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CLINICAL STUDY

The prediction of the tumor size of a vestibular schwannoma by clinical performance and vestibular function tests

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Abstract

Purpose To investigate the relationship between vestibular schwannoma (VS) size and the dysfunction and compensation of the vestibular system.

Methods One hundred fifty-two patients with unilateral VS were investigated using multiple auditory-vestibular function tests such as audiometry, sensory organization test (SOT), caloric test, cervical vestibular-evoked myogenic potential (cVEMP) test, and ocular VEMP (oVEMP) test.

Results In this study, 89% of patients with unilateral VS had mild to severe hearing loss on the involved side. All patients showed higher threshold values or no response in the cVEMP and oVEMP tests, which both exhibited a lower response rate on the affected side than on the unaffected side. Patients with a tumor size ≥ 30 mm had significantly lower equilibrium scores for condition 5 and condition 6 of the SOT, which were associated with vestibular dysfunction, higher rates of canal paresis in the caloric test, and lower response rates in the cVEMP and oVEMP tests on the affected sides, compared with the results of patients with a tumor size ≤ 14 mm and patients with a tumor size of 15–29 mm.

Conclusions A diameter > 30 mm may be the critical threshold at which vestibular function is affected and vestibular compensation is interfered with by a VS tumor. Functional performance of the vestibular system can help clinicians predict the size of a tumor and provide a basis for the development of treatment protocols.

Keywords Vestibular schwannoma · Sensory organization test · Caloric test · Vestibular-evoked myogenic potential

Introduction

Vestibular schwannoma (VS) is a slow-growing benign tumor that arises from the Schwann cell and surrounds the vestibular nerves [1]. Vestibular schwannoma has an estimated incidence rate of 19 tumors per 1 million individuals every year and accounts for approximately 6% of all intracranial neoplasms [2, 3]. The common clinical symptoms of VS are hearing loss, tinnitus, dizziness, vertigo, facial numbness, headache, and otalgia [4]. The most common first symptom is hearing loss, and the most distressing symptom is vertigo [5]. Because of its slow growth in the internal auditory meatus (IAM) and then into the cerebellopontine angle (CPA), the tumor can cause slow and progressive impairment of vestibular function, which can be gradually compensated for by central adaptive mechanisms [6]. Symptoms such as vertigo, dizziness, or disequilibrium can be minimized by vestibular compensation [7, 8].

Magnetic resonance imaging (MRI) is the gold standard for diagnosing VS. However, it cannot be applied in all patients with auditory-vestibular symptoms because of its expense [9]. Audiometry and various vestibular tests can provide auxiliary diagnosis of a VS. The sensory organization test (SOT) can appropriately distinguish which system—somatosensory, visual, or vestibular system—a patient with VS most relies on to maintain balance [10]. The caloric test always reflects lateral semicircular canal function [11].

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The cVEMP is used to evaluate saccular and inferior vestibular pathway function, and the oVEMP is used to reflect the function of utricular and superior vestibular pathway [12, 13].

Patients with VS with tumor growth can present with various degrees of vestibular loss. Vestibular function in patients with VS has been evaluated in some studies [7, 14, 15]; however, few studies have investigated the association between tumor size and the degree of vestibular loss by using multiple vestibular function tests. Therefore, in this study, the relationship between tumor size and auditory-vestibular function in patients with VS was systematically analyzed by using audiometry, SOT, caloric test, cVEMP and oVEMP with the goal of helping clinicians have a better understanding of the auditory-vestibular characteristics of VS.

