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Jong, M.A. de; Esch, B.F. van; Benthem, P.P.G. van; Zaag-loonen, H.J. van der; Bruintjes, T.D.; Thomeer, H.G.X.M.

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The Diagnostic Value of Multifrequency Tympanometry in Patients with Ménière's Disease: A Prospective Analysis

Marrigje A. de Jong[a] Babette F. van Esch[b] Peter Paul G. van Benthem[b]
Hester J. van der Zaag-Loonen[c] Tjasse D. Bruintjes[b, c] Hans G.X.M. Thomeer[a, d]

[a]Otorhinolaryngology and Head and Neck Surgery Department, University Medical Centre Utrecht, Utrecht, The Netherlands; [b]Department of Otorhinolaryngology and Head and Neck Surgery, Leiden University Medical Center, Leiden, The Netherlands; [c]Apeldoorn Dizziness Centre, Gelre Hospital, Apeldoorn, The Netherlands; [d]Brain Center, University Medical Centre Utrecht, Utrecht, The Netherlands

Keywords
Dizziness · Ménière's disease · Multifrequency tympanometry · Vestibular testing

Abstract
Introduction: Diagnosing Ménière's disease (MD) by its characteristics such as episodes of vertigo, fluctuating hearing loss, and tinnitus with aural fullness remains challenging. Available tests evaluating the presence of endolymphatic hydrops (EH) are often expensive or time assuming. An in-office quick and simple non-invasive diagnostic test is multifrequency tympanometry (MFT). It can measure conductance at 2 kHz probe tones, which was demonstrated to reflect variations in cochlear pressure. Previous studies investigating MFT as a diagnostic test for MD showed conflicting outcomes possibly biased by their retrospective design. ***Methods:*** We prospectively collected MFT results (Y width) in patients with dizziness and compared MFT test results in affected (group 1) and unaffected (group 2) ears of 37 MD subjects and in control ears of 33 non-MD subjects (group 3). ***Results:*** The mean value of the Y width in affected ears was 315.6 ± 70.2 daPa compared to 292.3 ± 98.6 daPa in unaffected ears in MD subjects and 259.4. ± 60.6 daPa in the non-MD group. A positive test result (i.e., a Y width of 235 daPa or more) was found in 35 ears in the MD group, 21 times involving the affected ear and 14 times involving the unaffected ear, compared to 16 in the non-MD group. No significant differences between the three groups could be demonstrated ($p > 0.05$). We found a sensitivity of 58.3% and specificity of 66.3% for detecting EH in an affected ear in MD subjects. ***Conclusion:*** There is a trend towards increased conductance tympanometry in affected ears. However, we noticed a high false positive rate of MFT and do not support standardized use of MFT as an additional diagnostic tool for detecting EH in MD patients. A negative test result on the contrary is unlikely related to EH.

Introduction

Ménière's disease (MD) is typically characterized by spontaneous episodes of vertigo, fluctuating hearing loss, and tinnitus with aural fullness. Endolymphatic hydrops (EH), first described in 1938, has been proposed as the essential histopathological substrate [Hallpike and Cairns, 1938]. The hydropic extension of the endolym-

Karger@karger.com
www.karger.com/aud

Correspondence to:
Hans G.X.M. Thomeer, h.g.x.m.thomeer@umcutrecht.nl

phatic space may be a result of unbalance in production or absorbance of endolymph; however, its etiological mechanism remains unknown [Paparella, 1985; Merchant et al., 1996]. Diagnosis mainly relies on a proper history taking and as other underlying pathologies might present with similar clinical symptoms (such as vestibular migraine, vestibular paroxysmia, hyperventilation), sometimes correct diagnosis is challenging. Therefore, supporting additional objective measures are of value.

Diagnostic procedures more directly evaluating the presence of EH include electrocochleography [Morrison et al., 1980; Moon et al., 2012], vestibular-evoked myogenic potentials [Young, 2013], and 3D fluid-attenuated inversion recovery MRI after intratympanic or intravenous gadolinium application [Fukuoa et al., 2011; Le et al., 2013]. These tests take a fair amount of time while more recently an in-office quick and simple non-invasive diagnostic test has been introduced, the multifrequency tympanometry (MFT). If such a test has a diagnostic value for MD, one can understand that it might have a role in diagnosing MD compared to other more expensive and time-consuming tests especially in clinics that lack such resources. MFT measures the acoustic admittance of the middle ear and the external ear canal at a wide range of frequencies, from 200 Hz to 2 kHz [Lilly, 1984; Franco-Vidal et al., 2005, 2015].

