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Measurement of tympanic cavity volume by the Cavalieri principle in Turkish population

Türk toplumunda timpanik kavite hacminin Cavalieri yöntemiyle ölçülmesi

Ayla Kürkçüoğlu, M.D.,[1] Şefik Sinan Kürkçüoğlu, M.D.,[2] Hasan Mete İnançlı, M.D.,[2]
Murat Enöz, M.D.,[3] Can Pelin, M.D.,[1] Ragıba Zagyapan, M.D.[1]

[1]Department of Anatomy, Medicine Faculty of, Başkent University, Ankara, Turkey;
[2]Department of Otolaryngology, Ankara Oncology Education and Research Hospital, Ankara, Turkey;
[3]Department of Otolaryngology, Yenibosna Safa Hospital, İstanbul, Turkey

Objectives: The aim of this study is to measure the tympanic cavity (TC) volumes with Cavalieri principle using computed tomography (CT) scanning of temporal bones, to investigate the difference between the right and the left ears with respect to sexes and to exemplify the TC volume measurements.

Patients and Methods: Clinical records of 91 patients (46 females 45 males; mean age 48.1 years; range 15 to 60 years) whose TCs were measured at ear nose throat clinic of Ankara Oncology Education and Research Hospital between January 2007 and March 2008, were retrospectively investigated. The CT scans which were obtained from two sides with a slice thickness of 1 mm were evaluated. Measurements of TC volumes were made with using the Cavalieri method.

Results: The mean TC volume in male subjects was 0.4721±0.0406 cm^3 on the left ears and 0.4883±0.0352 cm^3 on the right ears. In females the mean cavity volume was 0.4943±0.0501 cm^3 on the left ears and 0.4881±0.0485 cm^3 on the right ears.

Conclusion: There was no statistically difference in between of the both sexes for the TC volume measurements and between both sites of the same individuals.

Key Words: Computed tomography; stereology; tympanic cavity volume.

Amaç: Bu çalışmada, temporal kemik bilgisayarlı tomografi (BT) görüntüleri kullanılarak Cavalieri yöntemiyle timpanik kavite (TK) hacim ölçümleri yapıldı, sağ ile sol kulak arasında ve cinsiyete bağlı bir fark olup olmadığı araştırılarak TK hacim ölçümleri örneklerle açıklandı.

Hastalar ve Yöntemler: Ocak 2007 - Mart 2008 tarihleri arasında Ankara Onkoloji Eğitim ve Araştırma Hastanesi Kulak Burun Boğaz Kliniği'nde TK ölçümleri yapılan 91 hastanın (46 kadın, 45 erkek; ort. yaş 48.1 yıl; dağılım 15-60 yıl) hastane kayıtları geriye dönük olarak incelendi. Hastaların iki taraflı 1 mm'lik kesitler halinde çekilen BT görüntülemeleri değerlendirildi. Cavalieri yöntemi kullanılarak TK hacim ölçümleri yapıldı.

Bulgular: Erkek bireylerde ortalama TK hacmi sol kulakta 0.4721±0.0406 cm^3, sağ kulakta ise 0.4883±0.0352 cm^3 olarak bulundu. Kadın bireylerde ortalama TK hacmi sol kulakta 0.4943±0.0501 cm^3 ve sağ kulakta ise 0.4881±0.0485 cm^3 olarak bulundu.

Sonuç: Timpanik kavite hacim ölçümleri bakımından her iki cinsiyet arasında ve bireylerin sağ ve sol taraf ölçümleri arasında istatistiksel fark görülmedi.

Anahtar Sözcükler: Bilgisayarlı tomografi; stereoloji; timpanik kavite hacmi.

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Correspondence / İletişim adresi: Hasan Mete İnançlı, M.D. Ankara Onkoloji Eğitim ve Araştırma Hastanesi Kulak Burun Boğaz Kliniği, 06200 Demetevler, Yenimahalle, Ankara, Turkey.

