Original Article

Significance of Vestibular Testing on Distinguishing the Nerve of Origin for Vestibular Schwannoma and Predicting the Preservation of Hearing

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Abstract

Background: Determining the nerve of origin for vestibular schwannoma (VS), as a method for predicting hearing prognosis, has not been systematically considered. The vestibular test can be used to investigate the function of the superior vestibular nerve (SVN) and the inferior vestibular nerve (IVN). This study aimed to preoperatively distinguish the nerve of origin for VS patients using the vestibular test, and determine if this correlated with hearing preservation.

Methods: A total of 106 patients with unilateral VS were enrolled in this study prospectively. Each patient received a caloric test, vestibular-evoked myogenic potential (VEMP) test, and cochlear nerve function test (hearing) before the operation and 1 week, 3, and 6 months, postoperatively. All patients underwent surgical removal of the VS using the suboccipital approach. During the operation, the nerve of tumor origin (SVN or IVN) was identified by the surgeon. Tumor size was measured by preoperative magnetic resonance imaging.

Results: The nerve of tumor origin could not be unequivocally identified in 38 patients (38/106, 35.80%). These patients were not subsequently evaluated. In 26 patients (nine females, seventeen males), tumors arose from the SVN and in 42 patients (18 females, 24 males), tumors arose from the IVN. Comparing with the nerve of origins (SVN and IVN) of tumors, the results of the caloric tests and VEMP tests were significantly different in tumors originating from the SVN and the IVN in our study. Hearing was preserved in 16 of 26 patients (61.54%) with SVN-originating tumors, whereas hearing was preserved in only seven of 42 patients (16.67%) with IVN-originating tumors.

Conclusions: Our data suggest that caloric and VEMP tests might help to identify whether VS tumors originate from the SVN or IVN. These tests could also be used to evaluate the residual function of the nerves after surgery. Using this information, we might better predict the preservation of hearing for patients.

Key words: Caloric Test; Hearing Preservation; Inferior Vestibular Nerve; Superior Vestibular Nerve; Vestibular-evoked Myogenic Potential

Introduction

Vestibular schwannoma (VS) is a benign tumor arising from Schwann cells in the vestibular nerve. The vestibular nerve has two divisions in the internal auditory canal (IAC): the superior vestibular nerve (SVN) and the inferior vestibular nerve (IVN). The earliest symptoms in VS patients are auditory, such as hearing loss and tinnitus. VS primarily originates from one of the divisions of vestibular nerve, and hearing outcome might be affected by the origin of the tumor.[1,2] Therefore, distinguishing the nerve of tumor origin in patients with VS is very important.

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Caloric tests are used to estimate the function of the SVN, which innervates the horizontal semicircular canal and is responsible for the caloric response. Vestibular-evoked myogenic potential (VEMP) tests reflect the sacculocollic

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reflex and are used to evaluate IVN function. If the results of these two tests correlate with the nerve of tumor origin, they will be useful to preoperatively predict the odds of hearing preservation.[1,2]

For this study, we obtained the preoperative and postoperative results of caloric and VEMP tests. Furthermore, we also evaluated the correlations of those with the intraoperative findings regarding the nerve of tumor origin and hearing level in 106 VS patients. We evaluated the efficacy of determining the nerve of tumor origin of VS via these tests, and looked for a relationship between the nerve of tumor origin and hearing outcome after surgery.

Methods

Patient population

This study included 106 patients with unilateral VS (37 males, 69 females) who underwent surgical removal of the tumor between September 2012 and September 2015. Each patient received a caloric test, VEMP test, and hearing level test before the operation and at 1 week, 3 months, and 6 months after the operation. Only the patients for whom the nerve of tumor origin could be unequivocally identified during surgery were included in the analyses. This study was approved by the Ethics Committee of Sanbo Brain Hospital, Capital Medical University, and performed in accordance with the principles of the *Declaration of Helsinki*. All participants gave written informed consents.

Magnetic resonance imaging

A 3.0-T superconducting magnet with a standard head coil (Siemens 3.0-T Nova, Germany) was used for the head magnetic resonance imaging examinations.

