High Resolution Computed Tomography Analysis of the Human External Auditory Canal

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Abstract

Objectives*:* To accurately measure external auditory canal (EAC) dimensions by high resolution computed tomography (CT), determine demographic differences in EAC dimensions, and to compare with a traditional method of EAC measurement.

Study Design: Analysis of temporal bone CT scans with comparison to tympanometry.

Methods: Using an advanced multidimensional open source digital imaging and communications in medicine (DICOM) analysis program (OsiriX, Pixmeo, Geneva, Switzerland), 91 adult EACs were analyzed. Tympanometric data were also recorded for each ear. Demographic data were recorded. The methods were compared using a linear mixed effect model.

Results: EAC volume was compared between tympanometrically calculated volumes and CT measured volumes. It was found that CT measured volumes are, on average, smaller (1.12 cm^3, SE=0.04 cm^3) than tympanometry volumes (1.27 cm^3, SE=0.04 cm^3). There was a significant difference in CT measured volume between genders (p = 0.0125), with males having larger measured volumes (1.23 cm^3, SD = 0.28 cm^3) than females (1.06 cm^3, SD = 0.20 cm^3). There was a significant difference in average circumference between ear laterality (p = 0.0071), with the right ear having a slightly larger average circumference (2.49 cm, SD = 0.23 cm) than the left ear (2.44 cm, SD = 0.50 cm).There was also a significant difference in minimum circumference between age groups (p= 0.0448), with patients younger than 60 years having larger minimum circumferences (1.89 cm, SD =0.21 cm) than older patients (1.78 cm, SD = 0.25 cm).

Conclusions: This study demonstrates that CT analysis can provide more information about EAC dimensions than traditional techniques. Moreover, slight but statistically significant differences are associated with age, gender and laterality. Accurate estimation of EAC dimensions is important for the development of hearing aids and personal protective equipment and can also be helpful for surgical planning. Future research will focus on simplifying computation, as well as developing cross-cultural cohort comparisons.

Introduction

The human outer ear serves a vital role in the process of sound wave transmission. The lateral portion of the canal begins at the pinna, winds through the temporal bone and ends at the tympanic membrane, medially. Through its course, an s-shaped channel can be appreciated in the coronal plane. Due to this geometry, the measurement of the volume of the space requires consideration of the length, radius and its curved shape.[1]

Several methods have been described to accurately and precisely measure the volume and dimensions of the outer ear in a non-invasive fashion. These descriptions have included simple measurements from a head CT, measurements from a head CT adjusted in a formula as a correction factor, and using a computer program to create a three-dimensional model from two-dimensional images.[1,2,3] All of these methods have displayed different variations of accuracy and/or precision, but no measurement technique is currently considered the standard. To date, there has not been a method described that is inexpensive, accurate and efficient.

The goal of this study is to continue the work of comparing ear canal dimensions of different patient populations, while developing a method that uses an accessible, user-friendly, dimension measurement program. With this program, we were able to measure ear canal volumes, sagittal plane circumferences and roughly estimate ear canal lengths