Tel: +90 312 - 266 74 09 Fax *(Faks):* +90 312 - 234 11 80 e-mail *(e-posta):* hminancli@yahoo.com

The tympanic cavity (TC) is a highly complicated anatomical structure. It is an aircontaining narrow chamber located in the petrous part of the temporal bone and is lined with mucous membrane. It transmits the vibrations from the external acoustic meatus to the inner ear via the tympanic membrane and the auditory ossicles.[1] The TC communicates with the mastoid antrum posteriorly via the aditus at the level of epitympanic recess, and anteriorly with the nasopharynx through the auditory tube. Including the recess, the vertical and anteroposterior diameters of the cavity are 15 mm each. The transverse diameter is 6 mm superiorly and 4 mm inferiorly; but at the level of umbo, it is only 2 mm.[2] Many structures pass through this space, and the irregularity of its inner walls make the TC a complex structure of the human body.[1] Since the prevalence of middle ear diseases is high in the population and surgery is the choice of the treatment in the majority of them, determination of the size and the normal volume of the TC gains importance not only for the surgical procedures, but also for treatment planning and evaluation of patients.[3,4]

Recently, it has become more popular to use intratympanic steroids in the treatment regimens of cochlear diseases. Transtympanic application of drugs started with Brayn's first administration of lidocain to the middle ear in 1935. Several authors since tried different drugs with the same application method for the treatment of the acute hearing loss.[5-7] The target organ for acute hearing loss therapy is the cochlea and the most effective way to reach it is to apply the drugs through the round window transtympanically. The most important predisposing condition for decreasing TC volume are frequent attacks of acute otitis media in early childhood. Middle ear inflammation due to otitis media causes eustachian tube closure and volumetric changes.[6,7] We believe that data on the volumetric value of the TC could be important in middle ear surgery and medical treatment. The literature review revealed that there are insufficient studies done in human subjects measuring the TC volumes and possible effects of its on otologic surgery or otologic medications.

Computed tomography (CT) scans can also be helpful before surgical therapies of diseases which involve the TC.[8-10] Computed tomography is very useful for evaluating the anatomy of many structures. Rapid developments in the scanning systems in recent years, particularly three dimensional scanning, have enabled more detailed studies on the temporal bone.[11,12] Computed tomography provides important information during the diagnostic stage before surgical operations performed on TC related disorders as well as for postoperative assessment.[13,14]

The objective of this study is to measure the TC volume of the temporal bone using the Cavalieri principle in temporal bone CT scanning, to investigate the difference between the right and the left parts with respect to sex and to exemplify the TC volume measurements for the patients.

PATIENTS AND METHODS

Bilateral CT images of 91 patients, (46 females, 45 males; mean age 48.1; range 15 to 60 years) were analyzed for purposes of this study. The mean ages of the patients in relation to their sexes are presented in Table 1. The means of the both sexes were statistically similar.

The CT scans were obtained from the archives of Otolaryngology Department of Ankara Oncology Education and Research Hospital for this retrospective study. These were patients admitted to the otolaryngology polyclinic whose CT scans didn't show any radiologic or anatomic abnormalities. Audiometric and tympanometric tests were obtained from all patients and were all within normal limits. The patients did not have any history of otologic compliants or diseases such as sudden hearing loss, acustic trauma, otosclerosis, presbyacusis or use of ototoxic medications. After CT evaluation, the patients that had tumors in their middle ears and the ones with anatomical variations were excluded.

Computed tomography images were obtained in the axial plane using a General Electric high speed CT apparatus. Anatomical boundaries of the TC were defined as; the tegmen tympani superiorly, the tympanic membrane and surrounding annular ring laterally, the the promontory medially, and the jugular bulb and carotid canal (separated by a thin bony plate) inferiorly. The posterior wall of the TC has a triangular shape, superiorly wider, that corresponds to the epitympanic cavity and aditus

Table 1. Mean ages of the patients with relation to sex

Sex	n	Mean age±SD
Male	45	50.3±15.3
Female	46	46.0±15.0

SD: Standard deviation.

ad antrum, the space joining the TC to mastoid antrum.[1] Altogether, a total of 91 temporal bone CT examinations were performed while patients were lying supine in the neutral position, in the axial plane, parallel to the infraorbitomeatal line, with 1 mm slice thickness using a bone algorithm.

The area of each topographic slice was delineated manually by tracing the outlines on printed images with a permanent marker. A point-grid with a point associated area of 0.0156 cm^2 was used to estimate the area of TC profiles (Figure 1a). Randomly positioned systematic points were counted when they hit the cavity profile, including the lines used for delineation. The volume of TC in each section could be calculated by multiplying the total number of points hitting all profiles of the TC from one individual by the slice thickness (1 mm) (Figure 1b). In the present study, volume estimation was accomplished by the Cavalieri's principle as described previously using the modified formula given below, which includes the magnification ratio calculation:

$$V = t \times [((SU) \times d)/SL]^2 \times \Sigma P$$

where, "t" is the section thickness, "SU" is the scale unit (the real length of the scale marked on the CTs), "d" is the distance between two points in the point grid, "SL" is the scale length (the actual measure of the scale on CTs) and "ΣP" is the total number of points counted for one individual. The expression [((SU) x d)/SL] gives the real area represented by each point at the original tissue level independent of magnification.