Materials and methods

Patients

One hundred and fifty-two patients with unilateral VS were enrolled in this study. The patients were diagnosed with VS, based on MRI, and included 59 (39%) male patients and 93 (61%) female patients with a mean age ± the standard deviation (SD) of 47.8 ± 11.7 years and age range of 18–68 years. 80 (53%) patients were affected on the left side and 72 (47%) patients were affected on the right side. Patients were divided into three groups, based on maximum tumor diameters used in previous studies [15, 16]: group 1 (≤ 14 mm), group 2 (15–29 mm), and group 3 (≥ 30 mm). Patients were also divided into four groups according to the Koos classification [17, 18]: stage I (a tumor size ≤ 10 mm and confined to IAM), stage II (a size ≤ 20 mm and penetrating the CPA without contacting the brainstem), stage III (a size > 20 mm and filling in the CPA without compressing the brainstem), and stage IV (any tumor that compressed the brainstem). Before the surgical operation, all patients underwent a detailed history taking, audiometry, SOT, and caloric test. One hundred four of 152 patients underwent cVEMP and oVEMP tests.

Sensory organization test

All 152 patients underwent the sensory organization test (SOT), which was conducted using a computerized dynamic posturography system (EquiTest System; Neurocom Inc., Clackamas, OR, USA) under six conditions. Conditions 1–6 (C1–C6) were as follows: C1, eyes open with a fixed support surface; C2, eyes closed with a fixed support surface; C3, eyes open with sway-referenced visual surround and fixed support surface; C4, eyes open with a sway-referenced support surface; C5, eyes closed with a sway-referenced support surface; and C6, eyes open with sway-referenced visual surround and support surface. For each condition, the patients were asked to stand upright and maintain balance on the platform and underwent three trials. The equilibrium score (ES) of each condition was the mean score of three consecutive trials. The following were analyzed in all patients: the somatosensory ratio (R^{SOM}), which is $C2^{ES}/C1^{ES}$; the visual ratio (R^{VIS}), which is $C4^{ES}/C1^{ES}$; the vestibular ratio (RVEST), which is $C5^{ES}/C1^{ES}$; the visual preference ratio (RPREE), which is $(C3^{ES} + C6^{ES})/(C2^{ES} + C5^{ES})$; and the composite score (CES), which is the weighted average of the scores of all conditions.

Caloric test

All patients were evaluated with the caloric test. Patients lay supine on the examination chair with their heads flexed at 30°. Each ear was irrigated with a constant flow of air at 49 °C and 23 °C for 60 s. The GN Otometrics Type air irrigator (Otometrics, Taastrup, Denmark) was used to deliver the stimulus. There was a 5-min interval between each irrigation to avoid a cumulative effect. A vestibular asymmetry of ≥ 22% indicated canal paresis, and total responses of < 15°/s on both sides indicated bilateral canal paresis [13].

Vestibular-evoked myogenic potential test

The cervical and ocular VEMPs test results of 104 patients with unilateral VS were collected in the present study. The stimuli and recording techniques of VEMPs have been described in a previous study [19].

Statistical analysis

Data were analyzed using Stata 13.0 and GraphPad Prism 7 software (GraphPad, USA). All descriptive data are expressed as the mean ± the SD. The abnormal rates and response rates were all compared by using the χ^2 test. The differences in the ESs of the SOT and the thresholds and latencies of VEMPs between groups were checked by one-way analysis of variance (ANOVA) with Tukey's multiple comparisons test. In addition, the Kruskal–Wallis test was used to compare the differences in amplitudes between groups. The t-test was used to compare the thresholds and latencies of the VEMPs between the affected and unaffected sides. The Mann–Whitney test was used to compare amplitude values between the two sides. The threshold for statistical significance was $p = 0.05$.

Results

Clinical manifestations

The clinical manifestations of VS among the 152 patients consisted of hearing loss in 136 (89%) patients, followed by tinnitus in 104 (68%) patients, dizziness in 71 (47%) patients, vertigo in 41 (27%) patients, nausea/vomiting in 29 (19%) patients, aural fullness in 29 (19%) patients, headache in 27 (18%) patients, ataxia in 22 (14%) patients, and earache in 13 (9%) patients. 31 (20%) patients with unilateral VS had facial nerve dysfunction from Grade II to Grade VI according to House-Brackmann grading system: 17 patients (55% grade II), 7 patients (23% grade III), 3 patients (10% grade IV), 3 patients (10% grade V), 1 patients (3% grade VI). The median interval time between the initial symptoms and the time of diagnosis was 12 months. Statistical analyses of the clinical manifestations for the three groups are presented in Table 1. The groups were significantly different in terms of headache ($p = 0.019$) and ataxia ($p = 0.005$). There was no significant difference in these clinical manifestations between each group for Koos classification.

