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MAIN ARTICLE

Prognosis of patients with idiopathic sudden hearing loss: role of vestibular assessment

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Abstract

Objective: To evaluate the correlation between caloric and vestibular evoked myogenic potential test results, initial audiogram data, and early hearing recovery, in patients with idiopathic sudden hearing loss.

Materials and methods: One hundred and four patients with unilateral idiopathic sudden hearing loss underwent complete neurotological evaluation. Results for vestibular evoked myogenic potential and caloric testing were compared with patients' initial and final audiograms.

Results: Overall, abnormal vestibular evoked myogenic potential responses occurred in 28.8 per cent of patients, whereas abnormal caloric test results occurred in 50 per cent. A statistically significant relationship was found between the type of inner ear lesion and the incidence of profound hearing loss. Moreover, a negative correlation was found between the extent of the inner ear lesion and the likelihood of early recovery.

Conclusion: In patients with idiopathic sudden hearing loss, the extent of the inner ear lesion tends to correlate with the severity of cochlear damage. Vestibular assessment may be valuable in predicting the final outcome.

Key words: Sudden Sensorineural Hearing Loss; Vestibular Function Tests; Cochlea; Prognosis

Introduction

Idiopathic sudden hearing loss has been clinically recognised for more than 60 years, but despite a plethora of studies it is yet to be completely understood. It is defined as a 30 dB sensorineural hearing loss occurring in three contiguous frequencies and developing in three days or less.[1] The most commonly cited theories for the aetiopathogenesis of idiopathic sudden hearing loss are viral infection[2], ischaemia,[3] autoimmune reaction[4] and inner ear membrane rupture.[5]

It has been reported that the prognosis of patients with idiopathic sudden hearing loss can be determined by looking for early hearing improvement in the first weeks after treatment.[6] Suggested factors that may affect the likelihood of recovery include the patient's age,[1,7] the time between hearing loss onset and treatment,[7,8] and the initial severity[7,9] and type of hearing loss.[7,9–11]

Vestibular involvement is common in cases of idiopathic sudden hearing loss, in the form of unsteadiness or even rotatory vertigo. The general assumption is that disequilibrium is associated with more severe forms of hearing loss[12] and indicates a poorer prognosis,[7,10,13,14] especially when accompanied by high frequency hearing loss.[11] In addition, several studies have suggested that abnormal electronystagmographic (ENG) findings and hypoactive caloric responses at the time of presentation are also unfavourable prognostic indicators for the final outcome of sudden hearing loss.[12,13]

Recently, the new diagnostic method of vestibular evoked myogenic potential (VEMP) testing has been included in the evaluation of patients suffering idiopathic sudden hearing loss.[15–20] A recent study indicated that the results of audiovestibular function testing, including VEMP testing, correlated with the hearing outcome in cases of severe and profound sudden hearing loss.[19]

To date, the involvement of the otolithic organs in idiopathic sensorineural hearing loss remains controversial. Moreover, it is still unknown whether the detection of abnormal VEMP responses is useful in determining the patient's prognosis. This is partially due to the fact that previous studies have either enrolled small populations[16] or have focused on subgroups of idiopathic sudden hearing loss patients (e.g. patients with[17] or without[18] concomitant vertigo). To shed light on this issue, the current study differentiated the involvement of otolithic organ and horizontal semicircular canal afferents by performing both caloric and VEMP testing.[19] Another critical difference between

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the current study and previous investigations was that all patients were evaluated no later than two weeks from the onset of hearing loss, before any initially abnormal tests had normalised as part of the recovery process.[16]

The present study aimed (1) to clarify the clinical significance of vestibulopathy in a large group of subjects with idiopathic sudden hearing loss, by using two vestibular diagnostic methods as part of a complete neurotological evaluation, and (2) to investigate possible correlations between caloric and VEMP test results, initial audiography findings, and short-term hearing recovery after treatment.

Patients and methods

The study population consisted of 104 patients (56 women and 48 men, mean age 52.5 years) suffering from unilateral idiopathic sudden hearing loss. All patients were hospitalised and treated in the otorhinolaryngology department, Hippokration Athens Hospital, University of Athens, between February 2006 and May 2009. The right side was affected in 49 patients and the left in 55.