It derives several individual vectors: impedance (Z) defined as the total opposition of the middle ear system to the flow of acoustic energy and admittance (Y) which is the opposite, representing the amount of acoustic energy that flows into the middle ear. Admittance has three components: mass susceptance (Bm), stiffness susceptance (Bs), and conductance (G) which represent the resistive forces. G is the only contributor to the admittance (Y) at the resonance frequency (RF) of the middle ear, which occurs when the stiffness and mass elements of the ear are in balance. In other words, the RF is the frequency at which the phase angle of the middle ear admittance is 0°. It shifts towards lower frequencies with mass loading and toward higher frequency with abnormal stiffness.

As traditional tympanometry uses probe tones at a single low frequency of 226 Hz, it is relatively insensitive to middle ear pathologies. For example in otosclerosis where traditional tympanometry is often unremarkable, the MFT tympanogram shows a distinct pattern. Likewise, higher frequency tympanometry has been proposed as a diagnostic tool for EH. A possible explanation for the related mechanism has been described in a study on guinea pigs [Darrouzet et al., 2007]. Injecting a small amount of liquid into the scala tympani, increasing the cochlear pressure, resulted in a double peak in the conduction tympanogram at 2 kHz whereas aspiration of liquid from the scala tympani caused disappearance of the peaks. They concluded that the admittance, susceptance, and conductance measured at 2 kHz probe tones reflected the annular ligament and cochlear pressure. An increasing amount of injected fluid in the scala tympani resulted in a more widened double peak and therefore tympanometry at 2 kHz probe tones was suggested a useful method to measure variations in intracochlear pressure and possibly EH.

In 2005, it was demonstrated that MFT at a frequency of 2 kHz might reveal EH in MD patients, represented by an increased G width (between the two peaks) of the conductance tympanogram [Franco-Vidal et al., 2005], and therefore, may be suitable as a complementary test in the diagnosis of MD. Also, MD patients compared to controls revealed a decrease in the RF [Franco-Vidal et al., 2005; Lilly, 1984]. Study findings were validated as Franco-Vidal et al. demonstrated a reproducible increase of the inner ear pressure in normal subjects (by body tilts, Trendelenburg) with a concomitant increase of the G width [Franco-Vidal et al., 2015]. However, body tilt increased the RF. More recent studies did not all confirm a reduction in RF among MD patients, whereas they had a modest accuracy or conflicting results on the G width in the conductance tympanogram [Sugasawa et al., 2013; Ishuzu et al., 2018; Cetin et al., 2019].

With such conflicting results, further research is needed to evaluate the usefulness of MFT in clinical practice. No study has yet prospectively investigated the diagnostic value of MFT for patients suspected of MD. In the present study, we prospectively collected MFT results in patients with dizziness and will aim to answer the following question: is there a role for MFT in diagnosing MD (presence of EH)?

Materials and Methods

In this cross-sectional designed study, patients, who presented with complaints of dizziness to the Apeldoorn Dizziness Centre between 2016 and 2018, were prospectively included. All data were analysed anonymously.

Standard Diagnostic Procedure

In all dizzy patients, the workup included vestibular tests (oculomotor, caloric and positional tests, and video-head impulse test), pure tone audiometry, admittance tympanometry at multiple frequencies, and blood pressure monitoring (to detect orthostatic hypofunction). We used current available diagnostic criteria to confirm MD [Lopez-Escamez et al., 2015], benign paroxysmal positional vertigo [Lempert et al., 1995], vestibular neuritis [Jeong et al., 2013], vestibular migraine [Lempert et al., 2012], and benign