On the affected side, 20 (13%) patients with unilateral VS had mild hearing loss (26–40 dB nHL), 25 (16%) patients had moderate hearing loss (41–60 dB nHL), 38 (25%) patients had severe hearing loss (61–80 dB nHL), and 60 (39%) patients had profound hearing loss (≥ 81 dB nHL). The mean tumor size values were 20.4 ± 8.8 mm in patients with normal hearing, 19.5 ± 11.6 mm in patients with mild hearing loss, 20.3 ± 7.7 mm in patients with moderate hearing loss, 22.6 ± 10.7 mm in patients with severe hearing loss, and 22.9 ± 11.1 mm in patients with profound hearing loss. The tumor sizes were not significantly different between these five different hearing level groups ($p = 0.631$).

Sensory organization test (equilibrium score)

Table 2 presents the statistical analyses of the original SOT results for the three groups. There was no significant difference in $C1^{ES}$–$C4^{ES}$ between the three groups. The mean values of $C5^{ES}$ and $C6^{ES}$ were significantly decreased in group 3 ($p = 0.001$ and $p = 0.004$, respectively; Fig. 1a). The vestibular ratio (R^{VEST}) of group 3 was significantly different, compared with that of group 1 and group 2, based on the ANOVA and Tukey test ($p = 0.001$; Fig. 1b). The SOT composite score (CES) of group 1, group 2, and group 3 was 71.8% ± 8.4%, 68.3% ± 11.2% and 63.6% ± 11.5%, respectively. The CES was significantly decreased in group 3, compared with that of group 1 and group 2, based on the ANOVA and the Tukey test ($p = 0.004$; Fig. 1c).

There was no significant difference in $C1^{ES}$–$C4^{ES}$ between the four Koos groups according Koos classification. The mean values of $C5^{ES}$ and $C6^{ES}$ were significantly decreased in Koos IV patients ($p = 0.000$ and $p = 0.001$, respectively). The R^{VEST} of Koos IV patients (39.1% ± 22.6%) was significantly different ($p = 0.000$), compared with that of Koos I (63.2% ± 17.0%), Koos II (52.7% ± 18.1%), and Koos III (54.1% ± 19.2%). The SOT CES of Koos I, Koos II, Koos III and Koos IV patients was 73.3% ± 8.2%, 69.9% ± 7.6%, 67.9% ± 14.4%,and 62.8% ± 10.8%, respectively. The CES was significantly decreased in Koos IV patients, compared with that of Koos I, Koos II and Koos III, based on the ANOVA and the Tukey test ($p = 0.001$).

Caloric test

In the caloric test, 128 (84%) of 152 patients had canal paresis. The mean maximum tumor diameter of the 128 patients with canal paresis (22.5 ± 10.3 mm) was larger than that of 24 patients with normal responses (18.0 ± 10.4 mm; $p = 0.048$). Canal paresis was found in 27 (71%) of 38 patients in group 1, 68 (87%) of 78 patients in group 2, and

Table 1 The clinical manifestations among the three groups

Clinical manifestations	Unilateral VS patients			Significance (Chi square test)
	Group 1	Group 2	Group 3	
Tinnitus	29 (76%)	53 (68%)	22 (61%)	c2 = 2.0; p = 0.369
Dizziness	14 (37%)	37 (47%)	20 (56%)	c2 = 2.6; p = 0.268
Vertigo	7 (18%)	23 (29%)	11 (31%)	c2 = 1.9; p = 0.388
Facial nerve dysfunction	7 (18%)	13 (17%)	11 (31%)	c2 = 3.0; p = 0.218
Nausea/vomiting	7 (18%)	15 (19%)	7 (19%)	c2 < 0.1; p = 0.993
Aural fullness	4 (11%)	19 (24%)	6 (17%)	c2 = 3.3; p = 0.188
Headache	1 (3%)	18 (23%)	8 (22%)	c2 = 8.0; p = 0.019*
Ataxia	5 (13%)	6 (8%)	11 (31%)	c2 = 10.5; p = 0.005**
Earache	4 (11%)	6 (8%)	3 (8%)	c2 = 0.3; p = 0.876

