Middle Ear Resonant Frequency in Normal and Otosclerotic Ears: Effect of Procedural Variation

La fréquence de résonance de l'oreille moyenne dans l'oreille dite normale et celle avec otosclérose : effet de variation des procédures

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Abstract

The present study was designed to investigate the usefulness of resonant frequency information of the middle ear in the detection of otosclerosis that could not have not been identified using single component low frequency tympanometry. The effect of procedural variation in the estimation of resonant frequency was also investigated. Data were collected from 22 ears of seventeen participants with otosclerosis and 30 ears of 30 participants with normal hearing. The peak compensated static admittance value was within normal limits for all the participants. Resonant frequency was determined separately, based on delta susceptance and delta phase angle. The results revealed that the resonant frequency was significantly higher in ears with otosclerosis. The procedure used to determine resonant frequency also had a significant effect on the results obtained.

Abrégé

La présente étude voulait investiguer la pertinence de la mesure de la fréquence de résonance de l'oreille moyenne dans la détection de l'otosclérose, à savoir si elle n'avait pu être identifiée en n'utilisant que la tympanométrie en basses fréquences à composante simple. Les effets de variation au niveau des procédures d'estimation de la fréquence de résonance ont aussi été investigués. Des données ont été recueillies à partir de mesures effectuées sur 22 oreilles de dixsept participants ayant l'otosclérose et 30 oreilles de 30 participants ayant une audition normale. La valeur du pic compensé d'admittance statique était à l'intérieur des limites normales pour tous les participants. La fréquence de résonance était déterminée séparément, à partir du delta de susceptance et du delta de l'angle de phase. Les résultats ont montré que la fréquence de résonance était significativement plus élevée dans les oreilles avec otosclérose. La procédure utilisée pour déterminer la fréquence de résonance a eu aussi un effet significatif sur le résultat obtenu.

Key words: multifrequency tympanometry, otosclerosis, resonant frequency, hearing measurement

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Immittance evaluation is generally carried out using a low frequency probe tone (i.e., 220 Hz or 226 Hz) and the differential diagnosis of middle ear disorders is made based on the tympanometric pattern, tympanometric width and peak compensated static admittance. It has been reported in literature that participants with otosclerosis have low admittance at the tympanic membrane (Jerger, Anthony, Jerger, & Mauldin, 1974). However, a lot of overlap in peak compensated static admittance values have been observed

between normal ears and those with otosclerosis when a low frequency probe tone is used for tympanometry (Jerger, 1970; Jerger et al., 1974; Liden, Harford, & Hallen, 1974; Muchnick Hidescheimer, Rubinstein, & Gliteman, 1989; Margolis & Shanks, 1991). Jerger and colleagues (1974) have reported that 30 % of ears with otosclerosis had normal peak compensated static admittance values at the tympanic membrane. In a study by Muchnick et al., the peak compensated static admittance value was normal or higher in 67% of the ears with otosclerosis. Margolis and Shanks have observed that the tympanograms from participants with stapedial fixation were frequently normal with a probe tone frequency of 226 Hz or 678 Hz.

Attempts have been made to solve this dilemma in the differential diagnosis of middle ear pathologies by using multifrequency tympanometry. Liden et al. (1974) have stressed the importance of use of higher frequency probe tones for differential diagnosis of conductive impairments. Colletti (1976) has reported that multifrequency tympanometry is far more sensitive in identifying small changes in the transmission characteristics of the tympano-ossicular chain system, relative to monofrequency tympanometry. Margolis and Shanks (1991) have suggested that multifrequency tympanometry, by providing a method for estimating the resonant frequency of the middle ear, may prove to be an effective method for detecting stapedial fixation.

Resonant frequency of the middle ear is that frequency at which the opposition due to mass and spring elements in the middle ear cancel each other leading only to a friction component or conductance. In other words, susceptance is nil and the phase angle of the admittance is zero at the resonant frequency. There are a number of methods to estimate the resonant frequency of the middle ear using various parameters such as peak compensated susceptance, conductance, admittance, and phase angle. A review of literature shows that the measured resonant frequency varies with the method used for its estimation (Margolis & Goycoolea, 1993; Shanks, Wilson, & Camron, 1993; Shahanaz & Polka, 1997). At present, there is no consensus regarding the choice of procedure for estimating resonant frequency.

Commercially available instruments make use of different methods to check the resonant frequency. Certain instruments have the ability to record multifrequency tympanograms using sweep frequency or sweep pressure methods. Data gathered on both normal and pathological populations using these methods indicate that the value of the resonant frequency varies depending on the method used for estimation of resonant frequency (Margolis & Goycoolea, 1993;

Shahanaz & Polka, 1997; Shanks, 1984; Shanks et al., 1993).