Vestibular-evoked myogenic potential testing

VEMP tests were recorded using the ECLIPSE Objective Hearing Test Platform (Interacoustics, Copenhagen, Denmark). For measurements of VEMP, a surface electrode was placed on the upper half of the sternocleidomastoid muscle ipsilateral to the stimulated ear, with a reference electrode on the upper sternum. The patients were placed in a supine position and instructed to rotate their heads toward the nonstimulated ear. The ground electrode was placed on the nasion. The responses of VEMP were regarded as abnormal when the responses on the affected side were absent or decreased compared with those of the unaffected side. Rarefaction clicks (0.1 ms, 95 dB normal hearing level [nHL]) and short tone burst (500 Hz, rise/fall time 1 ms, plateau time 2 ms, 95 dB nHL) through an inserted earphone were used as the stimulus.

We analyzed the amplitude of the first positive–negative peak (p13-n23) of the VEMP. The evoked potential ratio of VEMP was calculated using the following formula:[3]

$$\text{VEMP asymmetry (\%)} = 100\ (Au - Aa)/(Au + Aa).$$

Where Aa is the amplitude of p13-n23 on the affected side and Au is the amplitude on the unaffected side. Based on the above ratio, patients were divided into three classes by VEMP tests: normal, reduced, and no response class.

Caloric tests

Caloric tests were performed by standard bithermal irrigation of the external auditory meatus using air at 24°C and 50°C for 20 s while performing electronystagmography. Canal paresis (CP) was calculated using the maximal slow-phase eye velocity of caloric nystagmus. CP values >12% were defined as abnormally decreased on the affected side. The unilateral weakness of the caloric test was calculated with peak slow-phase velocity of induced nystagmus as follows:[4]

$$([UW + UC] - [AW + AC])/(UW + UC + AW + AC) \times 100.$$

Where UW, UC, AW, and AC are peak slow-phase velocities of the responses to unaffected side warm, unaffected side cool, affected side warm, and affected side cool irrigations, respectively.

Patients were classified into the following groups according to the degree of preoperative caloric paresis: Group 1, normoreflexia, caloric paresis between 0 and 12%; Group 2, hyporeflexia, caloric paresis between 12% and 99%; and Group 3, areflexia, caloric paresis is 100%, there was no response.

Hearing level

The hearing level of the patients was classified into four classes, A, B, C, and D according to the American Academy of Otolaryngology-Head and Neck Surgery (AAO-HNS) Classification.[5] Preoperative hearing was categorized as Class A in 21 patients, Class B in 19, Class C in 11, and Class D with residual hearing remnants in 17 patients.

Statistical analysis

Statistical analysis was performed using SPSS software (version 16.0; SPSS Inc., Chicago, IL, USA). Continuous variables were shown as mean ± standard deviation (SD). The χ^2 test was used to analyze the data as appropriate. A value of $P < 0.05$ was considered statistically significant.

Results

The nerve of vestibular schwannoma origin

Among the 106 enrolled patients with VS, the nerve of tumor origin in 38 patients could not be unequivocally identified during the operation; therefore, they were not further evaluated. The nerve of tumor origin was identified in 68 patients by neurosurgeons. In 42 patients, the tumor arose from the IVN and in 26 patients, it arose from the SVN.

Vestibular tests

Based on the evoked potential ratio, patients were divided into three classes based on VEMP results: normal, reduced, and no response. Nine of the 68 VS patients displayed abnormal VEMP and normoreflexia from the caloric test [Table 1]. During the operation, patients with abnormal VEMP and normal caloric test had a tumor that originated

from the IVN. Thirteen patients showed normal VEMP and abnormal caloric tests [Table 2]. Those 13 patients had a tumor that originated from the SVN. The rest of the patients showed abnormal VEMP and caloric tests, and this group had tumors involving both the IVN and the SVN. The origin of these tumors could not be determined preoperation [Figures 1and 2].

Hearing preservation and tumor origin

Hearing was preserved in 23 patients. In 16 cases, the tumor originated from the SVN and in seven cases, the IVN was identified as the nerve of origin. Hearing quality revealed AAO-HNS Class A in six patients (two IVNs, four SVNs), Class B in five (one IVN, four SVNs), Class C in four (one IVN, three SVNs), and Class D with hearing remnants in eight (three IVNs, five SVNs). Among the 16 cases whose tumors originated from SVN, 12 showed normal VEMP and abnormal caloric tests, the rest showed both abnormal VEMP and caloric tests. Among the seven cases whose tumors originated from IVN, two cases showed abnormal VEMP and normal caloric tests, the rest showed both abnormal results [Table 3].