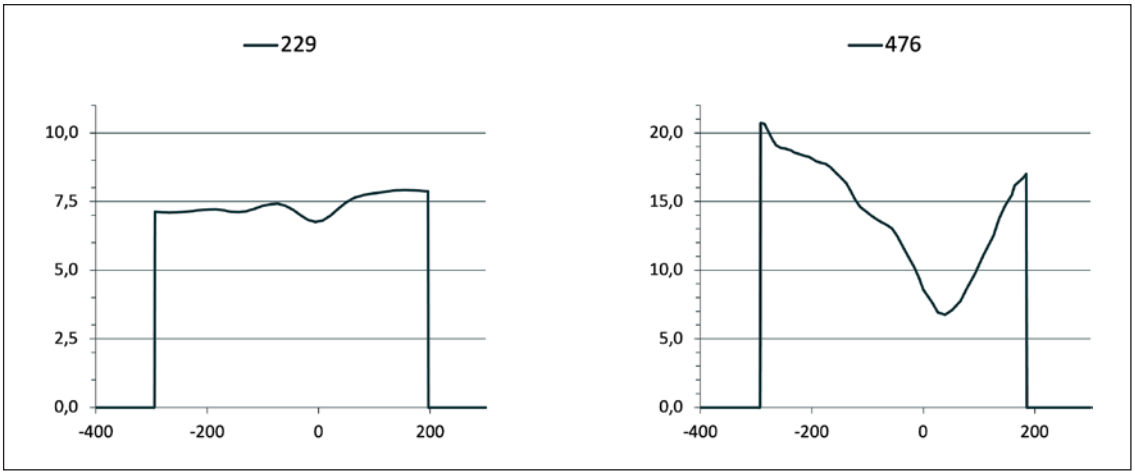

Fig. 1. Representation of the Y-width double peak for an unaffected ear (229 daPa) (left) and affected ear (476 daPa) (right), the latter one showing a clear M-shape. X-axis: air pressure (daPa). Y-axis: admittance (mmho).

recurrent vertigo [Leliever and Barber, 1981]. Orthostatic hypotension was defined by a reproducible fall in systolic blood pressure of 20 mm Hg during the first 2 min of standing. We diagnosed patients with a central vascular disorder based on clinical history and abnormal findings on neurologic and MRI examinations.

Patients were excluded from analysis in case they were suffering from an active additional neuro-otological disorder that mimics MD (e.g., vestibular migraine, benign recurrent vertigo, persistent postural perceptional dizziness, vertebro-basilar transient ischemic attacks, vestibular schwannoma). We excluded patients with a perforated eardrum, an active middle ear disease (e.g., otitis media acuta, otitis media with effusion), a history of intratympanic injections with corticosteroids, gentamicin, and ear surgery as these may influence the impedance of the middle and external ear transmission system [Ogut et al., 2008].

Multifrequency Tympanometry

The MFT was recorded using a Titan Firmware version 1.08.08 (Amplifon-EmiD-Interacoustics, USA, Titan PC Suite 3.2, hardware version 1.01). An admittance tympanometry at 226 Hz was recorded to exclude patients with middle ear abnormalities. The test was performed by inserting the tympanometry probe in the ear canal measuring the eardrum responses at different frequencies from 200 Hz to 2 kHz. A series of data were plotted as a tympanogram (shown in Fig. 1).

The admittance (Y), susceptance (B), and conductance (G) at 2 kHz were recorded with the MFT device. Similar to the methods of previous studies [Yasui et al., 2012; Sugasawa et al., 2013], the width of the double peaks in magnitude of the Y tympanometry (Y width) was used to identify presence of EH. The test was performed by trained laboratory technicians. Data imputation was executed by an independent research nurse whereas the results were analysed by two of the researchers.

Audiological Evaluation

The hearing thresholds were measured by pure tone audiometry at the frequencies of 500, 1,000, 2,000, and 4,000 Hz. "Definite" unilateral MD is defined by a sensorineural hearing loss on pure tone thresholds for bone-conducted sound that are 30 dB higher (i.e., worse) in the affected ear than in the contralateral ear present at each of two contiguous frequencies below 2,000 Hz [Lopez-Escamez et al., 2015]. Patients with a bilateral form of MD during inclusion had episodes of vertigo, fluctuating aural symptoms and documented low-frequency hearing loss in both ears during audiometry testing. In such cases, absolute hearing thresholds for bone-conducted sound must be 35 dB or higher in each of two contiguous frequencies below 2,000 Hz. A subclassification based on a potential aetiological substrate such as a genetic, auto-immune, or a migraine-related causative factor for bilateral MD was not performed.

Statistical Analysis

A Y width of 235 daPa or higher was defined as a presence of EH (positive test result). Subjects that met the diagnostic criteria for "definite" and "probable" MD as published in 2015 were eligible for inclusion in the MD group [Lopez-Escamez et al., 2015]. The diagnostic criteria are shown in the online supplementary material (see www.karger.com/doi/10.1159/000528852 for all online suppl. material). Subjects that did not meet the criteria were included in the non-MD group.

Values of the Y width and PTA as mean ± standard deviation were compared. Y width results of affected and unaffected sides in MD patients were compared to the Y width results of the non-MD subjects by applying the independent *t* test. A p value of <0.05 was considered statistically significant. Pearson's correlation coefficients were calculated to describe the relation between Y width and PTA in the MD patients. Analysis was performed using SPSS version 23.