All data were entered in a previously-prepared Microsoft Excel spreadsheet for automatic calculation of both the results of the above formula and the statistical evaluation parameters concerning the sampling strategy, including the nugget variance, total variance and the coefficient of error (CE).[14]

The volume of TC in each section was calculated by multiplying the area (cm^2) by slice thickness (1 mm). All the volumetric calculations were done by using the Cavalieri principle. The volumes of the right and left TC were expressed in cubic centimeters as mean±SD.

Distributions of the variables were controlled by Shapiro-Wilk normality test and were normal. Variances of the groups were homogeneous according to Levene's test. Differences between left and right TC volume means according to sex and control groups were analyzed by a Three-Factorial Repeated Measures Analysis of Variance. Results were expressed as mean±SD. The analyses were performed by using the SPSS version 11.5 (Statistical Package for the Social Sciences, SSPS Inc., Chicago IL, USA).

RESULTS

The mean TC volume in male subjects was 0.4721±0.0406 cm^3 on the left side, and 0.4883±0.0351 cm^3 on the right side. In females, the mean cavity volume was 0.4943±0.0501 cm^3 on the left and 0.4881±0.0485 cm^3 on the right sides.

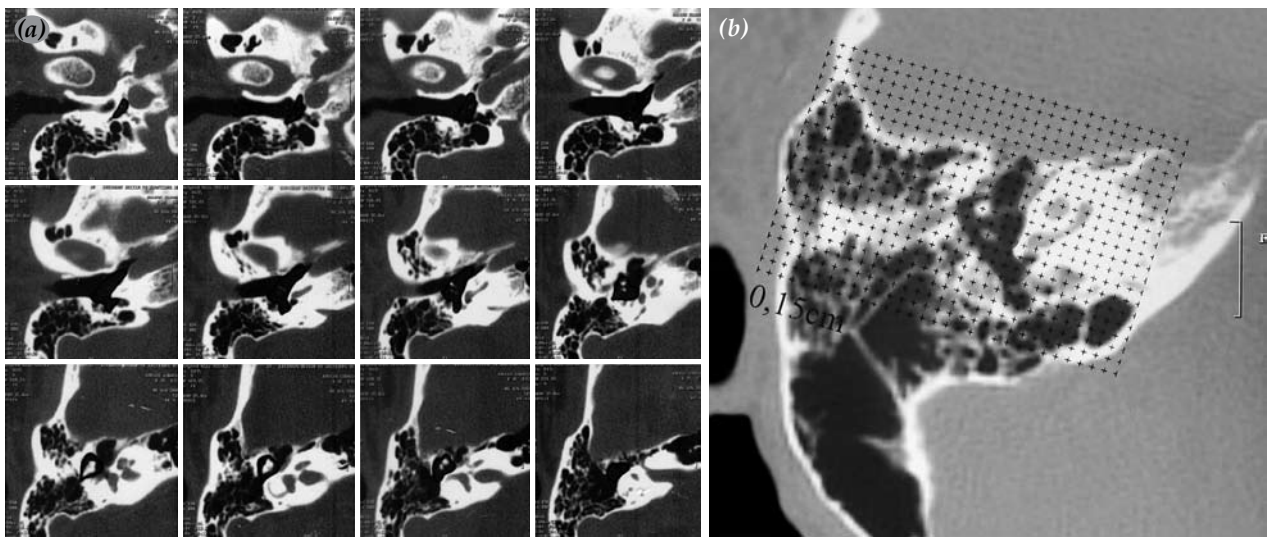

Figure 1. ***(a)*** *Computed tomography images of the right tympanic cavity in the axial plane.* ***(b)*** *Computed tomography scan (1 mm section) showing volume of tympanic cavity, the tecnique of counting points has been demonstrated on a axial tympanic cavity section via stereological methods*

Table 2. Means of left and right side tympanic cavity volumes (cm^3) in the patients with relation to sex

Sex	Left side Mean±SD	Right side Mean±SD
Male	0.4721±0.0406	0.4883±0.0351
Female	0.4943±0.0501	0.4881±0.0485

SD: Standard deviation.

There was no significant difference in TC volumes between sexes and between both ears. The results in these patients for each side are presented in Table 2.

