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ORIGINAL ARTICLE

Middle ear morphology and mastoid pneumatization: a computed tomography study

Bernardo Alfonso Fernández-Reyes et al., **Middle ear morphology and mastoid pneumatization**

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ABSTRACT

Background: Mastoid pneumatization is subject to numerous influencing factors including race, sex, and surrounding structures of the middle ear. This study aims to determine the mastoid air cell system (MACS) volume and its relationship with middle ear structures, and the influence of sex.

Materials and methods: A cross-sectional study was performed analyzing computed tomography (CT) scans in which MACS volume and the Estachian tube length (ETL) were visible. MACS volume, ETL, and width and height of the aditus ad antrum were obtained.

Results: A total of 100 CT were included with a mean age of 38.5 ± 15.3 years, of which 56 were women and 44 were men. The mean right and left MACS volume were 5.43 ± 3.15 cm^3 and 5.54 ± 3.43 cm^3 respectively , with a ETL of 24.55 ± 3.07 mm in right side and 24.24 ± 2.60 mm on left side. A aditus ad antrum width of 2.98 ± 0.65 in right and 2.98 ± 0.58 on the left and height of 4.51 ± 1.05 and 4.32 ± 0.85, on right and left side respectively. There were statistical differences between sexes in left ETL, and in MACS volume bilaterally. A low positive correlation between aditus ad antrum height and MACS volume was identified.

Conclusions: Mastoid pneumatization was bigger in men than women. There was a low positive correlation between mastoid volume and ETL on both sides, and a significant correlation between right mastoid volume and aditus ad antrum height. This could lead us to believe that the length of ETL does not affect the pneumatization of MACS.

Keywords: mastoid air cell system, aditus ad antrum, Eustachian tube, middle ear, anatomy

INTRODUCTION

The mastoid process is a prominent structure of the temporal bone and contributes to middle ear ventilation [6, 16, 35]. Its interior is variably pneumatized and can be described with large (anatomically constant) air cells known as the antrum, surrounded by smaller mastoid air cells [4, 31, 44]. The complete development occurs at the age of 10 in women and 15 in men ([2, 33, 34, 45]. Several factors may influence Mastoid air cell system (MACS) pneumatization: genetics, environment, nutrition, diseases, and anatomical structures are related [1, 8, 27, 40]. Although MACS function remains unclear, it plays an important role in gas exchange [15, 28, 32, 39, 42].

MACS can be affected by air pressure in the nasopharynx through the Eustachian tube (ET) [13, 45]. The ET is composed of a cartilaginous and a bony section. The isthmus is where these 2 portions connect and is considered a surgical limiting point [7, 12, 19, 20].

Patients with ET dysfunction have been described as having significantly smaller air cells, creating a positive correlation between mastoid volume and ETL [7, 12, 22, 45]. Previous studies have reported that a small mastoid, with short length and horizontal angle of the ET may influence the appearance of otitis media [11, 19, 36]; similarly, frequent pathologies in the middle ear decrease the volume of MACS [18, 46]. The aditus ad antrum is a triangular space between the epitympanic recess and the mastoid antrum. This orifice also contributes to the aeration of mastoid air cells, if this space gets obstructed it could predispose or accentuate middle ear pathologies [3, 23, 24, 44]. Despite their anatomical relationship to middle ear diseases, there is lacking evidence of anatomically statistical differences with otitis media [11, 25, 36, 43]. This study aims to determine normal values of MACS volume and its relationship with ETL, width and height of aditus ad antrum, and the influence of sex.

MATERIALS AND METHODS

A retrospective, cross-sectional study was designed, obtaining computed tomography (CT) studies from the database of the Radiology and Imaging Department. Screening encompassed consecutive cases of patients aged between 18 and 60 years who had undergone a head and neck CT scan, as ordered by their attending physician, for the assessment of diverse head and neck conditions, including sinusitis, or unrelated pathologies not pertinent to the area of interest. Patients with ossicular chain defects, cholesteatoma, tympanosclerosis, atelectasis, chronic otitis media, a history of temporal bone fracture, chronic Eustachian tube dysfunction, previous middle ear surgical intervention, cleft palate, or any pathology that modified the anatomy of the adjacent area were excluded from the study. Studies with abnormalities, artifacts, or poor quality were eliminated. This study adheres to the STROBE guidelines for the report of original observational studies [10].