Results

We included 70 subjects (n = 140 ears) in which MFT was performed. Among the 70 subjects, 37 patients eventually met the criteria for probable (n = 5) or definite (n

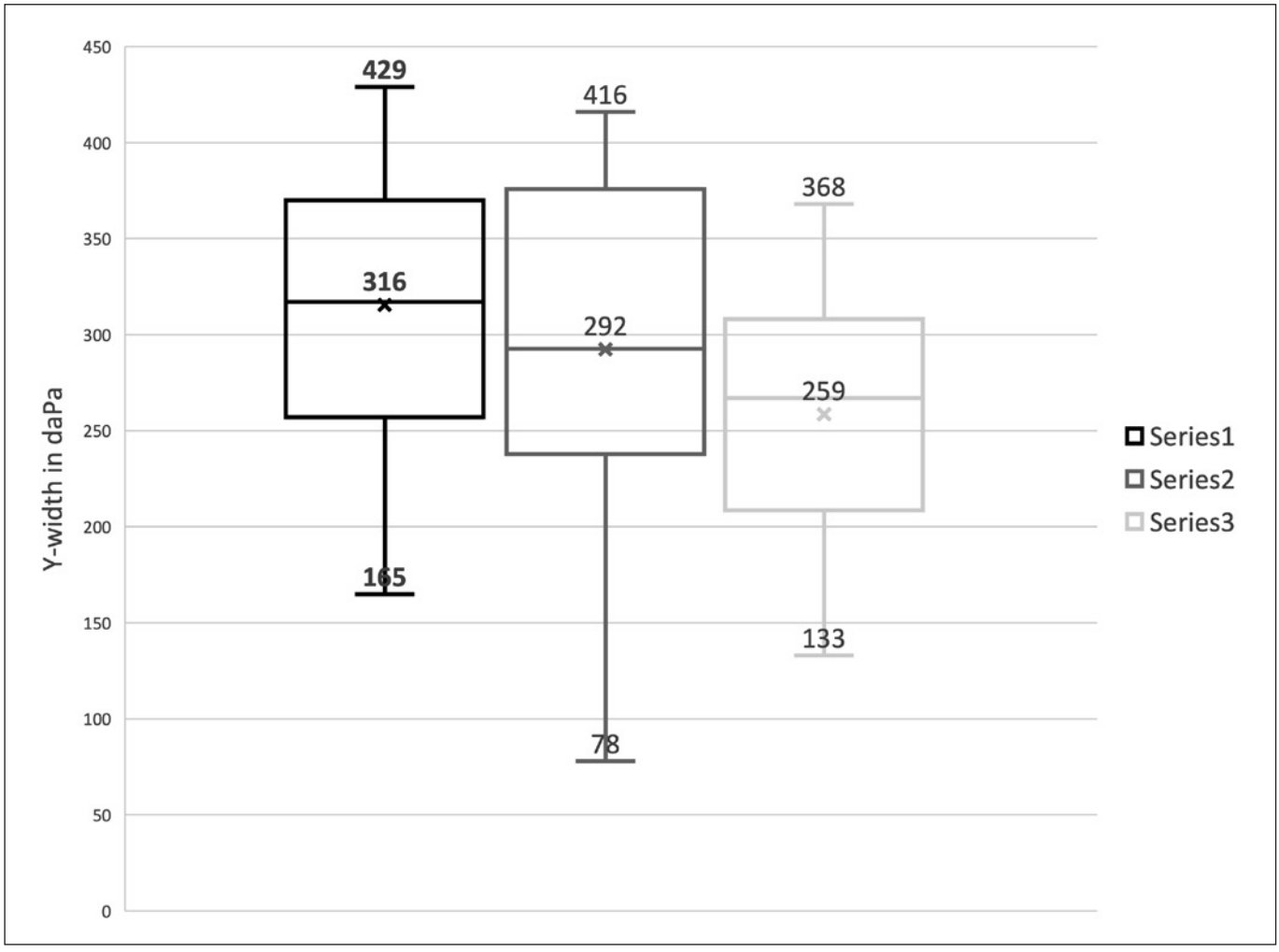

Fig. 2. Box plots of Y width at 2 kHz for three groups. Left: affected ears in the MD group. Middle: unaffected ears in the MD group. Right: control ears from the non-MD group.

