

Tympanometry and CT Measurement of Middle Ear Volumes in Patients with Unilateral Chronic Otitis Media

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Objectives. The goals of the study were to compare the middle ear (ME) volumes from both normal and lesioned ears, and these ME volumes were measured by a digital image processing computed tomography (CT) program in patients with unilateral chronic otitis media, and we wanted to compare the ME volumes of the lesioned ears by comparing the ME volumes obtained by tympanometry with those ME volumes measured by the digital image processing CT program.

Methods. Forty-four patients who had unilateral chronic otitis media (COM) and contralateral normal tympanic membranes (TM) and 100 subjects with normal TMs were included in the study. The normal volumes of the external auditory canal (EAC) were measured in the normal group. The tympanometric ME volumes in the ears with a perforated TM were calculated as the difference of the tympanometric volumes measured from the both ears in patients with unilateral COM. The CT ME volumes were measured by a digital image processing program.

Results. The tympanometric volumes of the EACs in the ears with normal TMs were 1.4 ± 0.3 mL. There were no significant differences according to gender, age and the side of the face the ear was on. The tympanometric volumes of the EAC in the normal-side ear of the patients with unilateral COM showed no significant differences when compared with those from the normal group. The ME volumes of the intact ears, as measured by CT, showed significantly higher values than those ME volumes of the lesioned ears. The ME volumes of the lesioned ears, as measured by tympanometry, showed a strong, significant linear correlation with those ME volumes calculated by CT; however, the ME volumes of the lesioned ears, as measured by tympanometry (1.5 ± 1.4 mL), were significantly larger than those ME volumes measured by CT (1.1 ± 0.8 mL).

Conclusion. Our results show that chronic otitis media causes reduced ME volumes compared to those ME volumes of the contralateral normal ears. Tympanometry can provide a valuable estimation of the ME volumes in chronic ears, although it tends to overestimate the ME volumes, and especially for the ears with a larger ME volume.

Key Words. Mastoid, Tomography, Imaging, Three-dimensional, Acoustic impedance tests

INTRODUCTION

Perforations of the tympanic membrane (TM) can result in a conductive hearing loss that ranges from negligible to 50 dB. It was reported that the degree of conductive hearing loss from a TM perforation increases as the size of the perforation increases,

and this loss varies inversely with the volumes of the middle ear (ME) and the mastoid air space, that is, hearing losses are greater in ears with small volumes (1). Thus, it has been suggested that clinicians can make qualitative judgments about whether or not a given perforation can explain the observed hearing loss based on the perforation size and some knowledge of the ME volume. However, it has not been exactly shown how tympanometry can predict the ME volume in patients with a perforated TM.

The goals of the study were to compare the ME volumes from both normal and lesioned ears, which were calculated by performing computerized tomography (CT), and to compare the ME volumes of the lesioned ears by performing tympanometry and high-resolution CT. In this study, we did not seek to determine the

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relationship between the degree of hearing loss and the size of the TM perforation because the patients could have additional ME pathology other than just a TM perforation.

MATERIALS AND METHODS

We studied patients who had a unilateral TM perforation and a normal TM in the contralateral ear to estimate the ME volume in the lesioned ear. We also measured the volumes of the external auditory canal (EAC) from 100 subjects who complained of sensorineural hearing loss and/or tinnitus and they had a normal EAC to determine the normative EAC volumes. We performed a retrospective chart review of all the patients who had unilateral chronic otitis media (COM) together with a perforated TM at the time of surgery between November 2005 and February 2007. Only those patients who had undergone both CT scans and tympanometry before surgery were included. Fifty three patients were identified; however, two patients were excluded because of their otorrhea at the time of the tests and seven patients were excluded because tympanometry could not estimate the volumes (≥ 7.2 mL) in their lesioned ears. Forty four patients (19 males and 25 females) were included in this study. Their age ranged from 19-69 yr. All the patients showed a dry perforated TM in the lesioned ear and an intact TM in the contralateral ear. Further, among the other patients who complained of hearing loss and/or tinnitus, 100 subjects (44 males, 56 females; aged 10-89 yr) who showed a normal TM and A types on tympanometry were included for determining the normal EAC volumes.

