Volume assessment of age-related conversion of the tympanic cavity by helical computerized tomography scanning

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ABSTRACT

Objective: To investigate the right-left asymmetry, and gender and age groups differences of the tympanic cavities (TC) using the Cavalieri principle for volume calculation on temporal bone computerized tomography (CT) scans.

Methods: This study was carried out over a 4-year period from 2000 to 2004 at Firat University, School of Medicine, Elazig, Turkey. The areas of the cavities were measured using trace and area measurement functions of CT scanner, and by multiplying the area by slice thickness (0.2 cm) and the volume of each slice was calculated. By summing all volumes of every slice based on the Cavalieri principle for volume calculation, the total volumes were obtained and analyzed.

Results: The mean (SD) volumes of right and left tympanic cavities in males were 0.52 (0.15) versus 0.55 (0.14) cm^3 and in females were 0.45 (0.16) versus 0.49 (0.14) cm^3, and there were statistically significant differences between males and females in both right and left sides (p=0.028 and p=0.043). There was a statistically significant difference in left TC volumes between age groups (p=0.019). However, no differences by age were noted for right TC volumes (p=0.065). A strong correlation was found between right and left volumes. However, there were no strong correlations between age and volumes of right and left cavities in both males and females, although the volumes increased by aging.

Conclusion: These results should help surgeons and radiologists to update their knowledge for evaluation of the middle ear region.

Saudi Med J 2004; Vol. 25 (10): 1378-1381

Tympanic cavity (TC) is a thin space in temporal bone. It communicates posteriorly with the mastoid antrum and via the mastoid air cells; anteriorly it communicates with the auditory tube. Also, it contains ossicle. The cavity has 2 parts: TC proper and epitympanic recess. While the vertical and anteroposterior diameters of the cavity, including the recess, are approximately 15 mm, the transverse diameter is approximately >6 mm and 4 mm below but opposite the umbo it is only 2 mm.[1-3] Due to its important anatomical neighborhood, the high prevalence of middle ear diseases in the population and surgery is the choice of treatment for those diseases in the majority; determination of size of TC may be beneficial for preparation against possible complications of ear surgery. Further developments in computed tomography (CT such as helical scanning, 3-dimensional temporal bone imaging and so forth) made the detailed imaging of the temporal bone.[4] This study was carried out to

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Received 21st March 2004. Accepted for publication in final form 12th May 2004.

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investigate the right-left asymmetry, and gender and age groups differences of the TC using the Cavalieri principle for volume calculation on temporal bone CT scans.

Methods. This study was carried out over a 4-year period, from 2000 to 2004 at Firat University, School of Medicine, Elazig, Turkey. For volume assessment of TC, 91 subjects with normal middle ears (47 males, ages between 7-49 years, and 44 females, ages between 6-55 years) were selected for this study from 317 patients who were performed temporal bone CT examination for identification of causes of their complaints on vertigo or tinnitus. Selection criteria were absence of any radiologically abnormal findings in temporal bone scans and of a history of congenital anomaly or other otological diseases. All patients were interviewed by an investigator, and the aim of the study and the procedure were explained in detail. They were not exposed to any excess radiation other than that necessary for investigating their underlying disease. Altogether, a total of 182 temporal bone CT examination was performed while patients were lying supine in the neutral position, in the axial plane, parallel to the infraorbitomeatal line, with 2 mm slice thickness using a bone algorithm. Window width was adjusted at 3636 and level was adjusted at +519. A ProSpeed helical CT scanner (General Electric, Milwaukee, Wisc, USA) was used. Scanning technique for this scanner was 120 kV, 150 mA, and 2 seconds scanning time. The areas of right and left tympanic cavities of each tomographic slice were determined by carefully tracing their outlines using the area measurement function of the CT scanner. For consistency and reliability of results, this procedure was carried out twice in each section by one of the authors (HY), and a mean value obtained. The volume of TC in each section was calculated by multiplying the area (cm^2) by slice thickness (0.2 cm). By summing all volumes of every slice based on the Cavalieri principle for volume calculation,[5] the total volumes of right and left TC were expressed in cubic centimeters as mean ± SD. We defined anatomical boundaries of TC in accordance with Gray's[6] definition as the tympanic membrane and its surrounding ring of bone laterally; the labyrinthine wall of TC, which presents the oval window and cochlea, the promontory, and the prominence of facial canal medially; the carotid wall of TC which corresponds with the carotid canal anteriorly; the mastoid wall of TC which presents the aditus to mastoid antrum, the pyramidal eminence, and the fossa of incus posteriorly; the tegmen tympani which is formed by a thin plate of bone superiorly; and the jugular wall of TC, which consists of a thin plate of bone which separates the tympanic cavity from the jugular fossa.

Student's t test was used to compare volumes between females and males before division into age groups. Comparisons of volumes between female and male subjects in each of the age groups were analyzed using Kruskal-Wallis test, followed by Mann-Whitney U test when significance was found. The correlation coefficients (r) among various parameters were calculated using Pearson's rank correlation and multivariate regression tests. All analyses were performed using SPSS 11.0 for windows software. The level for significance for all statistics was set at 0.05.