= 32) MD. The other 33 subjects, with a mean age of 58.1 ± 13.5 years, were not suspected of EH and did not suffer a neuro-otological or middle ear disorder as mentioned in the exclusion criteria. From the 37 patients with MD (13 female [35%] and 24 male [65%] with a mean age of 59 ± 13.3 years), a total of 33 (89%) suffered from a unilateral form, leaving 4 (11%) patients with a bilateral form of the disease. In 15 ears, the MFT failed as a result of a technical problem and no data could be analysed leaving 125 ears for evaluation. This resulted in 36 MFT test results in affected ears in the MD group, 25 MFT test results in unaffected ears in the MD group, and 64 MFT test results in the non-MD group.

Double peaks in the Y tympanometry curve were observed in 82 ears, 43 in the MD group (70.5% of the MFT measurements in the MD group) and 39 in the non-MD group (60.1% of the MFT measurements in the non-MD group). Of the 43 double peaks seen in the group with unilateral MD, 18 were related to a patient with MD on the same side and 20 to patients with MD on the opposite side. Among the 4 subjects with a bilateral form of MD, only one had a double peak in both ears; the remaining had a double peak only on one side. This resulted in 23 double peaks in affected ears. In 43 ears, no double peak could be detected, 18 of them in the MD-group and 25 in the non-MD group.

The mean value of the Y width in affected ears in the MD group was 315.6 ± 70.2 daPa compared to 292.3 ± 98.6 daPa in unaffected ears in the MD subjects and 259.4 ± 60.6 daPa in the non-MD group (shown in Fig. 2). With

Table 1. MFT test results for MD and non-MD subjects

	Affected ears in the MD group, $n = 36$	Unaffected ears in the MD group, $n = 25$	Non-MD group, $n = 64$
Double peak present	23	20	39
No double peak present	13	5	25
Number of positive test results in the groups (double peak with Y width 235 daPa or more), *n* (%)	21 (58.3)	14 (56.0)	16 (25.0)
Mean Y width for all double peaks, mean ± SD, daPa	315.6±70.2	292.3±98.6	259.4±60.6
Mean Y width for positive test results, mean ± SD, daPa	328.1±59.8	340.0±53.2	303.3±42.7
Difference in Y width for positive test results between group and affected ears in the MD group	–	$t(32) = -0.6$ ($p = 0.612$)	$t(34) = 1.39$ ($p = 0.061$)

SD, standard deviation.

respect to a positive test result (i.e., a Y width of 235 daPa or more), 35 ears from patients in the MD group revealed a positive test result, 21 times involving the affected ear and 14 times involving the unaffected ear, compared to 16 in the non-MD group. After extracting the positive test results, no significant differences between the three groups could be demonstrated ($p > 0.05$) by means of the independent *t* test. MFT results are summarized in Table 1.

When calculating the sensitivity and specificity for MFT test results in the total study population, we found a sensitivity of 58.3% and a specificity 66.3% for detecting EH in an affected ear in a patient with MD. There was a relatively high number of false positives (56.0%) mainly in unaffected ears of MD subjects.

Y Width Results Related to the Pure Tone Average

The mean average hearing loss was 51.8 ± 18.4 dB on the affected side and 26.0 ± 20.6 dB on unaffected side of the MD patients. Both visual inspection and linear regression analyses revealed no relationship between the amount of hearing loss and the Y width; beta regression coefficient was 0.006 for the left ear ($p = 0.74$) and 0.005 for the right ear ($p = 0.75$). We summarized our study results in Table 2 in comparison to the previous studies investigating the role of MFT in diagnosing MD.

Discussion

The present study was designed to investigate the usefulness of MFT in diagnosing an EH (pathophysiological substrate of MD) in our patients. As the studies of Vidal et al. showed promising results and a possible diagnostic role for MFT in MD, later studies revealed conflicting results [Kato et al., 2012; Ishuzu et al., 2018].

We suspect that previous study results could have been biased by their retrospective study design, not only in patient selection but also in test performance and data selection. In contrast, our study provides a prospective study design. During workup and data collection, the diagnosis of MD was not yet made or ruled out based on the classification criteria. Only two researchers (B.E. and M.J.) involved in the analysis were aware of the final diagnosis. Secondly, the non-MD group, serving as the control group, went through the same workup. This would most closely resemble the performance of MFT in daily practice. It might support and confirm a possible MD diagnosis after suspicion based on clinical assessment and physical examination.

A limitation in our study is a suspected inter- and intravariability in conducting MFT. Small variations can occur during the test, even when performed by the same technician in the same subject. Despite optimizing test standardization by using the same device in one institution by a limited number of laboratory technicians, MFT remains prone to variation in test results. Even sometimes, no measurement results, without a good explanation for test failure. This should be considered during interpretation of MFT results.