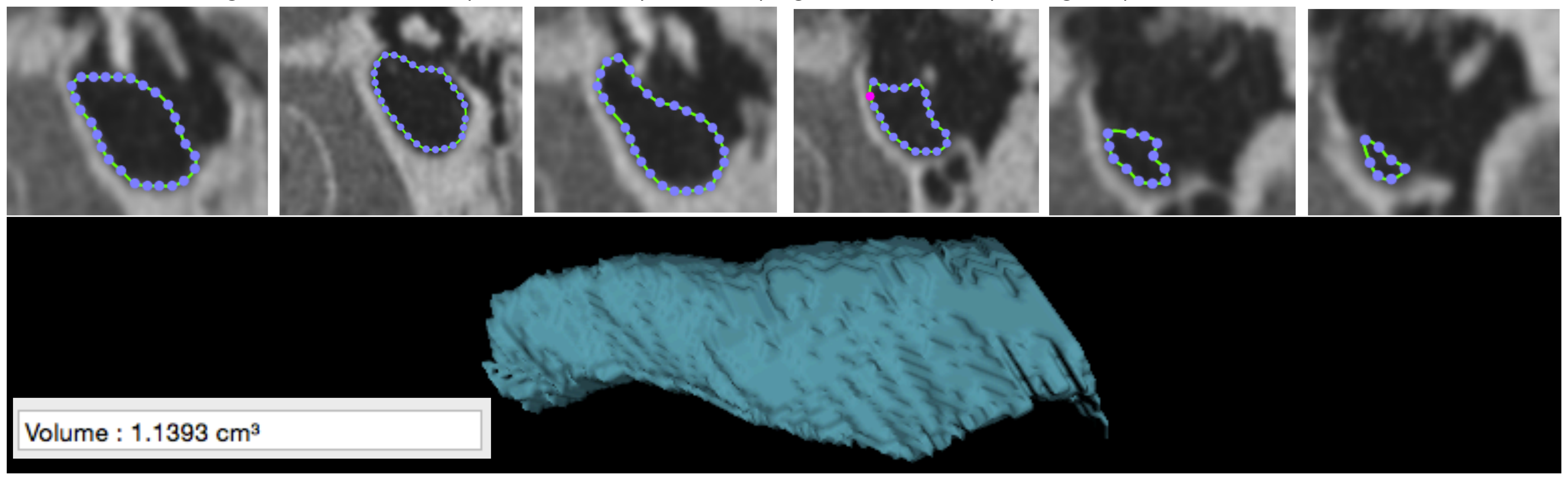
Materials and Methods

Participants:
46 participants were selected from a database of cochlear implant recipients at VCU Health Systems. Those who were selected had previously received a High-Resolution Temporal Bone CT scan by our neuroradiology department between January 2013 and December 2013, and also had audiometric testing performed in our clinic, which included tympanometrically measured ear canal volumes. The scans from 29 women and 17 men were analyzed in the study. The average age of patients was 60.5 years, with a range of 21-84 years. Inclusion criteria for the participants were that they were at least 18 years of age, had not previously had ear surgery, and did not have a diagnosed inner or outer ear malformation. The study was approved by Virginia Commonwealth University's Institutional Review Board.

Analysis:
The scans used for analysis were High-Resolution Temporal Bone axial CT scans performed by our neuroradiology department. The slice thicknesses were 0.6 mm. Both the right ear and left ear of each patient was measured. A total of 91 ears were measured. Each patient's CT Scan was analyzed using an advanced multidimensional open source digital imaging and communications in medicine (DICOM) analysis program (OsiriX, Pixmeo, Geneva, Switzerland) The program can be downloaded for free, and operates solely on a Mac operating system. One of the features of the program is the ability to create a 3D reconstruction of a volume manually traced on serial 2D scans. Once the 3D image has been rendered, the program can also calculate the volume of that image.

Measurement Method:
Measurements obtained included ear canal volume, sagittal plane circumference and an estimate of ear canal length. To make these measurements, DICOM sets for each patient were uploaded into OSIRIX. The lateral border of the ear canal measurement was the first bend, identified as the anterior-most aspect of the lateral portion of the canal when viewed in the axial image. The medial border of the canal was the tympanic membrane. Using OSIRIX, a sagittal image set was reconstructed from the axial images. Beginning from the lateral border of the canal, using the sagittal reconstruction, an outlining function was used to outline the border of the EAC (Figure 1). Moving medially, the border of the EAC was outlined on every other image slice until the medial border of the canal was reached. Once all of the outlines were created, the "lengths" (i.e. circumferences) of the EACs in each highlighted image were recorded. A 3D reconstruction was then created, and a volume was generated by the program (Figure 1). An estimate of length was calculated by multiplying the number of image slices outlined and the reconstructed image width.

Figure 1: A series of sagittal plane images, with an outline traced around the EAC, ending at the tympanic membrane (upper far right). Below, a 3-dimensional rendering of an external auditory canal created by the Osirix program, with a corresponding computed volume.



Results

Analysis by ear
Ear canal dimensions were compared between ear laterality. There was no evidence of a difference between left and right ears in tympanometry volume, measured volume, length, maximum circumference, or minimum circumference. There was a statistically significant difference in average circumference between ears (p = 0.0071), with the right ear having slightly larger average circumference (2.49cm, SD = 0.23cm) than the left ear (2.44cm, SD = 0.50cm). Table 1.

Analysis by gender
Dimensions were compared between genders. There was no evidence of a difference between females and males in tympanometry volume, circumference, maximum circumference or minimum circumference. There was a significant difference in measured volume between genders (p = 0.0125), with males having larger measured volume (1.23 cm^3, SD = 0.28) than females (1.06 cm^3, SD = 0.20). There was a significant difference in estimated length between genders (p = 0.0008), with males having longer lengths (1.40 cm, SD = 1485) than females (1.26 cm, SD = 1259). Table 2.

Analysis by age
Dimensions were compared between groups aged less than 60 years old and those 60 years old and older. There was no evidence of a difference between older and younger patients in tympanometry volume (mean: 1.32 and 1.24 cm^3), measured volume (mean: 1.10 and 1.14 cm^3), length (mean: 1.30 and 1.32 cm), mean circumference (2.45 and 2.48 cm), or maximum circumference (3.35 and 3.69 cm). There was a significant difference in minimum circumference between age groups (p= 0.0448), with younger patients having larger minimum circumferences (1.89 cm, SD =0.21) than older patients (1.78 cm, SD = 0.25). Table 3.

