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Peak Width in Multifrequency Tympanometry and Endolymphatic Hydrops Revealed by Magnetic Resonance Imaging

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Objective: To investigate the relationship between the peak width of the characteristic ''M''-shaped peak of 2 kHz conductance tympanometry and the degree of endolymphatic hydrops in magnetic resonance imaging (MRI) after intratympanic or intravenous gadolinium administration.
Study Design: Prospective study.
Setting: An academic university hospital.
Patients: One hundred twenty-eight ears in which multifrequency tympanometry was performed and endolymphatic space size was evaluated by MRI. Forty-five patients were examined bilaterally and 38 patients were examined unilaterally.
Interventions: Endolymphatic space size was evaluated by MRI after intratympanic or intravenous gadolinium injection.
Main Outcome Measures: Endolymphatic space size was classified into three groups: none, mild, and significant in the cochlea and in the vestibule. The relationship between the degree of endolymphatic hydrops and peak width of 2 kHz conductance tympanometry was investigated.
Results: The peak width in 94 ears in which significant endolymphatic hydrops was observed on MRI in the cochlea and/or the vestibule was 178.8 ± 102.7 daPa. The peak width in 21 ears in which mild but not significant endolymphatic hydrops was observed on MRI in the cochlea and/or the vestibule was 126.0 ± 77.1 daPa. The peak width in 13 ears with no endolymphatic hydrops in the cochlea and vestibule was 107.1 ± 84.1 daPa. The peak width in ears with significant endolymphatic hydrops was larger than that observed in ears with no endolymphatic hydrops. However, the peak width was not significantly different between cases of mild and absent endolymphatic hydrops.
Conclusion: Large peak width in multifrequency tympanometry was associated with significant endolymphatic hydrops.
Key Words: Endolymphatic hydrops—Magnetic resonance imaging—Multifrequency tympanometry—Peak width—Resonance frequency.

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Electrocochleography, glycerol test, vestibular evoked myogenic potential, and furosemide test have been used to investigate endolymphatic hydrops. Franco-Vidal et al. (1) reported that multifrequency tympanometry was also useful to detect endolymphatic hydrops. Recently, many studies have reported the morphologic evaluation of endolymphatic hydrops using magnetic resonance imaging (MRI) (2–5).

The relationships between morphologically evaluated endolymphatic hydrops and electrocochleograpy (6,7), glycerol test (7), and vestibular evoked myogenic potential (8) have been studied. In the present study, we investigated the relationship between endolymphatic hydrops revealed by MRI and the results of multifrequency tympanometry.

MATERIALS AND METHODS

Patients

The study included 83 patients (46 females and 37 males) aged from 17 to 81 years (average, 55.4 years). Both ears were examined in 45 patients and one ear only was examined in 38 patients.

This investigation included 128 ears (67 female and 61 male) with a normal tympanic membrane. Among these, 19 ears had definite Ménière's disease, five ears had probable Ménière's disease, and 26 ears had possible Ménière's disease according to the criteria of AAO-HNS (1995) (9). Sixteen ears were diagnosed as having delayed endolymphatic hydrops clinically.

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TABLE 1. *Grade of endolymphatic hydrops revealed by magnetic resonance imaging*

Grade of hydrops	Vestibule (area ratio[a])	Cochlea
None	≦33.3%	No displacement of Reissner's membrane.
Mild	>33.3%, ≦50%	Displacement of Reissner's membrane but the area of the endolymphatic space does not exceed the area of the scala vestibuli.
Significant	>50%	Exceeds the area of the scala vestibuli

[a]Ratio of the area of the endolymphatic space to that of the fluid space (sum of the endolymphatic space and perilymphatic space) in the vestibule measured on tracings of images.

Forty-four ears had other cochlear or vestibular symptoms, such as idiopathic sudden sensorineural hearing loss, acute low-tone sensorineural hearing loss, fluctuating hearing loss, and floating sensation. Eighteen asymptomatic ears were contralateral to ears with unilateral inner-ear diseases. The protocol was approved by the ethics review committee of Nagoya University School of Medicine (approval No.369, 587)

MRI and Grading of Endolymphatic Hydrops

Among the 45 patients examined bilaterally, MRI was performed after intravenous gadolinium injection in 43 patients and after bilateral intratympanic gadolinium injection in two patients. Among the 38 patients examined unilaterally, MRI was performed after unilateral intratympanic gadolinium injection in 29 patients and after intravenous gadolinium injection in 9 patients. Unilateral ears in 9 patients were excluded from this analysis because of type C tympanometry, unclear peak at tympanometry, presence of acoustic tumor, or impossible ear canal occlusion.