A control group consisting of 35 healthy, age-matched individuals with no previous hearing, vestibular or neurological disorders was also enrolled in the study for comparison.[20]

A medical history was taken from every subject, noting the time of onset of symptoms and the presence or absence of vertigo. All patients were evaluated within two weeks of the onset of hearing loss. In total, vestibular disturbances were reported by 36 patients (34.6 per cent). However, none of the study subjects was taking vestibular sedatives during the study period.

On the day of admission, all patients were evaluated with pure tone audiometry (PTA), tympanometry with acoustic reflex testing, bi-thermal caloric testing with ENG recordings, and VEMP testing. In addition, the standard neurotological evaluation which was conducted for every study subject, including magnetic resonance imaging of the brain and internal auditory canal, in order to exclude a retrocochlear lesion.

The PTA threshold was defined as the average of the thresholds for five frequencies (250, 500, 1000, 2000 and 4000 Hz). Hearing loss was classified into four degrees: mild (PTA < 40 dBHL), moderate (PTA 40–59 dBHL), severe (PTA 60–89 dBHL) and profound (PTA > 90 dBHL).[6] In addition, the type of hearing loss was registered (i.e. flat, high frequency, low frequency or profound). High frequency hearing loss was defined as an average loss at 4 and 8 kHz surpassing the average at 0.25 and 0.5 kHz by 30 dBHL or more.[14]

All study patients were treated similarly, with a tapering dose of intravenous steroids for nine days (prednisolone 75 mg for the first three days, 50 mg for the next three days and 25 mg for the last three days), followed by a course of oral prednisolone tapered from 15 to 5 mg over the next nine days.

Pure tone audiometry was repeated on every second day of treatment. Final audiograms were performed 15 days after the beginning of treatment.[6,8] Patients were considered to have partially recovered when their average PTA thresholds had improved by at least 20 dBHL, and to have fully recovered when there was complete restoration of the audiogram either to normal or to thresholds equivalent to the opposite ear (i.e. in cases of pre-existing presbycusis).

Bi-thermal caloric tests were performed with a Hortmann Airmatic air irrigator (Neurootometrie, GN Otometrics, Taastrup, Denmark). Electronystagmography recordings were performed with a Life-Tech model 3002 electronystagmograph (Houston, Texas, USA). The methodology has been reported in detail elsewhere.[21] The maximum slow-phase velocity of nystagmus induced by caloric stimulation of the right and left sides was calculated and recorded. Caloric asymmetry of more than 22 per cent was defined as canal paresis.[21]

Vestibular evoked myogenic potential testing was undertaken using a GN Otometrics (Taastrup, Denmark) EP version 5.2 analyser. The subject was seated in an upright position keeping his or her head turned to one side so as to maintain voluntary contraction of the sternocleidomastoid muscles. Subjects were asked to push with their jaw against the inflated cuff of a blood pressure sphygmomanometer while turning their heads to each side, maintaining sternocleidomastoid contraction at cuff pressures of 50 mmHg during the whole recording period.[22] Two active electrodes were placed symmetrically over the midpoint of each sternocleidomastoid muscle, a reference electrode was placed on the upper forehead and a ground electrode was applied to the middle of the forehead. The response of the ipsilateral sternocleidomastoid muscle to monaural stimuli was recorded. Acoustic stimuli (short tone bursts, 95 dBHL, 500 Hz, rate 5.1/second, ramp time 1 millisecond, plateau time 0 milliseconds) were delivered through TDH-40 headphones (Telephonics, New York, USA). The analysis time was 100 milliseconds, and the electromyographic (EMG) signal was band-pass filtered from 2 to 500 Hz. Every set of 150 sweeps was averaged, stored and repeated twice in order to verify the response reproducibility. The first positive waveform deflection was marked as P1 and the first negative deflection as N1. The latencies and amplitudes of these waveforms (P1–N1) were measured for each subject. In cases with no recognisable or reproducible waveforms, or with a waveform amplitude of less than 20 μV, the VEMP response was considered to be absent.