VS vestibular schwannoma

*p < 0.05; **p < 0.01

Table 2 Sensory organization test results of the three groups

SOT	Unilateral VS patients			p value (one-way ANOVA)
	Group 1 (n = 38)	Group 2 (n = 78)	Group 3 (n = 36)	
SOT ES (%)				
$C1^{ES}$	94.1 ± 1.6	93.7 ± 3.2	93.4 ± 2.2	0.6157
$C2^{ES}$	92.4 ± 2.7	91.3 ± 10.7	91.8 ± 2.6	0.7766
$C3^{ES}$	90.8 ± 4.0	89.1 ± 11.4	88.7 ± 6.2	0.5355
$C4^{ES}$	75.4 ± 11.3	72.8 ± 13.2	71.7 ± 13.0	0.4117
$C5^{ES}$	54.8 ± 17.1	49.3 ± 17.5	38.3 ± 24.2	0.0011**
$C6^{ES}$	51.5 ± 18.3	46.8 ± 18.7	36.5 ± 23.3	0.0042**
C^{ES}	71.8 ± 8.4	68.3 ± 11.2	63.6 ± 11.5	0.0055**
SOT ratios (%)				
R^{SOM}	97.6 ± 2.2	96.6 ± 11.3	96.7 ± 4.3	0.8082
R^{VIS}	79.6 ± 11.6	77.0 ± 13.9	76.2 ± 13.0	0.4786
R^{VEST}	58.5 ± 17.9	52.0 ± 18.2	41.0 ± 25.2	0.001**
R^{PREE}	94.9 ± 6.3	91.6 ± 13.9	93.1 ± 9.7	0.3451

SOT sensory organization test, *VS* vestibular schwannoma, *ES* equilibrium score

*p < 0.05; **p < 0.01

33 (92%) of 36 patients in group 3. Group 3 patients had a higher rate of canal paresis, compared with the other two groups (c2 = 7.0; p = 0.031).

Canal paresis was found in 15 (71%) of 21 patients in Koos I patients, 46 (84%) of 55 patients in Koos II, 32 (86%) of 37 patients in Koos III, and 35 (90%) of 39 patients in Koos IV. There was no significant difference between four Koos groups (c2 = 3.6; p = 0.304).

Vestibular-evoked myogenic potential test

The cVEMP test

In the cVEMP test, the unresponsive rate to stimulating sound was higher on the affected side (68%) than on the unaffected sides (13%) among 104 patients with unilateral VS (c2 = 67.2, p = 0.000). The typical cVEMP waveforms of a patient with VS are shown in Fig. 2a.

The cVEMP test results on the affected side showed that 17/29 (59%) patients had a response in group 1; 12/47 (26%) patients, in group 2; and 4/28 (14%) patients, in group 3. The group 1 patients had a higher response rate to the cVEMP, compared with the other two groups (c2 = 14.5, p = 0.001; Fig. 2c). There was no significant difference between each group in the thresholds, P1 latencies, N1 latencies, and amplitude values. The details of the cVEMP parameters in the three groups are presented in Table 3.

The cVEMP test results on the affected side showed that 11/18 (61%) patients had a response in Koos I; 10/32 (31%) patients, in Koos II; 5/24 (21%) patients, Koos III and 7/30 (23%) patients, in Koos IV. The Koos I patients had a higher response rate to the cVEMP, compared with the other two groups (c2 = 9.47, p = 0.024). There was no significant difference between each Koos group in the thresholds, P1 latencies, N1 latencies, and amplitude values.

The oVEMP test

In the oVEMP test, the unresponsive rate was higher on the affected side (79%) than on the unaffected side (24%) among 104 patients with unilateral VS (c2 = 62.5, p = 0.000). The typical oVEMP waveforms of a patient with VS are shown in Fig. 2b.

