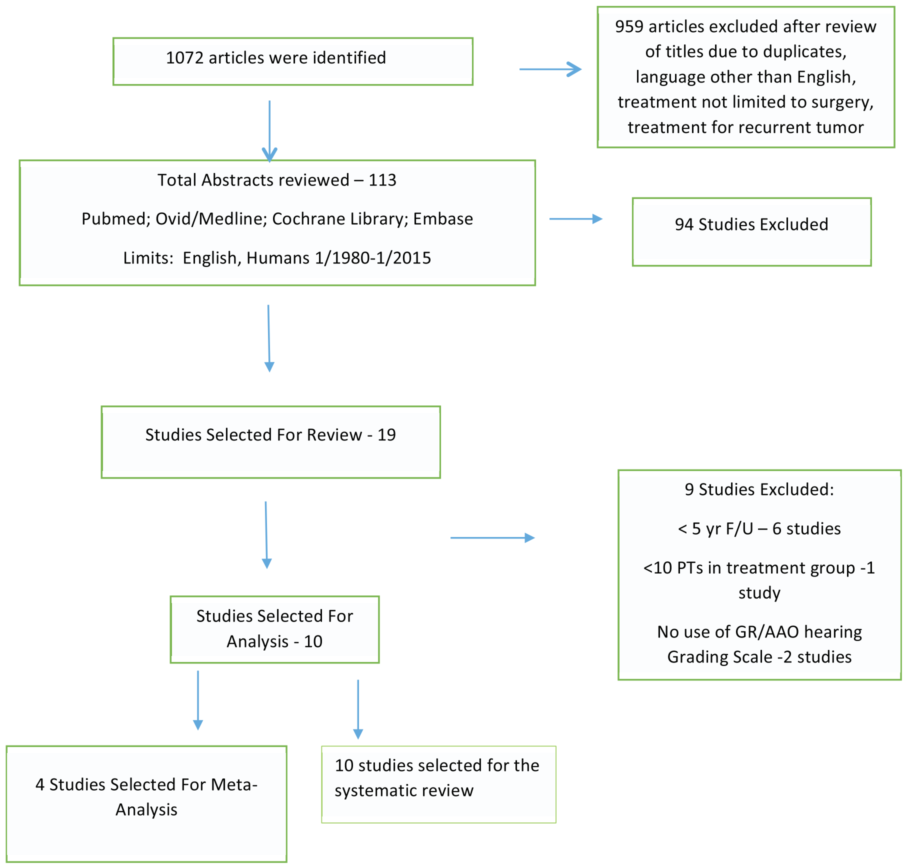

FIG. 1. Flow chart of search results.

heterogeneity across studies. Both random and fixed effects models were applied. Fixed effects estimate and restricted maximum likelihood estimators were used to report the results of the meta-analysis. *t* test was used to assess if the pooled effect size was significantly different from zero. Risk of publication bias was evaluated using funnel plot asymmetry. Specifically a regression test of Funnel plot asymmetry was performed. Study quality was assessed using MINORS criteria.

RESULTS

Figure 1 shows the flow chart of the search results. Of 1,072 articles identified, 113 abstracts were reviewed based on study criteria. A total of 19 articles met the initial inclusion criteria and were reviewed. Only 10 of these 19 reports had at least a 5-year average/mean follow-up duration and used the appropriate GR/AAO-HNS grading scale. Hearing preservation outcome (preservation, worsening) as well as other tumor factors, patient demographics, and extent of follow-up were collected from the articles. A total of 10 articles qualified for the systematic review while four articles could be combined for the meta-analysis (11,18–26).

Table 1 provides the characteristics of the 10 studies (type of study, study quality, level of evidence, surgical approach, number of patients, etc.). The four studies with complete audiometric data recorded (including preop, immediate postop, and long-term) were combined for meta-analysis totaling 109 subjects (18–21). Only four variables (preoperative and postoperative PTA and preoperative and postoperative WRS) could be analyzed.

The 10 studies used for the systematic review had an average of more than 5-year follow-up after surgery. The hearing durability ranged from 60 to 92% (average 78.9%) at last follow-up.

Of the 109 patients in the four studies used in the meta-analysis, the immediate postoperative usable hearing preservation ranged between 50 and 70% (18–21). All studies were retrospective, level 4 studies. These studies' methodological quality was thought to be fair to good (MINORS score 10–11 out of 16) (Table 1). The four studies were combined to evaluate preoperative PTA and WRS as well as postoperative PTA and WRS and their relationship to long-term hearing durability (Table 2).