Statistical analysis

The Statistical Package for the Social Sciences version 11.0 software program was used for statistical analysis. Chi-square testing was used to identify the possible relationships of profound hearing loss and high

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frequency hearing loss, in the four clinical groups defined by the extent of inner ear damage. Spearman's ρ analysis was performed to test the correlation between the severity of the inner ear lesion (ranked in three groups), the severity of hearing loss (ranked in four groups) and the degree of recovery (ranked in three groups). Logistic regression analysis was performed to evaluate the impact on early recovery of independent factors such as age, VEMP characteristics, caloric test results, type of hearing loss and presence of vertigo.

Results

In the controls, the mean P1 and N1 values for the normal VEMP waveform were 16.26 milliseconds (standard deviation (SD) 1.32) and 24.42 milliseconds (SD 2.52), respectively.[20] Delayed P1 and N1 VEMP responses were defined as any value greater than the mean + 2 SD of the normal population (i.e. any P1 value greater than 18.9 milliseconds and any N1 value greater than 29.46 milliseconds).

Fifty per cent of the idiopathic sudden hearing loss patients showed abnormal caloric results, while 28.8 per cent showed abnormal VEMP findings. However, all subjects showed normal responses for both testing procedures in the contralateral ear.

Caloric and VEMP test results were normal in 45 idiopathic sudden hearing loss patients (43.3 per cent).

Caloric test results were abnormal and VEMP results normal in 29 patients (27.9 per cent). In seven of these patients, spontaneous nystagmus was recorded, whereas the remainder (22 patients) demonstrated canal paresis on caloric testing.

Abnormal or absent VEMP recordings together with normal caloric test results were found in seven idiopathic sudden hearing loss patients (6.7 per cent).

Both VEMP and caloric test results were abnormal in 23 patients (22.1 per cent). On caloric testing, a canal paresis was found in all but two patients (who presented with spontaneous nystagmus). Twenty patients had absent VEMP waveforms, whereas three had delayed P1 latencies (Table I).

No statistically significant relationship was found between VEMP results and high frequency hearing loss (chi-square, $p = 0.499$). Likewise, no significant relationship was found between caloric test results and high frequency hearing loss (chi-square, $p = 0.135$).

Statistically significant relationships were found between VEMP results and profound hearing loss (chi-square, $p < 0.01$), and between caloric test results and profound hearing loss (chi-square, $p = 0.05$).

In order to study the role of vestibular lesions in idiopathic sudden hearing loss, the following four groups of patients were defined, using the terminology proposed in 2005 by Iwasaki *et al.*[16] Group C comprised subjects with normal caloric and VEMP test results, meaning that the inner ear lesion was located only in the cochlea. Group C + S comprised subjects with a normal VEMP result but an abnormal caloric test result, meaning that the lesion involved the cochlea and the horizontal semicircular canal. Group C + O comprised subjects with an abnormal VEMP result but a normal caloric test result, meaning that the lesion involved the cochlea and the otolithic organs (i.e. the saccule and possibly the utricle). Finally, group C + O + S comprised subjects in whom both the VEMP and the caloric test results were abnormal, meaning that the lesion involved the cochlea, semicircular canal and otolithic organs.

Chi-square analysis was performed to compare the percentage of high frequency hearing loss in these four groups. There was no significant relationship between the type of inner ear lesion and the occurrence of high frequency hearing loss. The percentages of patients with high frequency hearing loss in each of the four groups are presented in Table II.

Chi-square analysis was also performed to compare the percentage of profound hearing loss in the four groups. A statistically significant relationship was found between the type of inner ear lesion and the occurrence of profound hearing loss ($p < 0.01$). The percentages of patients with profound hearing loss in each one of the four groups are also presented in Table II, while their distribution in the four clinical groups is shown in fig.1.

We tested for a correlation between the severity of the inner ear lesion and the severity of hearing loss, and also for a correlation between the severity of the inner ear lesion and the grade of early recovery. The group with cochlear lesions only was judged as having the least severe lesion. Next came a mixed

TABLE I
VEMP AND CALORIC* RESULTS IN IDIOPATHIC SUDDEN HEARING LOSS PATIENTS

Caloric results	VEMP results (*n* (%))		Total (*n* (%))
	Normal	Abnormal	
Normal	45 (43.3)	7 (6.7) – Abs	52 (50)
Abnormal	29 (27.9) – SN 7 – CP 22	23 (22.1) – 20 Abs, 3 Del – 2 SN, 21 CP	52 (50)
Total	74 (71.1)	30 (28.8)	104 (100)