MRI was performed 24 hours after intratympanic gadolinium injection or 4 hours after intravenous gadolinium injection. The details of the MRI methods used were described previously (2–5). The degree of endolymphatic hydrops was evaluated by a radiologist who was blinded to the clinical symptoms. The degree of endolymphatic hydrops was classified into 3 groups; none, mild, and significant both in the cochlea and in the vestibule, as described previously (10) (Table 1). An example of MRI was shown in Figure 1

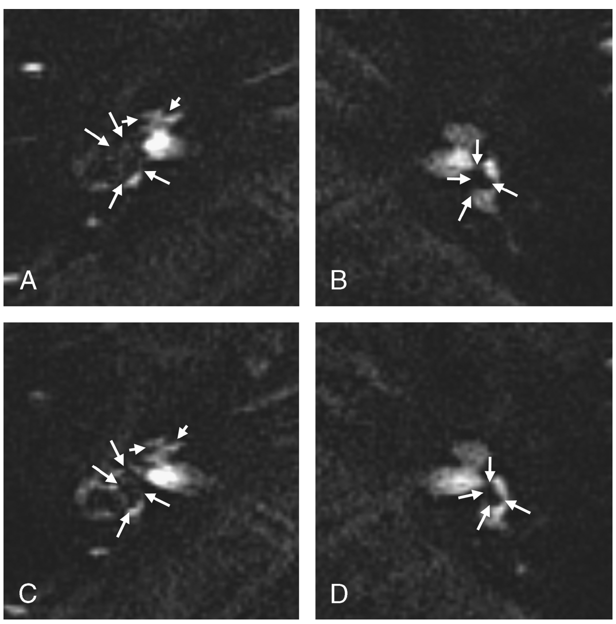

FIG. 1. An example of endolymphatic hydrops on MRI. Consecutive sections of heavily T2 weighted 3D-FLAIR MRI taken 4 hours after intravenous standard-dose gadolinium injection in a patient with significant endolymphatic hydrops in the right cochlea. *A* and *B*, *C* and *D*, are the same sections. Significant endolymphatic hydrops was observed in the right cochlea (*short arrows* in *A* and *C*) but no endolymphatic hydrops was observed in the left cochlea (*B* and *D*). The vestibular endolymphatic hydrops on the right side was larger than that on the left side (*long arrows*).

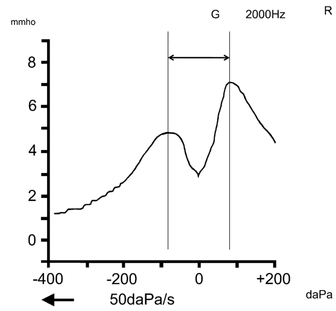

FIG. 2. Peak width in a 2-kHz conductance tympanometry.

Multifrequency Tympanometry

Multifrequency tympanometry was performed using a Garson Stadler CSI 33 Version 2 otoadmittancemeter (Eden Prairie, MN, U.S.A.). Two-kilohertz conductance tympanometry (G) was performed to measure the curve width of the characteristic ''M''-shaped peaks, as shown in Figure 2. When the maximum peaks tended to run together, giving an identical value at a given pressure range or showing one peak, the peak width was measured as zero. Resonant frequency was also measured as described previously (11).

Statistical Analyses

Data on age, sex, patients' clinical categorization, whether intratympanic or intravenous gadolinium injection, the degree of endolymphatic hydrops in the cochlea and the vestibule, the peak width, and resonant frequency were encoded into a computer and analyzed using SPSS. Analysis of variance (ANOVA) and multivariate analysis were used to analyze the data, and $p < 0.05$ was considered significant.

TABLE 2. *Peak width in each group of endolymphatic hydrops*

Model 1	Model 2	Model 3
No hydrops 107.1 ± 84.1 n = 13	**No hydrops** 107.1 ± 84.1 n = 13	**Not significant hydrops** 118.8 ± 79.1 n = 34
Mild hydrops 126.0 ± 77.1 n = 21	**Hydrops** 169.2 ± 100.3 n = 115	
Significant hydrops 178.8 ± 102.7 n = 94		**Significant hydrops** 178.8 ± 102.7 n = 94

Table is given as average peak width ± standard deviation. Unit: daPa.

RESULTS

The value of the peak width in none, mild, and significant endolymphatic hydrops is shown in Model 1 in Table 2. In Model 1, significant endolymphatic hydrops was observed on MRI in the cochlea and/or vestibule in the group of ''significant hydrops'', mild but not significant endolymphatic hydrops was observed in the cochlea and/or the vestibule in the group of ''mild hydrops'', and endolymphatic hydrops was observed neither in the cochlea nor in the vestibule in the group of ''no hydrops''. In Model 2, the groups of ''mild hydrops'' and ''significant hydrops'' were combined and termed *hydrops* group. In Model 3, the groups of ''no hydrops'' and ''mild hydrops'' were combined and termed *not significant hydrops* group. Analysis of these models revealed that the peak width in ears with significant endolymphatic hydrops was larger than that observed in ears with no endolymphatic hydrops. However, the peak width was not significantly different between cases of mild and absent endolymphatic hydrops.

The value of resonant frequency in each model is shown in Table 3. There was a tendency toward lower resonant frequency in ears with significant endolymphatic hydrops. However, this difference was not significant.

Figure 3 demonstrates the relationship between peak width and resonant frequency. There was a weak but significant relationship between these 2 values (Pearson's test r = –0.24, $p < 0.05$).