Size of tumor, completeness of the surgery, status of hearing in the opposite ear, surgical approach, and patient age could not be subjected to a systematic review because of incomplete data. Three studies reported completeness of resection that ranged from 88 to 99% (18,25,26). Because of incompleteness of data, only one of these studies (Nakamizo et al. (18)) was used in the meta-analysis. Therefore, we could not evaluate the extent of

TABLE 1. *Studies used for systematic review*

Study	Type of Study	MINORS—Quality of Study	Level of Evidence	Surgical Approach	Total Patients in Study	#PTS (Class A, B or GR-1/2)-IPO	Age (Yr)	Mean Follow-up Months (Range)	%>5 Year Hearing Preserved
Nakamizo et al. 2013	Retro	11	4	RS/SOC-100%	24	24	45.2 ± 11.1 (20–62)	68.8 ± 30.2 (14–123)	83.3
Mazzoni et al. 2012	Retro	11	4	DNS	94 (91>5 yr f/u)	54	DNS	168 (72–252)	87
Woodson et al. 2010	Retro	11	4	MCF-100%	49	46	48 (19–69)	85.6 (62–163)	92
Shelton et al. 1990	Retro	9	4	MCF-100%	25	17	44 (12–68)	96 (36–240)	82
Lin et al. 2005	Retro	12	4	RS/SOC-100%	113	30	47.3 (32–64)	114 (36–264)	60
Friedman et al. 2003	Retro	10	4	MCF-100%	119 (38>5 yr f/u)	23	Unknown	DNS-however >5 years	70
Wang et al. 2013	Retro	10	4	MCF-100%	103 (56> 5 yr f/u)	32	Unknown	DNS- however >5 years	84.4
Betchen et al. 2005	Retro	11	4	RS/SOC-100%	142	35	46.3 (25–66)	84	85.7
Chee et al. 2003	Retro	10	4	RS/SOC-100%	126	23	47.3 (32–64) SD 7.3)	113.6 (36–264)	69.6
Quist et al. 2015	Retro	10	4	MCF-100%	57	16	Unknown	>60 months	75

Class A, B—AAO-HNS grading scale.
DNS indicates did not specify; f/u, follow-up; GR, Gardner Robinson; IPO, immediate postop; MCF, middle cranial fossa; PTS, patients; Retro, retrospective; RS/SOC, retrosigmoid/suboccipital).

TABLE 2. *Studies used for meta-analysis*

Study (Yr)	Average Preop PTA for Preserved Patients	Average Preop WRS for Preserved Patients %	Average Preop PTA for Nonpreserved Patients	Average Preop WRS for Nonpreserved Patients %	Average Immediate Postop PTA for Preserved Patients dB	Average Immediate Postop WRS Preserved Patients %	Average Immediate Postop PTA for Nonpreserved Patients dB	Average Immediate Postop WRS for Nonpreserved Patients %	%>5 Year Hearing Preserved
Nakamizo et al. (2013)	24.4 (7.5–48.3)	92.75 (70–100)	25.4 (20–33)	95 (85–100)	29.1 (11.7–48.3)	91.3 (60–100)	31.7 (30.0–33.3)	93 (90–100)	83.3
Woodson et al. (2010)	24 (8–45)	89.6 (64–100)	31.4 (8–46)	84.9 (52–100)	32.4 (9–51)	89.0 (52.100)	42.6 (19–58)	79.8 (32–100)	92.9
Chee et al. (2003)	18.2 (5–38.3)	90 (70–100)	28.3 (8.3–38.3)	82 (64–100)	24.4 (5–46.7)	93 (80–100)	39 (23.3–48.3)	76 (52–92)	69.6
Quist et al. (2015)	20.6 (6–39)	99.7 (96–100)	30.5 (5–48)	99 (96–100)	29.8 (5–49)	94.5 (70–100)	43 (33–50)	98 (96–100)	75

Class A, B—AAO-HNS hearing classification. Preservation refers to long-term hearing preservation ≥5 years.
dB indicates decibel; GR, Gardner Robinson; PTA, pure-tone average; WRS, word recognition score;