*With electronystagmography. VEMP = vestibular evoked myogenic potentials; Abs = absent VEMP waveforms; SN = spontaneous nystagmus; CP = canal paresis; Del = delayed VEMP waveform latencies

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TABLE II
HEARING LOSS TYPE BY INNER EAR LESION

Hearing loss (pts (%))	C	C + S	C + O	C + O + S
High freq*	15.6	20.7	0	30.4
Profound†	11.1	10.3	28.6	52.2

Chi-square: $^{*}p = 0.29$, $^{\dagger}p < 0.01$. Pts = patients; C = cochlear lesion; S = horizontal semicircular canal lesion; O = otolithic organ lesion

group consisting of both the C + O and C + S groups (termed the cochlea and partial vestibular lesion group). The group with cochlear and complete vestibular lesions (i.e. C + S + O) was ranked as having the most severe lesion. Hearing loss was ranked as mild, moderate, severe or profound. Recovery was ranked as none, partial or complete. Spearman's ρ testing revealed a statistically significant positive correlation ($\rho = 0.430$, $p < 0.01$) between the severity of the inner ear lesion and the severity of hearing loss, and a significant negative correlation ($\rho = -0.577$, $p < 0.01$) between the severity of the inner ear lesion and the grade of early recovery. This means that the more the inner ear was affected, the less likelihood there was of recovery. A significant negative correlation ($\rho = -0.359$, $p < 0.01$) was also found between the severity of hearing loss and the grade of early recovery, meaning that the more severe the hearing loss, the lesser the chance of hearing recovery after two weeks' treatment.

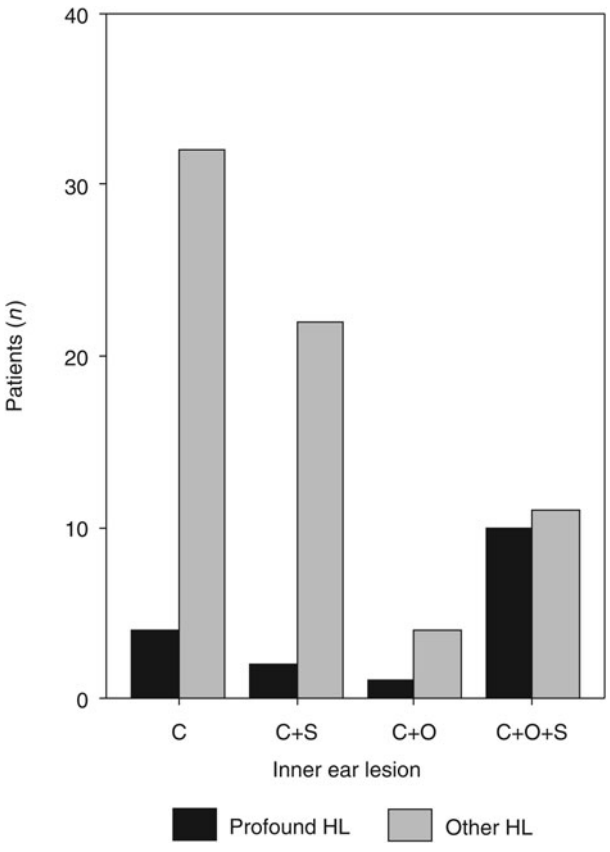

FIG. 1
Distribution of patients with profound hearing loss versus all other hearing loss grades (i.e. mild, moderate or severe) in each of the inner ear lesion groups. C = cochlear lesion; S = horizontal semicircular canal lesion; O = otolithic organ lesion; HL = hearing loss

Logistic regression analysis was performed in order to assess whether early recovery was affected by predictor variables such as age, vertigo, VEMP characteristics, caloric test results and type of hearing loss (i.e. flat, high frequency, low frequency or profound). Results indicated a significant predictive liability of age (negative), VEMP characteristics (positive) and caloric test results (positive). This means that as age advances the likelihood of recovery reduces, whereas normal findings on VEMP or caloric testing favour early recovery. The type of hearing loss did not appear to influence the chance of early recovery.

Discussion

Idiopathic sudden hearing loss has been extensively studied over the past decades. However, both the aetiopathogenesis and the optimal treatment of this clinical entity still remain unclear. The present study attempted to investigate further the various symptoms comprising the clinical picture of the disease, and to correlate them with the prognosis for recovery.