Tympanometric ME volumes

A Grason-Stadler Incorporated (GSI) impedance audiometry machine (GSI TympStar Middle Ear Analyzer v.2, VIASYS NeuroCare, WI, USA) with a probe tone frequency of 226 Hz was used. The tympanometry read-out for an ear with a TM perforation is an estimate of the combined volume within the EAC and ME, which includes the tympanic cavity and the mastoid air cell system. The term "ME volume" refers to the volume of the air contained within the tympanic cavity (including the epitympanum, hypotympanum and protympanum) and the mastoid collectively. Thus, the ME volume in the perforated ear can be calculated as the difference of volumes between the ear with a perforated TM and the contralateral ear with a normal TM. We used the EAC volume in the contralateral normal ear to provide an estimate of the EAC volume lateral to the TM in the ear with a perforation.

CT ME volumes and the image analyzing software

All the CT examinations were done with a 16 slice multidetector CT scanner (GE light speed 16 pro, General Electric, Milwaukee, WI, USA). Scanning was performed in the standard axial plane with the helical technique (a FOV of 18 cm, a pitch of 0.562, a

rotation time of 1 sec, a section thickness of 0.625 mm and a matrix of 512×512). The patients were scanned in a supine position to obtain the image plane parallel to the orbitomeatal line. All the image data sets were transferred from the CT scanner to the PC workstation, and the data sets were analyzed using 3D medical imaging software (Rapidia v2.8, Infinitt Co., Seoul, Korea).

The area of the air-containing cavity was measured semi-automatically. A volume of interest (VOI) was applied manually to cover the unilateral temporal bone area on each slice. To define the air-containing cavity within the VOI, the software selects all the voxels between -1,024 and -100 HU. The threshold range was chosen to exclude the non-aerated portions such as bone and the soft-density tissue. The volume of the air-containing cavity at each slice was computed by clicking on the air cavity within the VOI. No manual post-processing of the segmentation results was performed. The total volume of the air-containing cavity was calculated as the sum of the volumes of the air-containing cavities of each slice.

Statistical analysis was performed with Wilcoxon signed rank tests for paired observations, and with using the Mann-Whitney U test for unpaired observations. Linear correlation analysis was performed between the ME volumes obtained by tympanometry and those obtained by CT. A difference with a $P < 0.05$ was considered statistically significant.

RESULTS

Volumes of EAC

For the normal EAC group (N=100), the volumes (mean \pm SD) of the right versus the left EACs in the males (N=44) were 1.5 ± 0.4 mL vs. 1.4 ± 0.4 mL, respectively, and the volumes in the females (N=56) were 1.4 ± 0.2 mL vs. 1.4 ± 0.4 mL, respectively, and there was no significant difference between the males and females. There was also no significant difference between the right and left sides in both genders. The absolute value of the side differences of the EAC volumes from both ears were 0.2 ± 0.2 mL (first quartile=0.1 mL; median=0.1 mL; third quartile=0.3 mL; ranging from 0 to 0.7 mL). There was also no statistically significant difference of the EAC volumes between the different age groups (10's to 70's, N=196 ears, ANOVA, $P > 0.05$, Fig. 1). Overall, the volumes of the EACs were 1.4 ± 0.3 mL in 200 ears.

The volume of the EAC in the normal-side ear of the patients with a unilateral COM (N=44) was 1.4 ± 0.5 mL, and there were no significant differences when this volume was compared with those volumes from the normal EAC group.