Peak compensated susceptance is used to estimate the resonant frequency of the middle ear with a few instruments. The difference between susceptance at the tympanometric peak pressure and susceptance at an extreme ear canal pressure (delta susceptance) is plotted as a function of frequency. The frequency at which the difference is zero is considered as the resonant frequency. That is, at resonant frequency, there is no susceptance and the admittance measured is only due to conductance. The instrument also plots the difference between phase angle of admittance at tympanometric peak pressure and phase angle at extreme ear canal pressure (delta phase angle) as a function of frequency. Theoretically, this difference in phase angle is at its maximum at the resonant frequency as the total admittance is close to the real axis (x-axis) at tympanometric peak pressure. Extreme ear canal pressure increases the stiffness of the tympanic membrane and the resulting admittance value moves away from the real axis. In other words, at extreme ear canal pressures, both susceptance and conductance contribute to admittance, whereas at tympanometric peak pressure, only conductance contributes to admittance. For frequencies lower than resonant frequency, conductance and susceptance contribute to admittance at both tympanometric peak pressure and extreme ear canal pressure, but the contribution of stiffness component is more at extreme ear canal pressure. Thus, delta phase angle is lesser at other frequencies when compared to that at the resonant frequency. Lilly (1984) has reported the delta phase angle to be at maximum at resonant frequency. Clinical experience with instrumentation has shown that the frequency at which delta suseptance is zero and the frequency at which delta phase angle is maximum is not always the same. Thus, there is a need to assess whether there is a significant difference in the resonant frequency estimated using delta susceptance and delta phase angle in normal, as well as pathological groups.

One of the middle ear abnormalities in which the resonant frequency of the middle ear is affected is otosclerosis. Stapedial fixation will lead to an increase in stiffness of the middle ear, which in turn results in higher resonant frequency than that observed in participants with normal hearing. Colleti (1977) observed that the resonant frequency of the middle ear was increased in patients with otosclerosis, whereas it was reduced in those with ossicular chain discontinuity. Funasaka, Funai, and Kumakawa (1984) reported an abnormally high resonant frequency of the middle ear in a patient with otosclerosis. Shahanaz and Polka (1997) have reported that the mean resonant frequency of the middle

ear for the group with otosclerosis was higher than that for participants with normal hearing. They concluded that measures derived from multifrequency and multicomponent tympanometry outperform the measures obtained from standard low-frequency tympanometry. However, a close inspection of the data shows that there was an overlap in the 90% range obtained for the two groups. Valvik, Johnsen, and Laukli (1994) have also reported similar results. Results of an investigation by Miani, Bergamin, Baroti, and Isola (2000) revealed that the ears of patients with clinically advanced fenestral otosclerosis presented with a resonant frequency that is markedly higher than both that of normal hearing participants, as well as normal ears contralateral to an ear with otosclerosis. Therefore, the present study was directed at further investigating the usefulness of resonant frequency of the middle ear in the detection of otosclerosis that could not be detected using peak compensated admittance values. The effect of procedural variation in the estimation of resonant frequency was also investigated.

Method

Participants

Two groups of participants were considered for the study. Group I consisted of 30 ears from 30 participants with normal hearing. Equal number of males and females in the age range of 18 to 51 years were included. None of the participant reported a history of otological or neurological problems. All the participants had thresholds less than 25 dB HL at octave frequencies from 250 Hz to 8000 Hz. Normal middle ear functioning was confirmed through conventional immittance evaluation. Peak compensated static admittance ranged from 0.5 ml to 1.75 ml. Tympanometric peak pressure was in the range of +25 daPa to –50 daPa. The ear canal volume ranged from 0.8 to 2.4 ml. Ipsilateral and contralateral acoustic reflex thresholds ranged from 80 dBHL to 100 dBHL.

Group II consisted of 22 ears from 17 participants who were diagnosed by a qualified otolaryngologist to have otosclerosis. The age of the participants in Group II ranged from 18 to 51 years. Only those participants who exhibited conductive hearing loss on pure-tone audiogram, but had normal tympanogram with absent acoustic reflexes, were considered for the study. Peak compensated static admittance at the tympanic membrane varied from 0.5 ml to 1.75 ml for 226 Hz probe tone. The ear canal volume ranged from 1 to 2.5 ml. The tympanometric peak pressure was in the range of + 25 daPa to –50 daPa. None of the participants had any abnormalities of tympanic membrane. Also there was no history or indication of any other otological problems or neurological problems. The degree of hearing loss varied from mild to moderately severe.

Procedure

For all the participants in both groups, testing was initiated with pure-tone audiometry in a two-room sound treated suite using a calibrated diagnostic audiometer. Air conduction thresholds were established at octave frequencies from 250 Hz to 8000 Hz and bone conduction thresholds were established from 250 Hz to 4000 Hz using modified Hughson-Westlake procedure.