The oVEMP test results on the affected side revealed that 11/29 (39%) patients had a response in group 1; 6/ 47 (13%) patients, in group 2; and 5/28 (18%) patients, in group 3. The group 1 patients had a higher response rate to oVEMP, compared with the other two groups (c2 = 7.1, p = 0.029; Fig. 2d). There was no significant difference between the three groups in the thresholds, P1 latencies, N1 latencies, and amplitude values. The details of the oVEMP parameters of the three groups are presented in Table 3.

The oVEMP test results on the affected side showed that 8/18 (44%) patients had a response in Koos I; 7/32 (22%) patients, in Koos II; 3/24 (13%) patients, Koos III and 4/30 (13%) patients, in Koos IV. The Koos I patients had a higher response rate to the oVEMP, compared with the other two groups (c2 = 8.04, p = 0.045). There was no significant difference between each Koos group in the thresholds, P1 latencies, N1 latencies, and amplitude values.

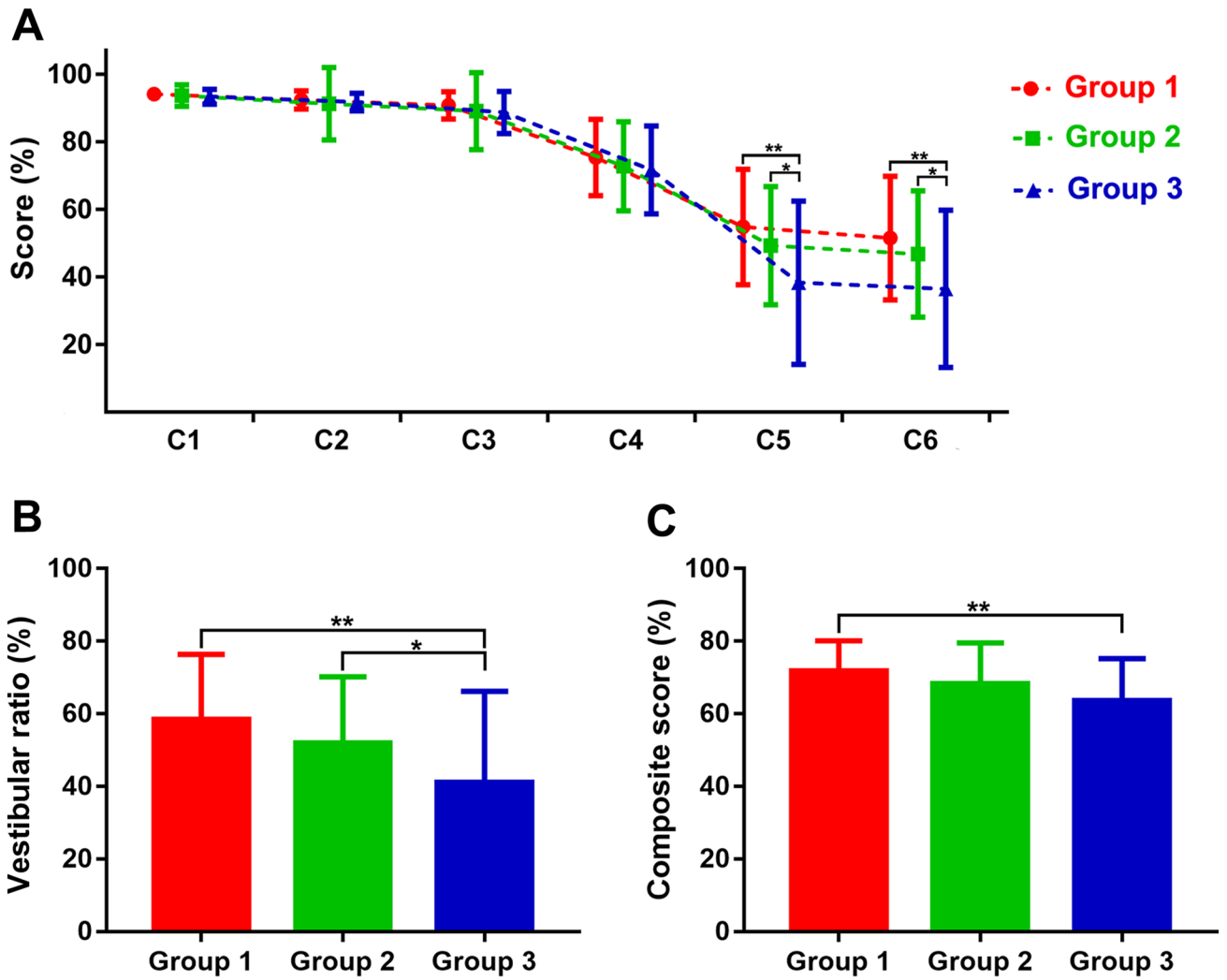

Fig. 1 **a** The mean equilibrium scores of condition 1 to condition 6 (C1–C6). The mean values of condition 5 equilibrium score (C5ES) and condition 6 equilibrium score (C6ES) are significantly decreased in group 3. **b** The mean vestibular ratio of the sensory organization test (SOT) in the three groups. The vestibular ratio of group 3 is significantly different, compared with that of group 1 and group 2. **c** The mean composition scores for the three groups. The mean composition scores are significantly decreased in group 3 than in group 1 and group 2

Discussion