Multivariate analysis of the influence of age, sex, whether intratympanic or intravenous gadolinium injection, patients' clinical categorization and degree of endolymphatic hydrops in the cochlea and the vestibule on peak width and resonant frequency showed that age and degree of endolymphatic hydrops influenced peak width significantly, but not resonant frequency. Peak width increased with age. In the multivariate analysis, none, mild, and significant endolymphatic hydrops scored 0, 1, and 2, respectively, in each cochlea and vestibule in Model 1. Hydrops (–) and hydrops (+) scored 0 and 1, respectively, in each cochlea and vestibule in model 2. Not significant hydrops and significant hydrops scored 0 and 1, respectively, in each cochlea and vestibule in Model 3. In Models 1 and 2, age and the degree of endolymphatic hydrops in the cochlea influenced peak width significantly. In Model 3, age and endolymphatic hydrops in the vestibule influenced peak width significantly.

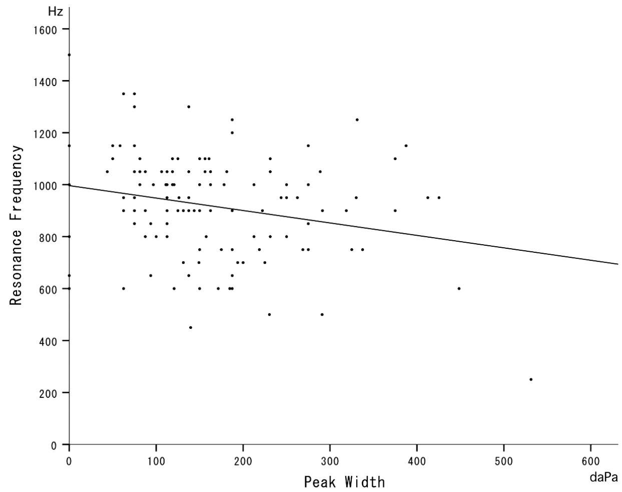

FIG. 3. Relationship between peak width and resonance frequency.

TABLE 3. *Resonance frequency in each group of endolymphatic hydrops*

Model 1	Model 2	Model 3
No hydrops	**No hydrops**	
926.9 ± 156.3	926.9 ± 156.3	**Not significant hydrops**
Mild hydrops		955.9 ± 154.6
973.8 ± 154.8	**Hydrops**	
Significant hydrops	917.4 ± 205.3	**Significant hydrops**
904.8 ± 213.7		904.8 ± 213.7

The number of patients in each group is the same as in Table 2. Table is given as average resonance frequency ± standard deviation. Unit: Hz.

DISCUSSION

Several reports have highlighted the influence of endolymphatic hydrops on the conductive hearing system. It has been reported that an air-bone gap was recognized at low-tone frequencies (from 25 to 32.5%) in patients with endolymphatic hydrops (12,13). The air-bone gap was thought to be caused by an increase in inner ear fluid volume and pressure and dampened footplate mobility (13). In an animal study, the injection of saline into the inner ear changed the peak pattern and enlarged the peak width of a 2 kHz conductance tympanometry (14). Colletti et al. (15–17) reported that a characteristic ''M''-shaped peak appears when the probe tone of multifrequency tympanometry increases and if the probe tone exceeds resonant frequency. Franco-Vidal et al. (1) reported that the peak width of conductance tympanometry at 2 kHz was increased, and resonant frequency was decreased in Ménière's disease. In our study, the peak width in conductance tympanometry at 2 kHz was significantly larger in ears with significant endolymphatic hydrops. Endolymphatic hydrops both in the cochlea and the vestibule were associated with peak width. However, the association between mild endolymphatic hydrops and peak width was not evident, nor was the association between endolymphatic hydrops and resonant frequency.

In the present study, age was positively associated with peak width. This is consistent with Holte's report (18), in which age was significantly associated with peak width in multifrequency tympanometry. Because the period of Ménière's disease may be longer in older patients, and the disease period is associated with the degree of endolymphatic hydrops, there is a possibility that age had a more significant effect in the present study compared with that observed in the normal volunteers used in the previous study.

The resonant frequency is significantly low and the air-bone gap is frequently observed in patients with large vestibular aqueduct (LVA) syndrome (11,19). Because endolymphatic hydrops exists in LVA syndrome, its effect on the results of multifrequency tympanometry also should be considered. However, the effect of the third window because of to the LVA may be much stronger than that of endolymphatic hydrops in multifrequency tympanometry in LVA syndrome. It is generally considered that the air-bone gap depends on the third window (19).

Electrocochleography (6,7), glycerol test (7), vestibular evoked myogenic potential (8), furosemide test, and caloric test (20), among others, have been used to investigate endolymphatic hydrops. Compared with those tests, multifrequency tympanometry is less time consuming and easier to perform in clinical practice. Accordingly, it can be used to evaluate not only the middle ear but also the inner ear.

CONCLUSION

We compared the degree of endolymphatic hydrops revealed by MRI and the peak width of conductance tympanometry. Peak width was associated with significant endolymphatic hydrops. However, the association between mild endolymphatic hydrops and peak width was not evident. Multifrequency tympanometry can be used to evaluate not only the middle ear but also the inner ear.

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