Table 1: Vestibular-evoked myogenic potentials and the nerve of tumor origin

The nerve of tumor origin	Normal (*n*)	Reduced (*n*)	No response (*n*)	Total (*n*)
SVN	13	8	5	26
IVN	0	33	9	42
SUM	13	41	14	68

SVN: Superior vestibular nerve; IVN: Inferior vestibular nerve; SUM: Summation.

Table 2: Caloric test and the nerve of tumor origin

The nerve of tumor origin	Normal (*n*)	Reduced (*n*)	No response (*n*)	Total (*n*)
SVN	0	16	10	26
IVN	9	22	11	42
SUM	9	38	21	68

SVN: Superior vestibular nerve; IVN: Inferior vestibular nerve; SUM: Summation.

Hearing preservation and tumor size

Unlike previous reports, smaller tumors tended to have better hearing results, in this study, hearing preservation did not have a significant difference with regard to tumor size, but a significant difference was found with the tumor origin. The mean tumor size measured 12.4 mm ± 4.2 mm; the SVN mean tumor size measured 12.7 mm ± 4.8 mm; and the IVN mean tumor size measured 10.9 mm ± 3.6 mm [Table 4]. Among the 23 patients with hearing preservation, the mean tumor size for patients with AAO-HNS Class A hearing was 11.5 mm ± 4.3 mm, for Class B, it was 11.2 mm ± 3.9 mm, for Class C, it was 12.3 mm ± 4.4 mm, and for Class D, it was 11.9 mm ± 3.8 mm. When comparing tumor size in patients with hearing preservation versus those who postoperatively lost their hearing, mean tumor size in hearing patients was 11.9 mm ± 4.6 mm, compared

Table 3: Hearing preservation and the nerve of tumor origin

The nerve of tumor origin	Normal VEMP (*n*)	Normal caloric test (*n*)	Both abnormal (*n*)	Total (*n*)
SVN	12	0	4	16
IVN	0	2	5	7
SUM	12	2	9	23

VEMP: Vestibular-evoked myogenic potential; SVN: Superior vestibular nerve; IVN: Inferior vestibular nerve; SUM: Summation.

Table 4: The nerve of tumor origin and results of vestibular tests in 106 patients with VS

The nerve of tumor origin	*n*	Tumor size (mm), mean ± SD	Number of patients with normal response	
			VEMP	Caloric test
Identified	68	12.4 ± 4.2	13	9
SVN	26	12.7 ± 4.8	13	0
IVN	42	10.9 ± 3.6	0	9
Not identified	38	15.4 ± 4.5	–	–

VS: Vestibular schwannoma; VEMP: Vestibular evoked myogenic potential; SVN: Superior vestibular nerve; IVN: Inferior vestibular nerve. –: N/A.

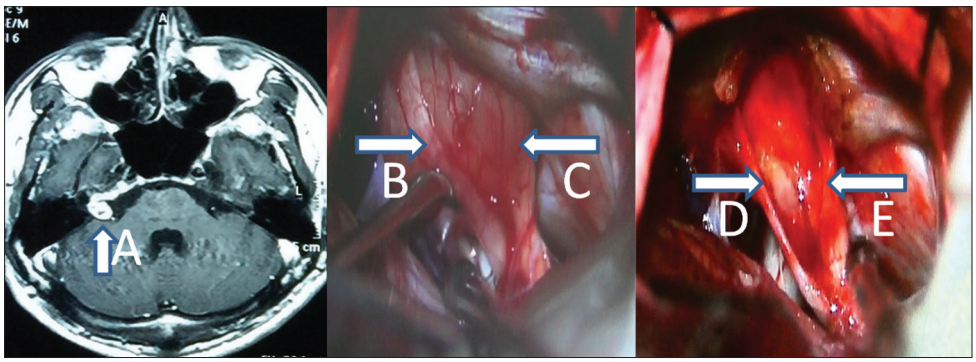

Figure 1: A 41-year-old man (case 1) with a right vestibular schwannoma. MRI revealed a 1.2 cm space-occupying lesion in the right cerebellopontine angle. (A) Vestibular schwannoma; (B) Superior vestibular nerve (preoperation); (C) Inferior vestibular nerve (preoperation); (D) Superior vestibular nerves (postoperation); (E) Inferior vestibular nerve (postoperation). MRI: Magnetic resonance imaging.