Patients with VS may have a variety of clinical symptoms such as hearing loss, tinnitus, dizziness, vertigo, facial paralysis, nausea/vomiting, aural fullness, headache, ataxia, and earache. Humphriss et al. [4] reported that, in patients with unilateral VS, 68% of patients had hearing loss, 30% of patients had tinnitus, and 75% of patients had dizziness. Huang et al. [20] investigated 1009 VS patients and found 86% of patients had hearing loss, 40% of patients had tinnitus, 45% of patients had ataxia, and 21% of patients had facial paralysis. The present study revealed that, among 152 patients, 136 (89%) patients had mild to severe hearing loss; 104 (68%) patients, tinnitus; 71 (47%) patients, dizziness; 31 (20%) patients, facial nerve dysfunction; and 22 (14%) patients, ataxia. The incidences of some symptoms in patients with VS in the present study were somewhat different from those reported in the aforementioned studies. In the present study, the incidences of other symptoms were also listed in detail to help clinicians recognize clinical alarm features.

No significant association between tumor size and hearing loss level was investigated in this study. Another study [21] also reported that the VS volume and the level of hearing loss were not significantly correlated.

In addition, we found that headaches were more likely to occur in VS patients who had a tumor size ≥ 15 mm, and ataxia was more likely to occur in patients who had a tumor size ≥ 30 mm. These findings may help clinicians estimate tumor size, based on the clinical symptoms, and guide