DISCUSSION

The embryologic development of the middle ear originates from first pharyngeal pouch. While the distal tubotympanic fossa is forming, the primitive TC that is the expanded proximal portion, forms the tuba auditiva.[15] At birth, the entire TC is filled with air. It then enlarges and is approximately 1.5 times as large in adults as in infants. The major factor in postnatal development of the TC volume is vertical head extension. The mean volume of the TC in males shows a tendency to be larger than that in females.[16] Our study did not reveal any statistically significant difference in TC volumes between genders among adults.

Several techniques have been used for estimating TC volume in various studies.[14-18] Computed tomography is the most widely used technique for determination of the TC volume. Another method is the water filling method. Defalque et al.[17] measured the TC volume in a lion using the CT method, and in a dog using the water filling method, then compared the results of these methods to each other. The results obtained by the water filling method were found to be higher than expected when compared to the results obtained by CT, moreover the water filling method was disadvantageous as it could not be applied on living organisms although it was a fast and inexpensive method. They concluded that CT imaging was a more accurate choice for TC volume measurements.[17]

Ito et al.[19] measured the total and regional volume of pneumatization of the temporal bone in healthy individuals. In this study on CT images of 41 healthy individuals Ito et al.[19] determined the TC volume as 0.45±0.07 cm^3. Although the total TC volume was greater in males, no side difference was reported in both sexes. Upon completion of the study they stated that the total volume of the air cells did not have a correlation with the volume of the air cells located in the petrous apex, mastoid cavity and the TC.[19] When the findings of this study and the existent study are compared we can state that the numerical values related to the average TC volume are similar to each other whereas in our study we did not find any statistical difference with respect to sex and right-left parts.

In another study, Colhoun et al.[20] measured the TC volume in order to perform a radiological method comparison on cadavers. They reported the TC volume as 0.77±0.14 cm^3 in 26 human cadavers. These findings were observed to be similar to the findings of our existent study. Though, they were a bit higher than those of our study. It was reported that tissue distortion existed even in cadavers operated within the first 12 hours, that cadavers lost 1.5 Ibs (0.7 kg) a day and that such a loss affected the soft tissue measurement values.[21] In cadaver studies, the fact that TC volume values were somewhat higher than normal values, a result of soft tissue losses, is not surprising.[22]

In recent years a few studies used stereological techniques for the calculation of TC volume. Kavaklı et al.[4] determined the TC volume on helical CT scanning images by using Cavalieri's method in different age groups. The mean volumes of right and left tympanic cavities in males were 0.52±0.15 and 0.55±0.14 cm^3 while these values were 0.45±0.16 and 0.49±0.14 cm^3 respectively in females. The authors reported a statistically significant difference between the two sexes. However a strong correlation between right and left sides was observed in both males and females.[4] Ikui et al.[16] found TC volumes as 0.64±0.69 cm^3 in eight normal left adult temporal bones and 0.45±0.68 cm^3 in six infants, when measured using a computer-aided 3-D reconstruction and measurement method, which they developed to measure the volume and height of the TC in temporal bones obtained from individuals at death. They reported that there was no statistically significant difference between values in males and in females and also reported that the average cavity volumes in eight adults cases were significantly larger than those in six infant cases.[16] We also found no significant difference between male and female subjects. On the other hand all the subjects were adults and their mean ages were 46.00±14.95 in females and 50.29±15.30 in males.

In the present study, the TC volume of healthy individuals was found to be 0.4821±0.0407 cm^3 on the left and 0.4983±0.0451 cm^3 on the right sides of males. In females, the cavity volume was 0.5043±0.0521 cm^3 on the left side and 0.4980±0.0495 cm^3 on the right. Kavaklı et al.[4] also studied the same population. Although their results are similar to those of ours, the authors reported significant differences between the two sexes.

Tos and Stangerup[23] stuided the causes of mastoid air cells' asymmetries on 79 children. They found asymmetry in 75 of the subjects between both sides. The same differences were supported by Kavaklı et al.[4] The possible reasons for these differences are frequent acute otitis media attacks which possibly causes middle ear volume reduction. We could not found any asymmetry in our adult study group and the subjects who had acute otitis were excluded from the study.

In summary, we found that the TC volume values did not differ between genders and sides. We also found the Cavalieri method reliable for measuring the irregular volumes of the TC so we prefer to use this technique. We believe that the TC volume measurements of our study group could give an idea about the normal TC volume ranges of the Turkish population. Further studies are needed to explain to normal values TC volumes in differents populations and effects of its on otologic surgeries or other otologic interventions.

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