In our present study, we used the Y width instead of the G width, similar to the methods of Yasui et al. [2012] and Sugasawa et al. [2013]. Double peaks in Y tympanometry were found to be more stable to record and less small compared to the G width. The rate of double peaks was previously found comparable (92% for Y width vs. 88% for G width) [Sugasawa et al., 2013]. At RF, G is the only contributor to admittance (Y) and therefore they closely represent each other. We found a similar trend for

Table 2. Overview of outcomes for MFT measurements in subjects with and without MD from the current and previous studies

Study	Measures	Mean double peak in daPa±SD in affected ears, MD (*n*)	Mean double peak in daPa±SD in unaffected ears, MD (*n*)	Mean double peak in daPa±SD in unaffected controls (*n*)	Mean RF in daPa±SD in affected ears, MD (*n*)	Mean RF in daPa±SD in unaffected ears, MD (*n*)	Mean RF in daPa±SD in unaffected controls (*n*)	Cut-off double peak, daPa	Sensitivity and specificity, %	Relation between double peak and PTA	Relation between RF and PTA	Mean double peak in daPa with EH (*n*)	Mean double peak in daPa without EH (*n*)	Mean RF in daPa with EH (*n*)	Mean RF in daPa without EH (*n*)
Franco-Vidal et al. [2005]	G width, RF	252.0±120.6 (46)***	225.8±126.1 (24)	133.6±56.6 (47)	752.0±223.4 (48)	820.7±190.6 (29)	926.0±238.1 (48)	235	56.5 and 95.7	NA	NA	NA	NA		
Kato et al. [2012]	G width, RF, EH	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	178.8±102.7 (94)**	118.8±79.1 (34)	955.9±154.6 (94)*	904.8±213.7 (34)
Yasui et al. [2012]	Y width	230.0±15 (36)**	unclear	179±9 (40)	NA	NA			NA	NA	NA	NA	NA	NA	NA
Sugasawa et al. [2013]	Y width, RF, PTA	256.5±126.1 (74)***	226.2±138.7 (57)*	175.4±66.6 (53)	978.5±324.2 (80)***	1,002.0±349.8 (57)*	1,123.0±274.8 (57)	237.5	47.3 and 86.8	None	None	NA	NA	NA	NA
Ishizu et al. [2018]	G width, RF, PTA	166.0±130.9 (57)**	135.9±86.1 (45)**	97.0±52.0 (160)	992.1±310.4 (57)*	994.3±283.5 (45)*	955.0±241.7 (160)	200	35.1 and 95.6	Not definite	NA	NA	NA	NA	NA
Cetin et al. [2019]	G width, RF during episode	157.5±79.1 (21)*	177.4±79.1 (20)*	139.6±87.5 (47)	1,015.3±505.5 (21)*	948.9±222.9 (20)*	925.5±244.8 (47)	NA	NA	NA	NA	NA	NA	NA	NA
The present study	Y width, PTA	315.6±70.2 (23)*	292.3±98.6 (20)*	259.4±60.6 (39)	NA	NA	NA	235	58.3 and 66.3	None	NA	NA	NA	NA	NA

RF, resonance frequency; EH, endolymphatic hydrops on MRI; PTA, pure tone audiometry thresholds; MD, Ménière's disease; NA, not assessed; SD, standard deviation. *No significant difference between groups, $p > 0.05$. **Significant difference compared to controls, $p < 0.05$. ***Significant difference compared to controls, $p < 0.001$.

the Y width in affected and unaffected ears of MD and non-MD subjects, namely, lower values for unaffected ears. But there is a relatively high percentage (56%) of positive test results for MFT in unaffected ears of MD patients. This is also represented by the low sensitivity and specificity we calculated (sensitivity 58.3% and specificity 66.3%). A study from 2017 found that lowering the cut-off to 200 daPa improved the sensibility to 35.1% with a specificity of 95% [Ishuzu et al., 2018]. Applying this cut-off to our data would not improve the sensitivity and negatively affect the specificity because the number of false-positive MFT tests in unaffected ears and non-MD subjects remains high. In our prospective study, we found a higher mean value for Y width (259.4 ± 60.6 daPa) among non-MD subjects, indicating the need for a higher cut-off value to improve the specificity at the expense of the sensitivity. This difference could partly be explained by the absence of selection bias, as well as the fact that studies have found cochlear and vestibular hydrops among healthy subjects [Conte et al., 2018]. The high number of false-positive results in unaffected ears of MD subjects is an example of possible EH in asymptomatic ears. Also, as a true representation of the clinical setting, our control group at inclusion suffered from dizziness in contrast to the control groups in previous studies. MD at that stage was not confirmed and another explanation was found for their symptoms. This raises an interesting question if those symptoms could be related to the high false-positive rate, but for the purpose of our study, we did not continue follow-up.