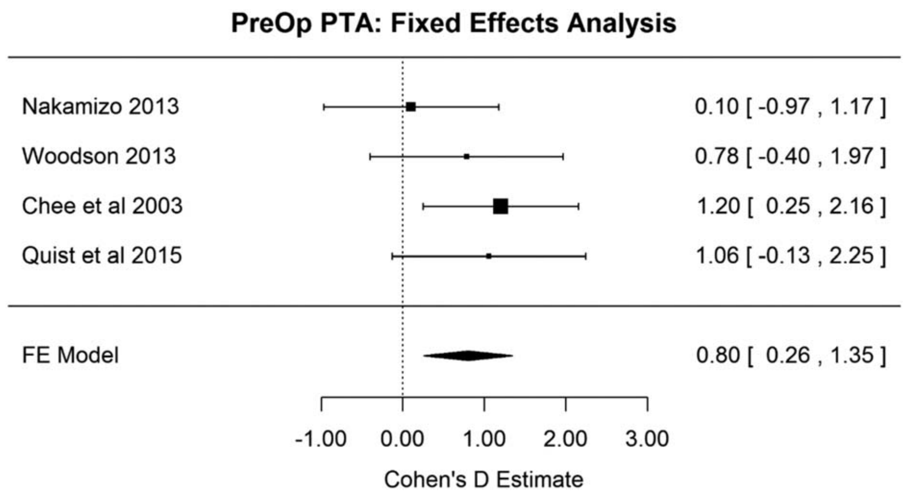

FIG. 2. Preoperative PTA and long-term hearing durability. Those with nonpreserved hearing showed 0.80 standard deviations higher preoperative PTA than those with preserved hearing. PTA indicates pure-tone average.

resection and its effects on hearing durability. Three studies reported that average tumor size was less than 20 mm for all patients (11,20,26). Nakamizo et al. (18) reported an average tumor volume in preserved patients of 4.45 versus 4.92 cm^3 for the nonpreserved hearing cases. In one study that examined several variables, there was no relationship of hearing preservation to size of tumor, preoperative hearing, origin of tumor, or follow-up period (20). Betchen et al. (26) also found no relationship of hearing preservation to size of tumor. Finally, when compared with the opposite ear, the operated ear had significant decline in speech discrimination score over time (11,19).

For the meta-analysis, we subjected the four studies for the analysis of publication bias via funnel plot asymmetry and found no such evidence. However, we only had four studies with all variances approximately equal. Also, postoperative WRS was the only variable that showed significant heterogeneity and thus restricted maximum likelihood was used instead of the fixed effects as done for the other three variables in performing the meta-analysis. Overall preoperative PTA and postoperative PTA showed significant effects. Specifically, those with nonpreserved hearing showed 0.80 standard deviations higher preoperative PTA ($p = 0.004$) compared with those with preserved hearing (Figs. 2 and 3). Those patients with nonpreserved hearing showed 1.01 standard deviations higher postoperative PTA ($p = 0.003$) compared with those with preserved hearing (Table 3). Using above-described Cohen's definition (Cohen) (17), these effects are considered large. It was also noted that those patients who had preserved hearing at 5 years or more tended to have $\geq$ 89% WRS at immediate postoperative period.

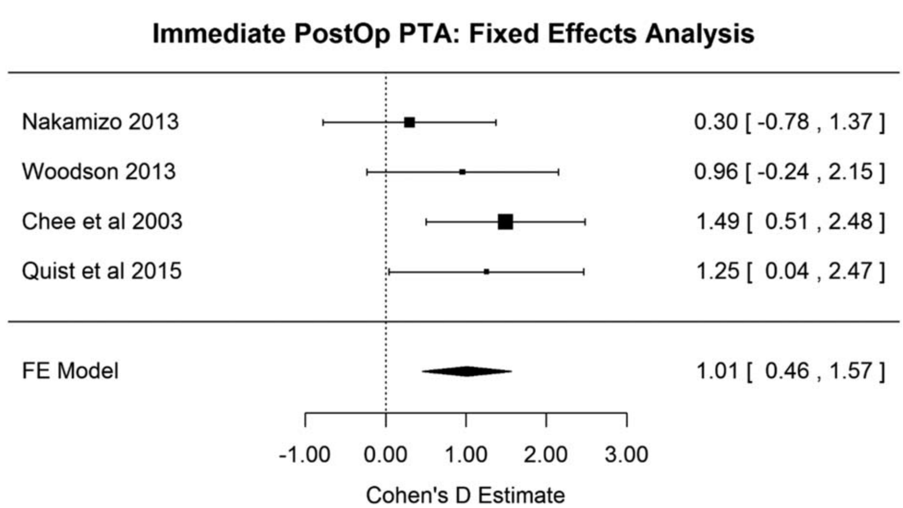

FIG. 3. Postoperative PTA and long-term hearing durability. Those with nonpreserved hearing showed 1.01 standard deviations higher postoperative PTA than those with preserved hearing. PTA indicates pure-tone average.