Vestibular evoked myogenic potential testing is a relatively newly developed vestibular diagnostic method which is used clinically to evaluate otolith function. This modality tests the neural pathway mediated by the saccule, the inferior branch of the vestibular nerve, the lateral vestibular nucleus, the vestibulospinal tracts and the sternocleidomastoid muscle.[23] A lesion anywhere in this pathway could result in abnormal VEMP test results. However, only a small number of recent studies have included VEMP testing in the evaluation of subjects suffering sudden hearing loss, and have reported contradictory results: the incidence of VEMP abnormality has ranged from 0 to 77 per cent in different patient series.[15–20] Abnormal VEMP findings in patients with sudden hearing loss have been attributed either to a sacculo-labyrinthine lesion[16,18] or to brainstem hypoperfusion.[17]

In the present study of over 100 sudden hearing loss patients, a considerable percentage had abnormal VEMP and/or caloric (with ENG) test results (Table I). Magnetic resonance imaging scans were normal for all subjects, as were ENG tests for central nervous system lesions. Therefore, abnormal VEMP responses in our study group were interpreted as indicating a sacculo-labyrinthine lesion.

Interestingly, patients with profound hearing loss showed a significantly higher incidence of abnormal VEMP responses, compared with those with mild or moderate hearing loss. Similarly, significantly higher rates of abnormal caloric test results were observed in patients suffering profound hearing loss. A statistically significant relationship was also seen when profound

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hearing loss was analysed according to the four clinical groups defined by combining VEMP and caloric test results. The highest rates of profound hearing loss (65.2 per cent) were found in the group with lesions involving the cochlea, otolithic organs and semicircular canal (Table II). This finding is in agreement with Iwasaki *et al.*,[16] who also found the highest incidence of profound hearing loss in this same patient group.

Regarding high frequency hearing loss, consistent results were observed for separate VEMP and caloric testing and for the combined inner ear status approach. No statistically significant relationship was found between high frequency hearing loss and VEMP or caloric test results. Moreover, taking all four clinical groups into account, the occurrence of high frequency hearing loss did not appear to correlate with the extent of the inner ear lesion. Previous reports are in disagreement on this subject. Park *et al.*[13] studied idiopathic sudden hearing loss patients presenting with different clinical forms of accompanying vertigo, and found that patients with benign paroxysmal positional vertigo (BPPV) (i.e. otolithic organ lesions) had worse PTA thresholds especially at high frequencies. Hong *et al.*[18] reported a statistically significant correlation between abnormal VEMP responses and profound high frequency hearing loss in patients with sudden hearing loss without vertigo. Other studies[14,24] have suggested that poorer high frequency hearing thresholds are associated with more severe horizontal canal paresis. However, closer consideration reveals a contradiction between the above results: some support a relationship between high frequency hearing loss and an otolithic organ lesion, whereas others support a relationship between high frequency hearing loss and semicircular canal paresis. The present study, based on a large patient population, showed no trend between high frequency hearing loss and any of the inner ear lesions investigated. Apparently, the subject needs to be further investigated.

A positive correlation ($p < 0.01$) was found between the extent of the inner ear lesion and the hearing loss severity; this is unsurprising. Similar studies have found a statistically significant relationship between VEMP test findings and both the degree of low frequency hearing loss in Ménière's disease[25] and the mean hearing level in subjects with high frequency sensorineural hearing loss.[26] Wilson *et al.*[12] studied sudden hearing loss patients and reported a correlation between the presence of profound hearing loss and abnormal ENG findings. Park *et al.*[13] reported that initial and fixed hearing levels were worse in patients with idiopathic sudden hearing loss and BPPV in whom otolith dysfunction was present. Iwasaki *et al.*[16] found a statistically significant correlation between patients' initial pure tone average and their type of inner ear lesion (ranked according to severity). The present study is in complete agreement with these findings.