The correlation between a positive MFT test result and EH in the MRI hydrops would be an interesting field for further study. Nowadays, an MRI hydrops is the gold standard for diagnosing and confirming EH. Kato et al. examined the relationship between the degree of EH and peak width of 2 kHz conductance tympanometry [Kato et al., 2012]. The peak width in ears with significant EH was larger than that observed in ears with no EH. There was no significant different peak width between cases of mild and absent EH. Secondly, in the presence of a significant EH, the average G width was 178.8 ± 102.7 daPa below the cut-off value of 235 daPa. They also found a tendency towards lower RF in ears with significant EH [Kato et al., 2012]; however, the difference was not significant. We did not analyse the RF in our population since previous results are very conflicting. Moreover, the RF decreased during the glycerol test in a study by Oz et al. from 2019 [Oz et al., 2019]. The glycerol test is a dehydration test used in the diagnosis of MD. It temporarily improves hearing thresholds by increasing plasma osmolality. Low-

er RF values were suspected to return to similar values as control ears; however, the opposite occurred. Average RF values for MD patients decreased significantly from 808.0 ± 410.1 Hz to 748.0 ± 402.1 Hz postulating that the inner ear dynamics for the RF are different in MD.

We also found that only 8.7% (n = 2) of affected ears in MD patients were tested negative for MFT. Applying a cut-off value of 200 daPa resulted in only one false-negative test case in the affected MD ears. Although our study sample is small, this suggests that a negative test result is unlikely related to an affected ear with EH. Performing an expensive and time-consuming MRI hydrops in such cases might therefore not be recommended.

A study conducted on MD patients during an acute episode showed no suspected increase in peak width or decrease in RF and values were not significantly different from controls [Cetin et al., 2019]. They concluded that the diagnostic utility of MFT in acute episodes of MD is nonexistent. Likewise, our prospective data do not provide convincing evidence supporting that MFT is useful as an additional diagnostic tool for detecting EH in MD patients.

Conclusion

Based on our analysis of prospective data regarding MFT test results in MD subjects and non-MD subjects from the Apeldoorn Dizziness Centre, we do not find evidence for the use of MFT as a diagnostic instrument in MD. Although there is a similar trend towards increased conductance tympanometry in affected ears and to a lesser extend in unaffected ears of MD subjects, the diagnostic utility is not convincing. We excluded possible bias through prospective measurements and data collection, closely simulating a daily clinical practice setting. As a result, we noticed the high false-positive rate of MFT. A negative test result, i.e., a double peak with conductance >235 daPa, is however unlikely related to EH. We do not support standardized use of MFT as an additional diagnostic tool for detecting EH in MD patients.

Statement of Ethics

This study protocol was in accordance with the ethical standards and in line with the Helsinki Declaration and approved by the Ethics Committee at Gelre Ziekenhuizen Apeldoorn. From all participants, a written informed consent was obtained to participate in the study.

Conflict of Interest Statement

All authors have no conflicts of interest to declare.

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Author Contributions

M.A. de Jong, B.F. van Esch, P.P.G. van Benthem, H.J. van der Zaag-Loonen, T.D. Bruintjes, and H.G.X.M. Thomeer all contributed to the process of study design, analysis, and/or writing this paper and gave agreement with the final version.

Data Availability Statement

The anonymized data are available upon request. Details are available through the corresponding author.

References

Cetin AC, Gurkan S, Kirkim G, Guneri E. Wideband tympanometry results during an acute episode of Ménière's disease. Audiol Neurotol. 2019;24(5):231–6.

Conte G, Lo Russo FM, Calloni SF, Sina C, Barozzi S, Di Berardino F, et al. MR imaging of endolymphatic hydrops in Ménière's disease: not all that glitters is gold. Acta Otorhinolaryngol Ital. 2018 Aug;38(4):369–76.

Darrouzet V, Dulon D, Franco-Vidal V. Multifrequency immittancemetry in experimentally induced stapes, round window and cochlear lesions. Audiol Neurootol. 2007;12(2):85–100.