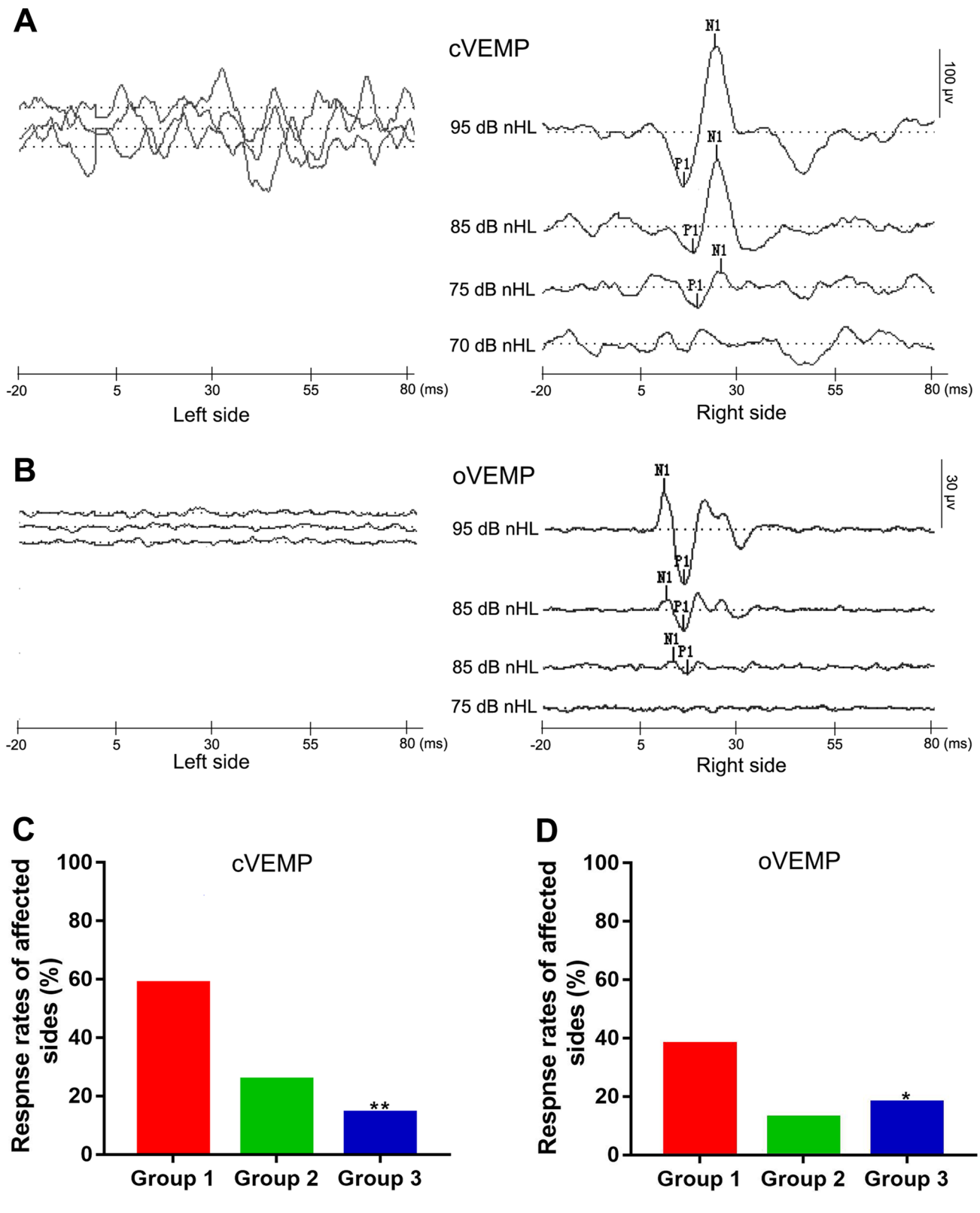

Fig. 2 **a** The typical cervical vestibular-evoked myogenic potential (cVEMP) waveforms in a patient with a unilateral vestibular schwannoma (VS). **b** The typical ocular vestibular-evoked myogenic potential (oVEMP) waveforms in a patient with a unilateral VS. **c** The cVEMP response rates of the three groups on the affected side. **d** The oVEMP response rates of the three groups on the affected side

Table 3 The cVEMP and oVEMP results of patients on the affected side responding to stimulating sounds among the three groups

	N	Thresholds (dB nHL)	P1 latencies (ms)	N1 latencies (ms)	Amplitudes (μV)
cVEMP					
Group 1	17	85.0 ± 7.3	16.8 ± 1.9	24.0 ± 2.0	127.6 ± 53.1
Group 2	12	83.3 ± 7.2	16.9 ± 1.5	24.7 ± 1.4	171.5 ± 121.4
Group 3	4	86.3 ± 8.5	16.2 ± 1.8	24.2 ± 2.0	155.8 ± 91.7
oVEMP					
Group 1	11	90.9 ± 4.4	15.4 ± 1.1	11.5 ± 0.7	9.0 ± 8.1
Group 2	6	92.5 ± 2.7	16.1 ± 1.4	12.5 ± 1.0	17.0 ± 20.4
Group 3	5	92.0 ± 4.5	16.0 ± 1.5	11.2 ± 0.8	7.2 ± 3.5

cVEMP cervical vestibular-evoked myogenic potential, *oVEMP* ocular vestibular-evoked myogenic potential

doctors in making comprehensive treatment programs for patients with possible large VS tumors.