The present study found a negative correlation ($p < 0.01$) between the extent of the inner ear lesion and the likelihood of early recovery; this finding is also supported by the literature. Wilson *et al.*[12] performed ENG and caloric testing, and reported that as the severity of the vestibular injury increased, the number of patients achieving recovery decreased. Iwasaki and colleagues'[16] findings suggested the same conclusion. In addition, Park *et al.*[13] proposed that, in patients suffering sudden hearing loss with vertigo, otolithic involvement may represent extended labyrinthine disease, which may result in poorer hearing recovery. Finally, in Wang and colleagues'[19] recent study of cases of profound sudden hearing loss, normal vestibular function test results (including VEMP test results) were associated with favourable hearing outcomes. We would add that, in the present study, the negative correlation ($p < 0.01$) found between hearing loss severity and the likelihood of recovery from idiopathic sudden hearing loss is self-evident: the more severe the hearing loss, the worse the chance of full recovery.

The present study attempted to assess the impact of various predictor variables on the incidence of early recovery. Only patient age showed a significant negative predictive liability, whereas both normal caloric test results and normal VEMP test results had positive predictive liability. This means that as the age of the patient advances, their likelihood of recovery from idiopathic sudden hearing loss reduces. On the other hand, normal caloric and VEMP test results both favoured early recovery from idiopathic sudden hearing loss, whereas abnormal VEMP or caloric test results represented unfavourable indicators for early recovery. Stamatiou *et al.*[20] studied the same patient group and found a positive correlation between age and the degeneration of subtle vestibular structures; these authors believed that such degeneration made the ear more sensitive to the probable viral or ischaemic incidents causing idiopathic sudden hearing loss. However, the same study found no correlation between semicircular canal paresis (also a negative predictive factor for recovery) and advanced age. The present study found that age preserved its negative predictive value for early recovery even when considered as a factor on its own, irrespective of the inner ear lesion.

The present study also found that audiogram type had no statistically significant effect on the likelihood of hearing recovery. This contradicts the belief that high frequency hearing loss is usually a negative predictor for recovery. According to Wilson *et al.*,[12] patients with high frequency hearing loss and abnormal ENG results (i.e. a labyrinthine lesion) recovered less well than those with normal ENG findings. Park *et al.*[13] reported that final hearing thresholds were worse in the high frequencies in idiopathic sudden hearing loss patients with BPPV (i.e. more extended vestibular damage). These facts could imply that a high frequency hearing loss is not in itself a negative

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predictor. Another possible explanation of our failure to find any predictive value for audiogram type is that the present study assessed only early recovery (i.e. recovery in the first two weeks after treatment); the overall incidence of improvement or complete recovery may have been higher at later follow-up examinations. Thus, the relative importance of the various predictor variables may have been better assessed from final recovery rates.

- **This study investigated patients with idiopathic sudden sensorineural hearing loss, and found a significant correlation between abnormal vestibular evoked myogenic potential and caloric (with electronystagmography) test results and profound hearing loss**
- **In these patients, the extent of vestibular dysfunction correlated with the cochlear lesion severity**
- **The type of vestibular lesion did not correlate with the occurrence of high frequency hearing loss, and the audiogram type had no significant effect on the likelihood of hearing recovery**
- **More severe hearing loss and greater age both acted as independent negative predictive factors for short-term hearing recovery, irrespective of the presence or absence of a labyrinthine lesion**

The presence of vertigo is generally considered to be of value when predicting recovery from idiopathic sudden hearing loss.[10,11,14] Park *et al.*[13] stated that hearing recovery rates were worse in patients with vertigo than in those without vertigo, but found no difference in recovery rates between patients with spinning versus non-spinning vertigo. In the present study, vertigo was found to have no value in predicting hearing recovery. Wilson *et al.*[12] also found no significant effect of vertigo on recovery; they attributed this fact to the high correlation between audiogram type and vertigo occurrence, and concluded that the predictive value of vertigo was less important than that of ENG results.

Conclusion

The results of the present study indicate that VEMP testing could be a useful additional diagnostic tool in the neurotological evaluation of patients suffering idiopathic sudden hearing loss. The availability of VEMP test results sheds new light on the prediction of early hearing recovery, and enhances the predictive value of other, previously noted factors such as vertigo. The extent of the labyrinthine lesion seems to correlate with the severity of cochlear damage, and the likelihood of hearing recovery tends to reduce as the degree of labyrinthine involvement increases. Increasing age is a negative predictive factor for recovery from idiopathic sudden hearing loss. In contrast, normal VEMP and/or caloric test results appear to favour early recovery.

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