Analysis of tympanometry vs. measured volumes
Because each patient had also received a tympanometrically measured ear canal volume, we also compared these volumes and the volumes measured using the 3D reconstruction. There was a significant difference between tympanometry measured and CT measured volumes (p = 0.0007), where CT measured volumes are on average smaller (1.12 cm^3, SE=0.04) than tympanometry volumes (1.27cm^3, SE=0.04).

Table 1: Volumetric Summaries by Ear

	Left Ear (N = 46)				Right Ear (N = 45)			
	Mean	SD	Min	Max	Mean	SD	Min	Max
Tymp Volume (cm^3)	1.25	0.39	0.50	2.30	1.30	0.48	0.60	2.80
CT measured Volume (cm^3)	1.11	0.26	0.53	1.90	1.14	0.24	0.67	1.77
Length (mm)	13241	1568	10000	17570	13009	1415	10000	15791
Mean Circumference (cm)	**2.44**	**0.50**	**1.81**	**3.11**	**2.49**	**0.23**	**1.92**	**3.01**
Max Circumference (cm)	3.54	0.79	2.23	6.46	3.53	0.66	2.33	5.32
Minimum Circumference (cm)	1.81	0.24	1.15	2.22	1.85	0.24	1.27	2.27

Table 2: Volumetric Summaries by Gender

	Females (N = 58)				Males (N = 33)			
	Mean	SD	Min	Max	Mean	SD	Min	Max
Tymp Volume (cm^3)	1.28	0.48	0.50	2.80	1.26	0.35	0.60	2.30
CT measured Volume (cm^3)	**1.06**	**0.20**	**0.53**	**1.54**	**1.23**	**0.28**	**0.62**	**1.90**
Length (mm)	**12632**	**1259**	**10000**	**15003**	**13994**	**1485**	**11426**	**17570**
Mean Circumference (cm)	2.43	0.21	1.89	2.92	2.53	0.28	1.81	3.11
Max Circumference (cm)	3.48	0.73	2.23	6.46	3.65	0.72	2.31	5.45
Minimum Circumference (cm)	1.84	0.23	1.25	2.22	1.83	0.27	1.15	2.27

Table 3: Volumetric Summaries by Age

	Under 60 (N = 40)				60 and Over (N = 51)			
	Mean	SD	Min	Max	Mean	SD	Min	Max
Tymp Volume (cm^3)	1.32	0.39	0.70	2.60	1.24	0.46	0.50	2.60
CT measured Volume (cm^3)	1.10	0.22	0.62	1.54	1.14	0.27	0.53	1.54
Length (mm)	12954	1395	10019	16094	13261	1562	10000	16094
Mean Circumference (cm)	2.45	0.21	1.81	2.92	2.48	0.26	1.89	2.92
Max Circumference (cm)	3.35	0.56	2.31	5.45	3.69	0.81	2.23	5.45
Minimum Circumference (cm)	**1.89**	**0.21**	**1.42**	**2.27**	**1.78**	**0.25**	**1.15**	**2.27**

Discussion

This project is a preliminary feasibility study that describes a unique and simple method for measuring ear canal dimensions. Accurate measurement of ear canal caliber, length, and shape can have numerous clinical applications as subtle anatomic variations may have implications for sound transmission. The design of personal protective equipment, commercially available water plugs, headphones, and other ear canal devices would benefit from improved understanding of ear canal dimensions. These data suggest that subtle, but significant differences exist within even a relatively small cohort when compared with traditional ear canal volume measurement techniques. Certainly variations in ear canal dimensions amongst different ethnic groups could be of importance in the design and function of amplification devices .[3]

Improved understanding of canal anatomy may also assist in the planning of trans- or endaural surgical approaches, particularly endoscopically assisted procedures. In patients with curved or smaller caliber ear canals, the space required may be insufficient to accommodate both scope and instrumentation. In knowing ear canal architecture pre-operatively, microscopic (rather than endoscopic) intervention may be the preferable approach in order to minimize operative time and complications.

Future studies with international collaborators will be aimed at establishing normative data, and comparing with homogenous cohorts of other ethnic groups. Additionally, our group intends to further define the CT characteristics most critical for successful endoscopic transcanal surgery.

Conclusion

This project describes a new method for analyzing external auditory canal dimensions. The methods are both accessible and relatively simple, and the applications are numerous. We believe that this foundational study can be applied to many future studies exploring endoscopic ear surgery outcomes, variations of ear canal dimensions among patient demographics, the correlation between ear dimension and pathologies, as well as the design of personal protective equipment and hearing aids.

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