Sensory organization test studies of patients with VS are relatively few. The SOT can be used to identify balance deficits and distinguish which system (i.e., somatosensory, visual, or vestibular system) a patient with VS relies on most to maintain balance. A previous study [8] reported that patients with VS may display altered postural performances, compared with healthy volunteers. In the present study, there was no significant difference between group 1 and group 2 in $C5^{ES}$ and $C6^{ES}$; however, the ES was significantly lower in group 3 than in the other two groups. Likewise, there was no significant difference between Koos I, Koos II and Koos III patients in $C5^{ES}$ and $C6^{ES}$; however, the ES was significantly lower in Koos IV than in the other three Koos groups. Abnormal results in $C5^{ES}$ and $C6^{ES}$ can provide available cues of vestibular dysfunction. Balance compensation occurred gradually in the VS patients with a tumor size < 30 mm because the tumor was slow growing. However, a larger VS (i.e., ≥ 30 mm) tended to compress the cerebellum and brainstem and could interfere with adaptive vestibular compensation, which relies on normal structure and function of the central nervous system and may cause ataxia and headache. Therefore, the ES was lower for C5 and C6 in group 3 patients, compared with group 1 and group 2 patients, which implied that vestibular function was influenced by tumor size in patients with unilateral VS. Ribeyre et al. [8] also reported that the VS size could be a determinant factor in implementing adaptive mechanisms. The ES was also lower for C5 and C6 in Koos IV patients because the large tumor compressed the brainstem.

A significant difference in R^{VEST} existed between group 2 and group 3, but there was no statistical difference in the SOT composite scores. This finding may be because the visual and somatosensory system compensated for the defective vestibular function in maintaining balance in these VS patients.

The cVEMP and oVEMP tests reflect the function of inferior and superior afferent pathways coming from the otolith organs, and the caloric test can reflect the function of lateral semicircular canals, which are innervated by the superior vestibular nerve. In the present study, in patients with unilateral VS, the affected side had a lower response rate ($p \leq 0.01$) and higher thresholds ($p \leq 0.01$) in the cVEMP and oVEMP tests, compared with the unaffected side. This finding indicates that vestibular schwannomas may impair the function of the inferior and superior afferent nerves arising from the otolith organs.

In this study, 84% of patients had canal paresis, and 68% of patients and 79% of patients had no response in the cVEMP and oVEMP tests, respectively, on the affected side. Taylor et al. [15] reported that patients with a schwannoma > 14 mm had at least two abnormal vestibular test results among the three tests (i.e., cVEMP, oVEMP and video head impulse tests). Other research has shown no response to the caloric and VEMP tests on the affected sides in patients with a large unilateral VS, which indicates that the function of the superior and inferior nerve was impaired in parallel [14, 15]. In this study, we also found that the patients in group 3 tended to have lower response rates in VEMPs and higher rates of canal paresis, compared with the response rates of the patients in the other two groups. Likewise, Koos IV patients tended to have lower response rates in VEMPs and higher rates of canal paresis, compared with the response rates of the patients in the other three Koos groups. Hence, tumor size could be a factor that affects vestibular function in patients with VS, and abnormal results in vestibular tests may more readily manifest with a large VS (i.e., ≥ 30 mm) than with a small tumor (i.e., < 30 mm).

Conclusions

Vestibular dysfunction performance, as well as headache and ataxia, are positively correlated with tumor size in patients with unilateral VS. A tumor with a diameter > 30 mm may be the critical line at which a VS affects vestibular function and interferes with vestibular compensation. Clinicians

could basically estimate the tumor size, based on a patient's symptoms and vestibular function test results.

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Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

Ethical approval This study was approved by the institutional review board of EENT Hospital, Fudan University, Shanghai, China.

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