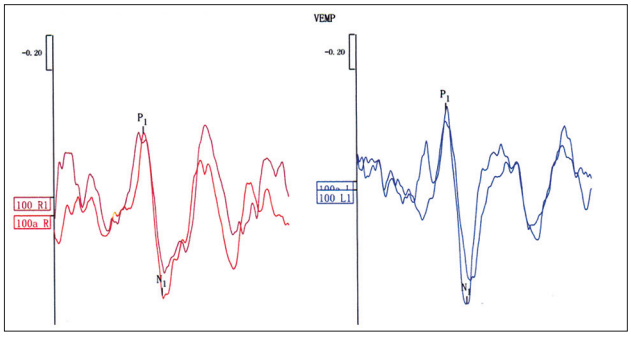

Figure 2: VEMP results of one case, which showed a bilateral normal threshold. Amplitude ratio of R/L (=1.2) is slightly less than the normal value (=1.6). The degree of asymmetry (=0.09) is also slightly less than the normal value (=0.25). VEMP: Vestibular-evoked myogenic potential; R/L: Right/Left.

with 12.5 mm ± 4.1 mm in patients with postoperative deafness ($P = 0.623$, χ^2 test).

Discussion

In this study, we investigated whether vestibular testing such as VEMP or caloric tests are predictive of the nerve of origin for VS and postoperative hearing preservation.

The horizontal semicircular canal can be primarily stimulated by caloric testing. Caloric testing represents the function of SVN, which innervates the horizontal semicircular canal. VEMP testing represents the function of IVN, which innervates the posterior semicircular canal. In combination with caloric testing, VEMP tests have facilitated separate examinations of the inferior and SVN functions.[6] VEMP tests could be useful for the diagnosis of VS, especially for classifying VS according to their nerve of origin.[3]

In this study, the results of caloric testing and VEMP tests were different between patients with SVN tumors and those with IVN tumors. These responses indicate that there are clear correlations between the vestibular tests and the nerve origin of the tumor. In the patients with no VEMP and normal/weakened caloric testing, the nerve of tumor origin was IVN. Therefore, the VEMP test aids the neurosurgeon to distinguish the nerve of origin. In patients classified as areflexia based on caloric testing and normal VEMP, the nerve of tumor origin was SVN. Chen *et al.*[7] also reported that in patients with a normal caloric response and no VEMP, the tumor had originated from the IVN. Tsutsumi *et al.*[8] reported that the complete disappearance of VEMPs was observed only in patients with tumors arising from the IVN. In patients with vestibular neuroma, VEMP could be used as an indicator of IVN involvement.[9,10]

The nerve of origin in 68 patients (68/106,64.15%) of all the VS patients could be identified. In 26 patients (26/68,38.24%) of identified patients, the nerve of origin was the SVN, and 42 patients (42/68,61.76%) of identified of patients had inferior VS. These numbers were in agreement with previous reports.[11-14] In this study, the nerve of tumor origin for most of the patients whose hearing was preserved (16) was the SVN; the number of IVN origins was only seven. This suggests that the tumor origin is important to the success of hearing preservation. At the same time, vestibular tests are also a predictive factor for hearing preservation preoperation. The probability of hearing preservation in patients with normal VEMP and abnormal caloric tests was larger compared with abnormal VEMP and normal caloric test. The hearing in 12 of 16 patients of SVN origins with normal VEMP and abnormal caloric tests was preserved compared with two of seven of IVN origins with abnormal VEMP and normal caloric tests [Table 3]. The close relationship between the cochlear nerve and the greater potential for tumor extension under the transverse crest is considered responsible for the low rate of hearing preservation associated with schwannomas originating from the IVN.[2,15] Adhesion of the tumor to the adjacent structures, including the cochlear nerve, is considered to be another risk factor.[16] Normal VEMP suggests that the nerve of tumor origin is the SVN, indicating that the IVN and the cochlear nerve are less affected.