Immittance evaluation was carried out using a middle ear analyzer (GSI 33, Version-2). Tympanogram and peak compensated static admittance were recorded using a probe tone of 226 Hz. The air pressure was varied from +200 daPa to –400 daPa, at a rate of 200 daPa/sec, to record the tympanogram. Resonant frequency of the middle ear was established using Multi Hertz option. The probe tone was swept from 250 Hz to 2000 Hz, in steps of 50 Hz, with air pressure in the ear canal maintained at + 200 daPa. Susceptance and phase angle measurements were stored in memory. A second probe tone sweep was carried out with the air pressure in the ear canal at tympanometric peak pressure. The instrument then calculated the difference in susceptance (delta susceptance) and phase angle (delta phase angle) values between the two sweeps and plotted it on a graph as a function of frequency. The frequency at which delta susceptance was zero was selected as the resonant frequency by the instrument and this was called RF1. The

Table 1
Mean, Standard Deviation, and Range of the Resonant Frequency (RF1 & RF2) in Normal Ears and Otosclerotic Ears

	Group I		Group 2	
	RF1	RF2	RF1	RF2
Mean (in Hz)	929.33	1049.83	1063.64	1209.30
SD (in Hz.)	185.11	188.45	235.30	221.76
Range (in Hz.)	560-1290	610-1420	700-1430	720-1460

experimenter then identified the frequency at which delta phase angle was at maximum by moving a cursor with the help of the soft key, and that frequency was called RF2.

Results

The data obtained were tabulated and analyzed via computer using SPSS (Version 7.5) software. The mean, standard deviation, and range as a function of procedure (i.e., delta susceptance vs. phase angle) and middle ear condition (i.e., normal and otosclerotic) are presented in Table 1. A two-factor analysis of variance was undertaken to investigate differences in mean resonant frequencies as a function of procedure and middle ear condition. Significant main effects were found for both procedure ($F = 12.98, p < 0.01$) and middle ear condition ($F = 10.6, p < 0.01$). The procedure by middle ear condition interaction was not significant ($F = 0.095, p > 0.05$). In other words, and as evident in Table 1, the delta phase angle procedure generated significantly higher resonant frequencies and those with otosclerotic ears had significantly higher resonant frequencies.

Discussion

Even though the resonant frequency values reported in different studies are comparable, there is a variation in the mean values, as well as in the range values obtained by different investigators (Colleti, 1976,1977; Margolis & Goycoolea, 1993; Miani et al., 2000; Shahnaz & Polka, 1997; Shanks et al., 1993; Valvik et al., 1994). A number of factors including the selection of participants and the procedure and equipment used may have affected the results of these investigations. In the present study, the resonant frequency of the middle ear varied with the procedure used for estimating the resonant frequency. The resonant frequency was significantly higher when delta phase angle was used to estimate the resonant frequency. Thus, the results of the present study reinforce the consensus that the value of the resonant frequency varies depending on the procedure used for the estimation of resonant frequency (Margolis & Goycoolea, 1993; Shanks et al.; Shahanaz & Polka, 1997). None of the methods estimate the true resonant frequency of the middle ear. Only an approximate value is obtained based on the admittance characteristics at the tympanic membrane; hence, there is a difference in results. Therefore, it seems that there is an urgent need to standardize a procedure for estimating resonant frequency of the middle ear in an effort to enable comparison of results across different studies and clinics.

It has been reported that the resonant frequency value is increased in participants with otosclerosis (Colletti, 1977; Funasaka et al., 1984; Miani et al., 2000; Shahanaz & Polka, 1997). Theoretical knowledge about the immittance of normal and pathological middle ears indicate that the increased stiffness in the ears with otosclerosis should result in increased compliant reactance, which in turn will increase the resonance frequency of the middle ear. Thus, estimation of the resonant frequency using multi frequency tympanometry will help in identification of ears with otosclerosis. The results of the present study also revealed that the resonant frequency is higher in ears with otosclerosis. The group data showed that the mean resonant frequency was significantly higher in ears with otosclerosis when compared to those of normal ears. These results support the view that the multifrequency tympanometry provides additional information which is not obtained through standard low frequency tympanometry as all the participants in Group II had normal (0.5 to 1.75 ml) peak compensated admittance value for 226 Hz probe tone. However, there was a clear overlap in the range of resonant frequency values obtained for participants with normal hearing and those with otosclerosis. A review of the range of resonant frequency values for normal and otosclerotic ears shown in Table 1 reveals that it is not possible to differentiate between the two groups if the cut-off value for identifying otosclerosis is given based on the range obtained. Results of earlier investigations also have shown an overlap in the range of resonant frequency of the middle ear for the two groups (Shahanaz & Polka, 1997; Colleti, 1976, 1977).

Conclusion

In conclusion, data obtained in the present study suggest that the resonant frequency of the middle ear is higher in participants with otosclerosis when compared with that of normal ears. However, the resonant frequency value varies depending on the method used for the calculation of resonant frequency. Further research is required to standardize the method used for estimation of resonant frequency and one standard method should be adopted for use with all commercially available assessment instruments.

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Author Notes

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