TABLE 3. *Tests of heterogeneity and results of meta-analysis*

Variable	I^2 Statistic	Test of Heterogeneity *p* Value	Modeling Method	Estimate (95% CI)	*p*
Preop PTA	0.0%	0.477	Fixed-effects	0.80 (0.26, 1.35)	0.004
Preop WRS	12.8%	0.362	Fixed-effects	−0.49 (−1.03, 0.04)	0.072
Postop PTA	2.7%	0.427	Fixed-effects	1.01 (0.46, 1.56)	0.003
Postop WRS	80.4%	0.002	REML	−0.61 (−1.89, 0.66)	0.347

Postop WRS is the only variable that showed significant heterogeneity, and thus REML was used instead of fixed effects analysis.
PTA indicates pure-tone average; CI, confidence interval; REML, restricted maximum likelihood; WRS, word recognition score.

DISCUSSION

For those managed conservatively without treatment, long-term hearing stability for VS ranges between 41 and 57%. Meanwhile, after radiation treatment, hearing preservation has been reported to be about 74 and 44.5% at 3 and 10 years, respectively (13,27,28). A study by Paek et al. (29) with 8-year follow-up reported a 5-year serviceable hearing preservation rate of 46% after radiosurgery treatment. Our study shows a 70% rate of hearing durability at greater than 5 years after surgery. Therefore, those patients who were able to preserve hearing (Class A/B or GR 1or 2) after surgery, 70% maintained useable hearing at last follow-up (>5 yr). Thus, if 50 to 70% of patients, in general, preserve their hearing immediately after surgery, then 35 to 49% of all patients undergoing hearing preservation surgery will continue to maintain useable hearing at 5 years after surgery.

Being able to predict long-term hearing preservation after VS surgery would help in counseling patients when deciding on hearing-sparing surgery versus radiotherapy or observation. There is no good predictive model to determine the durability of hearing preservation once surgery is performed and the patient has serviceable hearing in the immediate postoperative period. Our study shows that long-term hearing preservation after hearing preservation surgery is similar to that of radiotherapy. Previous meta-analysis by Maniakis and Saliba (30) showed that radiotherapy was associated with significantly better long-term hearing preservation compared with microsurgery. Their study reported long-term useful hearing preservation rate of 49.4% for RS approach and 51.3% for the MCF approach. This falls close to the range of 35 to 49% that we calculated. Their study included studies with less than seven patients in the treatment group for the meta-analysis. The slight difference noted between the present review and that study may be due to the limit of minimum 10 patients required for our study inclusion. They also reported a higher hearing preservation rate with radiotherapy than with microsurgery. However, they used studies with total patients of three and four patients with 100% success rate with RT and therefore, the difference between the two groups can be explained by the low number of patients reviewed in the radiotherapy group (30). Further evaluation of the stereotactic radiotherapy literature reveals that when followed for more than 5 years out, the rates of hearing preservation range between 23 and 55% (31,32). Carlson et al. (31) reported rates of serviceable hearing at 1, 3, 5, 7, and 10 years following radiotherapy to be 80, 55, 48, 38, and 23% respectively. Similarly, Kim et al. (32) noted 5-year hearing preservation (Gardner-Roberson grade 1 or 2) rate of 55%. This reveals that hearing preservation continues to decline more than 5 years out from radiotherapy.

Our study highlights the lack of prospective studies in evaluating the durability of hearing. There is also a lack of complete data recording of patient and tumor characteristics in many studies that preclude combining these studies for a more robust analysis. Overall, our study demonstrates that there is a significant relationship between long-term hearing durability and preoperative and postoperative PTA. Patients with preserved long-term hearing had better preoperative as well as immediate postoperative PTA. Overall, there is about 70% hearing durability (maintenance of immediate hearing preservation over long term) at a minimum average of 5-year follow-up. No difference in rate of hearing decline was noted between MCF or RS approach. In addition, there was no relationship to sex, age, status of the opposite ear, size of tumor, and long-term hearing preservation in those who had hearing in the serviceable range immediately after hearing preservation surgery. There may very well be other correlative variables, but given methodological flaws in reporting and lack of standardization, our conclusions are limited to the relevance of the PTA information and long-term hearing durability.