Study technique

The head CT scans were performed using a General Electric Light Speed VCT64-slice CT (General Electric, Milwaukee, WI, USA) with a helical rotation scan of 0.4 seconds and slice thickness of 0.625mm. The reformatting program Volume Rendering (software number: 12HW14.6_SP1-1-1V40_H_H64_G_GTL) was used to subsequently make a bony reconstruction. To visualize the images, a 3D workstation Carestream VUE-PACS (software version 11.2.1.0) was used. CT scans were later uploaded to the Lifex software for their segmentation. The images and measurements were assessed independently by two radiologists and recorded in a database using millimeters with two decimal unit precision.

Morphometric parameters

Definition and anatomical fundamentals for interpretation of the mastoid and ET measurements through CT scan have been described.

- MACS: Using a threshold of –1024 Hounsfield units (HU) and an upper threshold of –200 HU to represent the mastoid air cell tracts [21].
- ETL: Distance Between the medial end of the bony portion of the ET and the tip of the torus lip (14) (Fig. 1).
- Aditus ad antrum height: was measured by taking up-down distance using a sagittal plane (29) (Fig. 2).
- Aditus ad antrum width: was measured by the left and right distance using a coronal plane (29) (Fig. 3).

Statical analysis

Sample size calculation was made with the formula for estimating a mean in an infinite population with a power of 97.5%, a confidence of 95%, and a margin of error of 5% resulting in a total of 130 mastoid processes. Central tendency and dispersion data were obtained for the sample variables, performing Kolmogorov-Smirnov test for normality. The comparisons between the different groups for the categorical variables were made by Pearson's Chi-Square test. Due to the normality distribution of sample data, the comparison between sex groups was made with a two-tailed Student T-test. The mean difference and the corresponding 95% confidence interval (CI) were obtained. Correlation tests were performed by Pearson correlation coefficients and the coefficient of determination also was calculated. Furthermore, the inter-observer agreement was assessed by the intraclass correlation coefficient. The values for ICC were interpreted as poor (< 0.40), weak (0.40–0.59), good (0.60–0.74), or excellent (0.75–1.00). A p-value of < 0.5 was considered statistically significant. The database was analyzed using the SPSS Version 26.0 program for Windows 10 Pro (IBM, Armonk, NY, USA).

Ethical considerations

This study was previously reviewed and approved by the University's Ethics and Research Committees with the registration number AH20-00004, making sure it adheres to the Helsinki Declaration, as well as national and international standards of research. The authors declare no financial or commercial gain for the realization of this study. The authors declare no conflict of interest. None of the imaging studies were performed for the purposes of this study.

RESULTS

A total of one hundred CTs were included, with a mean age of 38.5 ± 15.3 years, 56 were women (39.0 ± 13.9 years) and 44 were men (37.8 ± 17.2 years). All sets of inter-observer reliability analyses resulted in substantial reliability (ICC >0.85). Descriptive statistics of the measurements stratified by sex are shown in Table 1. Statistically differences between sexes were identified in left ETL, right and left MACS volume.

The left ETL mean was 25.28 mm (range 20–30.8 mm) for men and 23.42 mm (range 19.1–30 mm) for women. The mean difference was 1.86 mm (95% CI, 0.88–2.84; p = < 0.001). The right MACS volume mean was 6.2 cm^3 (range 0.9–16.6 mm) for men and 4.82 cm^3 (range 0.7–12 mm) for women. The mean difference was 1.38 cm^3 (95% CI, 0.15–2.62; p = 0.03). The left MACS volume mean was 6.43 cm^3 (range 0.9–18.1 mm) for men and 4.84 cm^3 (range 1–12.1 mm) for women. The mean difference was 1.59 cm^3 (95% CI, 0.24–2.93; p = 0.03).

Pearson's correlation coefficient between variables are shown in Tables 2 and 3. A statistically significant and weak positive correlation between Aditus ad antrum height and MACS (r = 0.26; r2 = 0.06) was identified.

DISCUSSION

The volume of the MACS and ETL were measured and stratified by sex. Men had a higher volume on both sides and a longer left ET than women as Falkenberg-Jensen et al. [14] and Yegin et al. [45], unlike Lee et al. [27] who did not find statistical differences between sexes. On both sides, positive and negative correlations between MACS volume, ETL, and aditus ad antrum width and height were found in this study, however, these were low in all the cases as Yegin et al. [45] except between right MACS volume and AAH, which had a significant correlation.