Poor hearing results have been observed in patients with tumors originating from the IVN.[1] The close anatomical relationship between IVN schwannomas and the cochlear nerve requires a more deliberate dissection, which might compromise blood supply and directly traumatize the cochlear nerve.[2]

In the patients with no VEMP and a normal caloric test or with areflexia caloric testing and a normal VEMP, prediction of the VS nerve of origin was definite. In other cases, for example, the patients with no VEMP and hyporeflexia caloric testing, or with areflexia caloric testing and hyporeflexia of VEMP, the prediction of the nerve of tumor origin was difficult. In other cases, the patients with hyporeflexia of both VEMP and caloric tests, the prediction was impossible. Some researchers have also found that the VEMP might be useful to distinguish between IVN and SVN tumor origins. Chen *et al.*[7] reported that patients with a normal caloric response and no VEMP had tumors originating from the IVN. Tsutsumi *et al.*[8] reported that the complete disappearance of VEMPs was observed only in patients with tumors arising from the IVN. Iwasaki *et al.*[6] also reported that with abnormal VEMP responses and normal caloric test responses, some patients might be diagnosed as having disease that only involves the IVN region.

The nerve of tumor origin has been shown to be correlated with the size and location of the tumor.[17,18] Some results also suggested that the VEMP test could be useful for the diagnosis of AN, especially for classifying ANs according to the involved nerves.[3] In this study, the nerve of tumor origin in 38 of the 106 patients could not be determined. The reasons for this will be the subject of future studies. VS of the intracanalicular type might simultaneously compress the SVN and IVN via a scissor-like hold between the tumor and the IAC wall, resulting in a disturbance of both the vestibular nerves.[17]

In this study, prolonged VEMP latencies were not only caused by tumor compression to the brain stem or vestibular

spinal tract, but also by tumor compression isolated to the IVN.[17] VEMP tests are considered to be a clinical test of the IVN, whereas caloric testing is a clinical evaluation of the superior vestibular system. In combination with caloric response testing, VEMP responses have facilitated separate examinations of the inferior and SVN functions.[6]

This study had several limitations. The hearing of 23 patients was preserved. The nerve of tumor origin in 16 of them was the SVN and the others arose from the IVN. Hearing preservation had a distinct and clear relationship with the nerve of tumor origin. At the same time, it was found that the patients whose hearing was preserved also had smaller tumors. This suggests that hearing preservation has a relationship with nerve origin and tumor size simultaneously. However, tumor volume has not yet been considered as an independent factor for hearing in this study because of the small patient population, there was no statistical analysis. In a future study, we will increase the sample size and further analyze this relationship.

In conclusion, this study indicated that the results of VEMP and caloric tests in patients with VS could be used to identify the nerve origin of the tumor. The vestibular tests can predict the nerve of tumor origin and disclose the residual function of the IVN. This study showed a clinical application of VEMP testing to determine IVN integrity.[7] In some cases, a prediction of the nerve of origin for VS could be made depending on VEMP testing.[8] The vestibular tests are short and inexpensive; therefore, it would be practical to make this part of the routine examination for patients with VS, as vestibular tests are also important for predicting hearing preservation.

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Conflicts of interest

There are no conflicts of interest.