The mechanisms of long-term hearing loss are unclear. Some suggest microscopic tumor recurrence, development of endolymphatic hydrops, or toxicity due to the use of muscle in packing the IAC as some of the factors for the decline (22,33,34). One study noted a decrease in histopathological changes in the cochlea when packing of the IAC was switched from muscle to fat while another noted no effect on hearing deterioration when using abdominal fat versus muscle (22,35).

For future studies we recommend a long-term follow-up (> 5 yr) and good data collection to identify patient, tumor, and audiometric variables that may be used to predict hearing preservation. In addition, it is important to use a standardized classification of hearing preservation (either GR, 1995 AAO-HNS criteria, or using the recently developed scattergram format for reporting hearing) to be able to communicate hearing preservation and to develop consistency in reporting hearing preservation (36). Standardized classification along with audiometric variables is important in analyzing data from a variety of centers.

The limitations of this analysis include the low number of patients in the reports and a lack of well-controlled prospective trials in the meta-analysis. In general, results of meta-analysis may depend more on inclusion criteria and not necessarily the data. We acknowledge that our study is limited by the trials included with their own methodological weaknesses. However, by applying strict criteria and accounting for heterogeneity, a good attempt can be made to reduce some of these weaknesses. More patients will be needed to confirm our findings.

CONCLUSIONS

This meta-analysis and review of the literature suggests there is a relationship between preoperative and postoperative PTA and long-term hearing durability. Those patients with better preoperative and postoperative PTA had durability of their hearing at long-term follow-up. However, these conclusions must be interpreted with caution due to the limitations of this analysis.