ME volumes by tympanometry and CT

The ME volumes by tympanometry and CT in the lesioned ears were 1.5 ± 1.4 mL (range: -0.3-5.0 mL) and 1.1 ± 0.8 mL (range: 0-3.5 mL), respectively, and the ME volumes measured

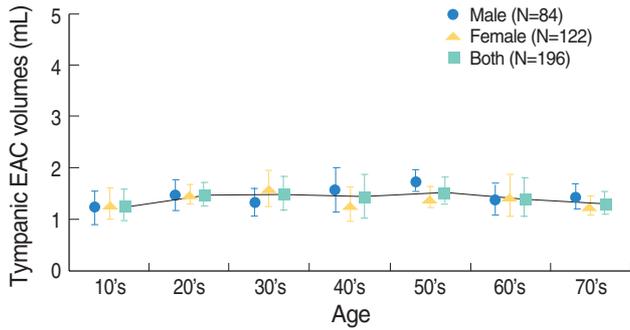


Fig. 1. The distribution of external auditory canal (EAC) volumes according to age group. There was no statistically significant difference in EAC volumes between age groups. The mean values are illustrated with error bars indicating ± 1 SD.

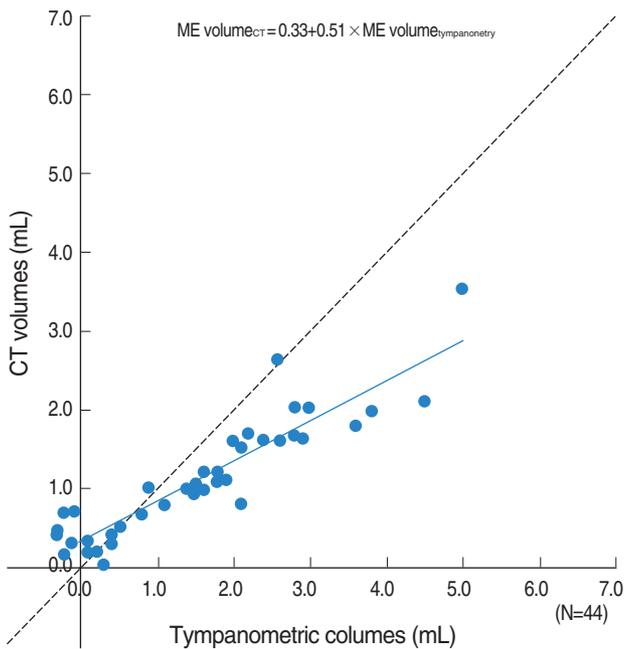


Fig. 3. The correlation of the middle-ear (ME) volumes measured by CT and tympanometry. The solid lines represent a best-fit linear regression line through the data points. Linear regression analysis gives a strong correlation coefficient ($R\text{-sq}=0.85$), and highly significant correlation ($P<0.001$). The dotted lines indicate a slope of 1 (CT volumes = tympanometric volumes).

by tympanometry in the lesioned ears were significantly larger than those obtained by CT in the lesioned ears ($P=0.001$, Fig. 2). The ME volumes by CT in the contralateral normal ears in the patients with unilateral chronic otitis media were 5.2 ± 3.1 mL (range: 0.6-13.4 mL) and they were significantly larger than those ME volumes of the lesioned ears that were measured by CT ($P<0.001$).

Fig. 3 shows the ME volumes obtained by tympanometry as plotted against the ME volumes obtained by CT. A strong significant linear correlation was found between the values, and the equation of the line was $\text{ME volume}_{\text{CT}} = 0.33 + 0.51 \times \text{ME volume}_{\text{tympanometry}}$ ($R\text{-sq}=0.85$; $P<0.001$ for the slope).

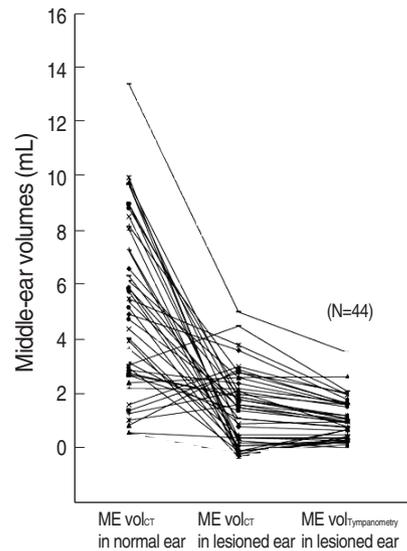


Fig. 2. Middle-ear volumes by tympanometry and CT.