Results. The mean (±SD) volumes of right and left TC in males were 0.52 ± 0.15 versus 0.55 ± 0.14 cm^3 and in females were 0.45 ± 0.16 versus 0.49 ± 0.14 cm3, and there were statistically significant differences between males and females in both right and left sides (p=0.028 and p=0.043). Kruskall-Wallis test showed that there was statistically significant difference in left TC volumes between age groups (p=0.019). However, no differences by age were noted for right volumes (p values were not significant [NS]). The results in age groups for each side are presented in **Table 1**. There were strong correlations between right and

Table 1 - Volumes of right and left tympanic cavities in age groups (cm^3).

Age groups (years)	Right tympanic cavities volume						Left tympanic cavities volume					
	Male			Female			Male			Female		
	n	Mean ± SD	Range	n	Mean ± SD	Range	n	Mean ± SD	Range	n	Mean ± SD	Range
5-10	9	0.49 ± 0.15	0.29-0.70	9	0.39 ± 0.08	0.32-0.51	9	0.51 ± 0.14	0.29-0.72	9	0.42 ± 0.08	0.33-0.59
11-15	10	0.44 ± 0.06	0.36-0.55	9	0.42 ± 0.09	0.31-0.53	10	0.46 ± 0.08	0.36-0.65	9	0.44 ± 0.11	0.32-0.58
16-20	8	0.50 ± 0.18	0.29-0.76	9	0.49 ± 0.24	0.26-1.04	8	0.54 ± 0.13	0.32-0.70	9	0.49 ± 0.16	0.28-0.76
21-25	10	0.57 ± 0.17	0.38-0.94	8	0.46 ± 0.18	0.20-0.70	10	0.58 ± 0.11	0.43-0.82	8	0.56 ± 0.14	0.36-0.75
>25	10	0.60 ± 0.13	0.31-0.76	9	0.48 ± 0.18	0.25-0.88	10	0.63 ± 0.17	0.27-0.90	9	0.53 ± 0.18	0.27-0.88

left TC volumes in both males and females (r=0.79, $p<0.001$). On the other hand, multivariate regression analysis revealed that age was not a significant predictor of either right ($R^2=0.398$, p=NS) or left TC enlargement ($R^2=0.344$, p=NS).

Discussion. A TC has an endodermal origin and develops from the first pharyngeal arch. While tubotympanic fossa, which is the distal portion, is forming, primitive TC that is the expanded proximal portion, forms tuba auditiva.[7] In the 8 fetal months, embryonic mesenchyme is seen in the upper two-thirds of TC and it reduces gradually. At birth, the entire TC is filled with air.[8] It then enlarges and approximately 1.5 times as large in adults as in infants. The major factor in postnatal development of the volume of TC is vertical extension. The mean volume of TC in males shows a tendency to be larger than that in females.[9] The evaluation of TC by using CT provides important knowledge on volumetric changes.[10-12] Images obtained by helical CT scanning may be beneficial for screening before surgery in patients with TC diseases. We believe that the volumetric values of TC are important from the point of middle ear surgery. There is a little knowledge on age-related expansion of TC. Ito et al[13] found TC volume as 0.45 ± 0.07 cm^3 in 41 normal ears by using CT. Colhoun et al[14] found TC volume as 0.77 ± 0.14 cm^3. The results of our study are in agreement with these values. The results of our study also demonstrated that the volume of TC increases by aging but the correlation between age and volume was not strong. In addition, there was a strong correlation between right and left volumes. Ikui et al[9] found TC volumes as 0.64 ± 0.07 cm^3 in 8 normal left adult temporal bones and 0.45 ± 0.07 cm^3 in 6 infants, when measured using a computer-aided 3-D reconstruction and measurement method, which was developed to measure the volume and height of the TC in temporal bones obtained from individuals at death by them. They reported that there were no differences between values in males and in females statistically and also reported that the average cavity volumes in 8 adult cases were significantly larger than those in 6 infant cases. In contrast, we found that the mean volumes of TC in males were significantly larger than in females. The results of this study demonstrated that there were not strong correlations between age and volumes of right and left cavities in both males and females, although the volumes increased by aging. But infants were not included in our study. The difference of enlargement rate of TC between adults and infants may be due to the fact that TC enlarges significantly during childhood and does not significantly during adulthood. On the other hand, Ikui et al[9] have been studied only 14 temporal bones (7 from males and 7 from females), 6 from infants and 8 from adults. We think that this number of cases (especially related to infants) is insufficient for the statistical logic. Further studies with very number of cases should be conducted to identify the volume difference accurately between infant and adult tympanic cavity volumes.

Tos and Stangerup[15] found that a mean difference in size of the mastoid air cells between the largest and the smallest side was 18.6% of the mean size and also found that there was asymmetry between 2 sides in 75 from 79 children. In TC sizes, we also found surprisingly a similar finding suggesting the different of enlargement rate between 2 sides of middle ear by aging that left TC volumes were different between age group, although right volumes were not. We suggest that this asymmetrical enlargement rate can partly be explained by pathological changes of the middle ear mucosa and disturbance of the normal pneumatization process caused by upper respiratory tract infections resulting in unilateral acute otitis at the ages of TC development. In the present study, the subjects who have congenital anomaly or history of other otological diseases are excluded and this asymmetrical enlargement can be the results of middle ear infections, which some patients could not remember or history of subclinically otitis.

In conclusion, a strong correlation was found between right and left volumes. But, there was not strong correlation between age and volumes of right and left cavities in both males and females, although the volumes increase by aging. Although routine CT volume study is not necessary for healthy subjects, it may be useful for evaluating the middle ear volume in the patients who have ear pathology. The results of present study may be help surgeons and radiologist to update their knowledge for evaluation of the middle ear.

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