REFERENCES

1. Stangerup SE, Tos M, Caye-Thomasen P, et al. Increasing annual incidence of vestibular schwannoma and age at diagnosis. *J Laryngol Otol* 2004;118:622–7.
2. Kari E, Friedman RA. Hearing preservation: Microsurgery. *Curr Opin Otolaryngol Head Neck Surg* 2012;20:358–66.
3. Brackmann DE, Owens RM, Friedman H, et al. Prognostic factors for hearing preservation in vestibular schwannoma surgery. *Am J Otol* 2000;21:417–24.
4. Hillman T, Chen DA, Arriaga MA, et al. Facial nerve function and hearing preservation acoustic tumor surgery: Does the approach matter? *Otolaryngol Head Neck Surg* 2010;142:115–9.
5. Sameshema T, Fukushima T, McElveen J Jr, et al. Critical assessment of operative approaches for hearing preservation in small acoustic neuroma surgery: Retrosigmoid vs. middle fossa approach. *Neurosurgery* 2010;67:640–5.
6. Arts HA, Telian SA, El-Kashlan H, et al. Hearing preservation and facial nerve outcomes in vestibular schwannoma surgery: Results using the middle cranial fossa approach. *Otol Neurotol* 2006;27:234–41.
7. Colletti V, Fiorino F. Is the middle fossa approach the treatment of choice for intracanalicular vestibular schwannoma? *Otolaryngol Head Neck Surg* 2005;132:459–66.
8. Holsinger FC, Coker NJ, Jenkins HA. Hearing Preservation in conservation surgery for vestibular schwannoma. *Am J Otol* 2000;21:695–700.
9. Staecker H, Nadol JB Jr, Ojeman R, et al. Hearing preservation in acoustic neuroma surgery: Middle fossa versus retrosigmoid approach. *Am J Otol* 2000;21:399–404.
10. Kumon Y, Sakai S, Kohno K, et al. Selection of surgical approaches for small acoustic neurinomas. *Surg Neurol* 2000;53:52–60.
11. Friedman RA, Kesser B, Brackmann DE, et al. Long-term hearing preservation after middle fossa removal of vestibular schwannoma. *Otolaryngol Head Neck Surg* 2003;129:660–5.
12. Meyer TA, Canty PA, Wilkinson EP, et al. Small acoustic neuromas: Surgical outcomes versus observation or radiation. *Otol Neurotol* 2006;27:380–92.
13. Stangerup SE, Thomsen J, Tos M, et al. Long-term hearing preservation in vestibular schwannoma. *Otol Neurotol* 2010;31:271–5.
14. Moher D, Liberati A, Tetzlaff J, et al. Preferred reporting items for systematic reviews and meta-analysis: The PRISMA statement. *Ann Intern Med* 2009;151:264–9.
15. OCEBM Levels of Evidence Working Group. ''The Oxford 2011 Levels of Evidence''. Oxford Centre for Evidence-Based Medicine. Available at: http://www.cebm.net/index.aspx?o=5653 (Accessed in June 2015 and on April 17, 2016).
16. Slim K, Nini E, Forestier D, et al. Methodological index for non-randomized studies (MINORS): Development and validation of a new instrument. *ANZ J Surg* 2003;73:712–6.
17. Cohen J. *Statistical Power Analysis for the Behavioral Sciences*, 2nd ed Hillsdale, NJ: Lawrence Earlbaum Associates; 1988.
18. Nakamizo A, Mori M, Inoue D, et al. Long-term hearing outcome after retrosigmoid removal of vestibular schwannoma. *Neurol Med Chir (Tokyo)* 2013;53:688–94.
19. Woodson EA, Dempewolf RD, Gubbels SP, et al. Long-term hearing preservation after microsurgical excision of vestibular schwannoma. *Otol Neurotol* 2010;31:1144–52.
20. Chee GH, Nedzelski JM, Rowed D. Acoustic neuroma surgery: The results of long-term hearing preservation. *Otol Neurotol* 2003;24:672–6.
21. Quist TS, Givens DJ, Gurgel RK, et al. Hearing preservation after middle fossa vestibular schwannoma removal: Are the results durable? *Otolaryngol Head Neck Surg* 2015;152:706–11.
22. Mazzoni A, Zanoletti E, Calabrese V. Hearing preservation surgery in acoustic neuroma: Long-term results. *Acta Otorhinolaryngol Ital* 2012;32:98–102.
23. Shelton C, Hitselberger WE, House WF, et al. Hearing preservation after acoustic tumor removal: Long-term results. *Laryngoscope* 1990;100:115–9.
24. Lin VY, Stewart C, Brebenyuk J, et al. Unilateral acoustic neuromas: Long-term hearing results in patients managed with fractionated stereotactic radiotherapy, hearing preservation surgery, and expectantly. *Laryngoscope* 2005;115:292–6.
25. Wang AC, Chinn SB, Than KD, et al. Durability of hearing preservation after microsurgical treatment of vestibular schwannoma using the middle cranial fossa approach. *J Neurosurg* 2013;119:131–8.
26. Betchen SA, Walsh J, Post KD. Long-term hearing preservation after surgery for vestibular schwannoma. *J Neurosurg* 2005;102:6–9.
27. Godefroy WP, Kaptein AA, Vogel JJ, et al. Conservative treatment of vestibular schwannoma: A follow-up study on clinical and quality of life outcome. *Otol Neurotol* 2009;30:968–74.
28. Chopra R, Kondziolka D, Niranjan A, et al. Long-term follow-up of acoustic schwannoma radiosurgery with marginal tumor doses of 12 to 13 Gy. *Int J Radiat Oncol Biol Phys* 2007;68:845–51.
29. Paek SH, Chung HT, Jeong SS, et al. Hearing preservation after gamma knife stereotactic surgery of vestibular schwannoma. *Cancer* 2005;104:580–90.
30. Maniakis A, Saliba I. Microsurgery versus Stereotactic radiation for small vestibular schwannomas: A meta-analysis of patients with more than 5 years' followup. *Oto Neurotol* 2012;33:1611–20.
31. Carlson M, Jacob J, Pollock B, et al. Long-term hearing outcomes following stereotactic radiosurgery for vestibular schwannoma: Patterns of hearing loss and variables influencing audiometric decline. *J Neurosurg* 2013;118:579–87.
32. Kim Y, Kim D, Han H, et al. Hearing outcomes after stereotactic radiosurgery for unilateral intracanalicular vestibular schwannomas: Implication of transient volume expansion. *Int J Radiation Oncol Biol Phys* 2013;85:61–7.
33. Clemis JD, Mastricola PG, Schuler-Vogler M. The contralateral ear in acoustic tumors and hearing conservation. *Laryngoscope* 1981;91:1792–800.
34. Ylikoski J, Collan Y, Palva T, et al. Cochlear nerve in neurilemomas. Audiology and histopathology. *Arch Otolaryngol* 1978;104: 679–84.
35. Inoue Y, Kanzaki J, Ogawa K, et al. The long-term outcome of hearing preservation following vestibular schwannoma surgery. *Auris Nasus Larynx* 2000;27:9–13.
36. Gurgel RK, Jackler RK, Dobie RA, et al. A new standardized format for reporting hearing outcome in clinical trials. *Otolaryngol Head Neck Surg* 2012;147:803–7.