DISCUSSION

The ME volumes in normal ears were reported to show a wide range, from 2 to 20 mL (2). It has also been reported that the average ME volumes in the normal ears, as measured using CT, were 5.6-7.9 mL, which is similar to our results (3-6).

Tympanometry is a method of measuring the volume contained within a closed air space (7, 8). It offers a clinically practical method for measuring the physical volume, in milliliters, of the air space medial to the sealed probe tip. However, it is known that commercial tympanometries are insensitive to volumes greater than 7 mL (1). When considering that the mean of the EAC volumes measured in the normal ears was 1.4 ± 0.3 mL, tympanometry cannot evaluate the combined volumes of the EAC and ME in a patient with a perforated eardrum in all cases. That is the reason why the tympanometric volume of the perforated ear had the highest value (7.2 mL) in seven patients of this study, and they were not included in this study because tympanometry reported a volume of 7.2 mL for any volume of that magnitude or larger. However, it has been reported that the mastoid size in the diseased ears of COM patients was smaller than that in the healthy controls (9). In this study, the ME volumes, as measured by CT, were 1.1 ± 0.8 mL in 44 ears with chronic otitis media, which were smaller than the normal values. Therefore, it is possible in most cases to measure the ME volume by tympanometry when evaluating a patient with a perforated TM.

It was reported that the size of the perforation is an important determinant of the hearing loss. Larger perforations result in a greater hearing loss, and this effect is present at all audiometric frequencies. It was also reported that the ME volume is also a determinant of hearing loss in the ears with TM perforations. Small ME volumes are predictive of larger air-bone gaps (1, 10). Identical perforations in two different ears are predictive of a conductive

hearing loss that can differ by up to 35 dB, if the ME volumes substantially differ (10).

In this study, linear regression analysis showed a strong correlation coefficient ($R\text{-sq}=0.85$) and highly significant correlation between the ME volumes obtained by tympanometry and CT. However, the ME volumes by tympanometry were significantly larger than those measured by CT. The slope of the line (<1) in Fig. 3 indicates a tympanometric overestimation of the ME volumes, and especially for the larger ME volumes. The larger the ME volume is, the greater is the overestimation by tympanometry. This overestimation of the ME volume through performing tympanometry can cause underestimation of the hearing losses, which was suggested by a previous report (1).

If the tympanometric volume is measured as 7.2 mL in an ear with a perforated TM, then it means that the ME volume estimated by tympanometry would be ≥ 5.8 ($7.2-1.4$) mL and the ME volume estimated by CT would be ≥ 3.3 ($0.33+0.51 \times [7.2-1.4]$) mL, where 1.4 is the estimated EAC volume from the normal group, according to our regression line. The EAC volumes from 200 normal ears were 1.4 ± 0.3 mL in this study.

It has been suggested that an ear with a ME volume greater than 7 mL would have had a tympanometric measurement that underestimated the actual volume, and this would lead to a model prediction that overestimates the hearing loss in that ear when 7 mL is used for the estimated ME volume (1). In our study, 7 patients had tympanometric volumes of 7.2 mL in the lesioned side, and their ME volume as estimated by CT would be 3.3 mL from the regression line in this study, and these patients showed a much higher mean ME volume by CT of 6.0 mL (range: 2.8-10.1 mL). This finding is consistent with a previous report (1).

In summary, tympanometry does represent the ME volumes with a strong correlation coefficient, although tympanometry was shown to overestimate the ME volumes in the ears with larger ME volumes. If the tympanometric volume is measured as 7.2 mL in an ear with a perforated TM, then the ME volume estimated by CT would be ≥ 3.3 mL, suggesting that the hearing loss would mostly come from other pathology than a reduced ME volume.

If the tympanometric volume is measured as less than 7.2, then the hearing loss can come from the size of the TM perforation, the reduced ME volume and other pathologies. The level of hearing loss due to the size of TM perforation and the reduced ME volume could be estimated more accurately if we combine the methods of this study with those of a previous report (1). If there is a large difference between the estimated hearing loss and the actual hearing loss in patients with a perforated TM, then we should expect to find additional pathology in the diseased ear.

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