Franco-Vidal V, Bonnard D, Bellec O, Thomeer H, Darrouzet V. Effects of body tilt on multifrequency admittance tympanometry. Otol Neurotol. 2015;36:737–40.

Franco-Vidal V, Legarlantezec C, Blanchet H, Convert C, Torti F, Darrouzet V. Multifrequency admittancemetry in Ménière's disease: a preliminary study for a new diagnostic test. Otol Neurotol. 2005;26(4):723–7.

Fukuoka H, Takumi Y, Tsukada K, Miyagawa M, Oguchi T, Ueda H, et al. Comparison of the diagnostic value of 3T MRI after intratympanic injection of GBCA, electrocochleography, and the glycerol test in patients with Ménière's disease. Otol Neurotol. 2011;32:472–7.

Hallpike CS, Cairns H. Observations on the pathology of Ménière's syndrome. Proc R Soc Med. 1938;31(11):1317–36.

Ishizu K, Tamae A, Kubo K, Yoshida T, Matsumoto N, Yasui T, et al. Diagnosis and following up of Ménière's disease using multifrequency tympanometry: cutoff values and temporal changes in measurements. Auris Nasus Larynx. 2018;45(1):81–7.

Jeong SH, Kim HJ, Kim JS. Vestibular neuritis. Semin Neurol. 2013;33(3):185–94.

Kato K, Yoshida T, Teranishi M, Sano R, Otake H, Sone M, et al. Peak width in multifrequency tympanometry and endolymphatic hydrops revealed by magnetic resonance imaging. Otol Neurotol. 2012;33(6):912–5.
Le CH, Truong AQ, Diaz RC. Novel techniques for the diagnosis of Meniere's disease. Curr Opin Otolaryngol Head Neck Surg. 2013; 21(5):492–6.
Leliever WC, Barber HO. Recurrent vestibulopathy. Laryngoscope. 1981;91:1–6.
Lempert T, Gresty MA, Bronstein AM. Benign positional vertigo: recognition and treatment. BMJ. 1995;311(7003):489–91.
Lempert T, Olesen J, Furman J, Waterston J, Seemungal B, Carey J, et al. Vestibular migraine: diagnostic criteria. J Vestib Res. 2012;22(4): 167–72.
Lilly DJ. Multiple frequency, multiple component tympanometry: new approaches to an old diagnostic problem. Ear and Hearing. 1984;5: 300–8.
Lopez-Escamez JA, Carey J, Chung WH, Goebel JA, Magnusson M, Mandalà M, et al. Diagnostic criteria for Ménière's disease. J Vestib Res. 2015;25:1–7.
Merchant SN, Ravicz ME, Rosowski JJ. Acoustic input impedance of the stapes and cochlea in human temporal bones. Hearing Res. 1996; 97(1–2):30–45.
Moon IJ, Park GY, Choi J, Cho YS, Hong SH, Chung WH. Predictive value of electrocochleography for determining hearing outcomes in Ménière's disease. Otol Neurotol. 2012;33(2):204–10.
Morrison AW, Moffat DA, O'Connor AF. Clinical usefulness of electrocochleography in Meniere's disease: an analysis of dehydrating agents. Otolaryngol Clin North Am. 1980; 13(4):703–21.
Ogut F, Serbetcioglu B, Kirazli T, Kirkim G, Gode S. Results of multiple-frequency tympanometry measures in normal and otosclerotic middle ears. Int J Audiol. 2008;47(10):615–20.
Oz I, Hizal E, Cam OH, Ozluoglu LN, Ozluoglu N. Effects of glycerol test on resonance frequency in patients with Ménière's disease. Audiol Neurootol. 2019;24(6):285–92.
Paparella MM. The cause (multifactorial inheritance) and pathogenesis (endolymphatic mal absorption) of Meniere's disease and its symptoms (mechanical and chemical). Acta Otolaryngol. 1985;99(3–4):445–51.
Sugasawa K, Iwasaki S, Fujimoto C, Kinoshita M, Inoue A, Egami N, et al. Diagnostic usefulness of multifrequency tympanometry for Ménière's disease. Audiol Neurootol. 2013;18(3):152–60.
Yasui T, Iwasaki S, Sugasawa K, Sakamoto T, Kashio A, Suzuki M, et al. Admittance tympanometry with 2-kHz probe tones in patients with low-frequency hearing loss. Laryngoscope. 2012;122(10):2252–5.
Young YH. Potential application of ocular and cervical vestibular evoked myogenic potentials in Ménière's disease: a review. Laryngoscope. 2013;123(2):484–91.