References

1. Brackmann DE, Owens RM, Friedman RA, Hitselberger WE, De la Cruz A, House JW, *et al.* Prognostic factors for hearing preservation in vestibular schwannoma surgery. Am J Otol 2000;21:417-24. doi: 10.1016/S0196-0709(00)80054-X.
2. Jacob A, Robinson LL Jr., Bortman JS, Yu L, Dodson EE, Welling DB. Nerve of origin, tumor size, hearing preservation, and facial nerve outcomes in 359 vestibular schwannoma resections at a tertiary care academic center. Laryngoscope 2007;117:2087-92. doi: 10.1097/MLG.0b013e3181453a07.
3. Murofushi T, Matsuzaki M, Mizuno M. Vestibular evoked myogenic potentials in patients with acoustic neuromas. Arch Otolaryngol Head Neck Surg 1998;124:509-12. doi: 10.1001/archotol.124.5.509.
4. Stockwell CW. Vestibular function tests. In: Paparella MM, Shumrick DA, Gluckman JL, Meyerhoff WL, editors. Otolaryngology. Philadelphia: W.B. Saunders Company; 1991. p. 921-48.
5. Committee on Hearing and Equilibrium guidelines for the evaluation of hearing preservation in acoustic neuroma (vestibular schwannoma). American Academy of Otolaryngology-Head and Neck Surgery Foundation, INC. Otolaryngol Head Neck Surg 1995;113:179-80.
6. Iwasaki S, Takai Y, Ito K, Murofushi T. Abnormal vestibular evoked myogenic potentials in the presence of normal caloric responses. Otol Neurotol 2005;26:1196-9. doi: 10.1097/01.mao.0000194890.44023.e6.
7. Chen CW, Young YH, Tseng HM. Preoperative versus postoperative role of vestibular-evoked myogenic potentials in cerebellopontine angle tumor. Laryngoscope 2002;112:267-71. doi: 10.1097/00005537-200202000-00013.
8. Tsutsumi T, Tsunoda A, Noguchi Y, Komatsuzaki A. Prediction of the nerves of origin of vestibular schwannomas with vestibular evoked myogenic potentials. Am J Otol 2000;21:712-5.
9. Murofushi T, Halmagyi GM, Yavor RA, Colebatch JG. Absent vestibular evoked myogenic potentials in vestibular neurolabyrinthitis. An indicator of inferior vestibular nerve involvement? Arch Otolaryngol Head Neck Surg 1996;122:845-8. doi: 10.1001/archotol.1996.01890200035008.
10. Takeichi N, Sakamoto T, Fukuda S, Inuyama Y. Vestibular evoked myogenic potential (VEMP) in patients with acoustic neuromas. Auris Nasus Larynx 2001;28 Suppl:S39-41. doi: 10.1016/S0385-8146(01)00075-X.
11. Clemis JD, Ballad WJ, Baggot PJ, Lyon ST. Relative frequency of inferior vestibular schwannoma. Arch Otolaryngol Head Neck Surg 1986;112:190-4. doi: 10.1001/archotol.1986.03780020070016.
12. Cohen NL, Lewis WS, Ransohoff J. Hearing preservation in cerebellopontine angle tumor surgery: The NYU experience 1974-1991. Am J Otol 1993;14:423-33. doi: 10.1097/00129492-199309000-00002.
13. Slattery WH 3rd, Brackmann DE, Hitselberger W. Middle fossa approach for hearing preservation with acoustic neuromas. Am J Otol 1997;18:596-601.
14. Komatsuzaki A, Tsunoda A. Nerve origin of the acoustic neuroma. J Laryngol Otol 2001;115:376-9. doi: 10.1258/0022215011907910.
15. Rachinger J, Rampp S, Prell J, Scheller C, Alfieri A, Strauss C. Tumor origin and hearing preservation in vestibular schwannoma surgery. J Neurosurg 2011;115:900-5. doi: 10.3171/2011.7.JNS102092.
16. Moriyama T, Fukushima T, Asaoka K, Roche PH, Barrs DM, McElveen JT Jr. Hearing preservation in acoustic neuroma surgery: Importance of adhesion between the cochlear nerve and the tumor. J Neurosurg 2002;97:337-40. doi: 10.3171/jns.2002.97.2.0337.
17. Suzuki M, Yamada C, Inoue R, Kashio A, Saito Y, Nakanishi W. Analysis of vestibular testing in patients with vestibular schwannoma based on the nerve of origin, the localization, and the size of the tumor. Otol Neurotol 2008;29:1029-33. doi: 10.1097/MAO.0b013e3181845854.
18. Ushio M, Iwasaki S, Chihara Y, Kawahara N, Morita A, Saito N, *et al.* Is the nerve origin of the vestibular schwannoma correlated with vestibular evoked myogenic potential, caloric test, and auditory brainstem response? Acta Otolaryngol 2009;129:1095-100. doi: 10.1080/00016480802552543.