The mastoid volume variation could be influenced by age, genetics, and the pathologic involvement of the middle ear [38–40]. This last one appears to be more crucial. The degree of the middle ear disease affects the variation of mastoid pneumatization. The exclusion of these patients could improve the understanding of the anatomical factors in mastoid pneumatization.

Falkenberg-Jensen et al. [14] measured the ETL defined as the distance between the medial end of the bony portion of the ET and the tip of the torus lip. The mean and standard deviation were 26.8 ± 2.1, 26.6 ± 2.0, and 26.7 ± 2.1mm for left, right, and both sides respectively. There was no statistically significant difference between sides. They had similar results to ours, in that women had shorter lengths than men. We found a similar result in MACS volume as those in the literature [45]. Men had a higher volume than women on both sides. Curiously, it has been described that the mastoid air cell system is bigger in women until puberty, it may be due to the earlier physical growth [5].

Yegin et al. [45] studied the relation between the volume of the MACS and the length and angle of the PT. They divided it into 3 groups depending on the degree of pneumatization, with similar results. They report a positive and statistically significant correlation between MACS and ETL ($r = 0.159$, $p = 0.002$), and assume that MACS is decreased by a shorter ET, similar to our findings. However, the evidence is still lacking and the correlation between these two variables can only be hypothesized.

Takasaki et al. [41] analyze the ETL of normal adults without Otitis media with efussion using CT scan in healthy adult ears. ETL was 42.5 ± 62.8 and 42.9 ± 62.9mm for the right and left ear, respectively. This difference may be due to the inclusion of the bony portion of the ET, similar to Yegin et al [45].

Chronic otitis media may delay mastoid air cell system development [1]. In a study made by Csakanyi et al. [9], results show children with otitis media had a significantly lower volume of MACS, when compared with healthy children, 2.82 ± 1.51 vs. 10.05 ± 5.3 mL. Previous studies speculate that a short ETL influences the appearance of otitis media. Despite their anatomical relationship, results indicate there is no statistical difference between ETL of patients with and without otitis media [11]. Even though results demonstrate a positive correlation between MACS and ETL, it isn't strong enough to establish an influence in mastoid volume and its possible contribution to the development of disease.

Variations in mastoid pneumatization, influenced by factors such as age, genetics, and middle ear pathologies, hold significant clinical implications [1, 2]. Patients with underdeveloped mastoids may encounter surgical challenges, including limited exposure. Conversely, excessive pneumatization can complicate surgical access and heighten the likelihood of complications like facial nerve injury [13–15, 19]. Therefore, in surgical procedures involving the temporal bone, preoperative assessment of mastoid pneumatization is critical for planning and risk assessment [13, 45]. Surgeons need to anticipate anatomical variations to minimize intraoperative complications and optimize outcomes for their patients [19, 39].

The mastoid air cell system plays a role in middle ear function by regulating ventilation and pressure. Disruptions in pneumatization can disturb this balance, potentially resulting in conditions like eustachian tube dysfunction and recurrent middle ear infections [11, 45]. Clinicians must factor in mastoid pneumatization when devising treatment plans for affected patients. Furthermore, accurate interpretation of radiological findings regarding mastoid pneumatization is essential for diagnosing and managing otologic conditions [21].

The importance of cartilaginous ETL has not been stressed enough, which is the site of the balloon dilatation approach for ET dysfunction [12, 26]. The preferred position to place the balloon is in the cartilaginous portion and it is the target in balloon treatments, even though there is controversy if it can harm the carotid artery if it is dilated in the bony part [14, 30, 31]. Our results show that the left ETL is 25.28mm (range 20–30.8 mm) for men and 23.42 mm (range 19.1–30 mm) for women. The balloon dimensions are 3 mm wide and 20 mm large [37]. Considering the ETL in both men and women, it is enough for the placement of the balloon before the bony portion. Even though it is safe we recommend a previous radiological study before the procedure. Anatomical studies help create safety parameters for these types of interventions as well as other structures that may be at risk [17, 43]. The variabilities and similarities between populations and previous studies can be seen in Table 4.

Our study has some limitations. We did not compare between ages and the patients' anthropometric characteristics were not included in the analysis. The study was conducted using Hispanic patients, however, larger samples are needed to make a comparison between different populations. Due to the design of this study, there may be some errors from individual variation.

CONCLUSIONS

The volume of the mastoid air cells system can be obtained by CT 3D reconstruction. The MACS was greater in men than women, with a low positive correlation between MACS and ETL on both sides. There was a significant correlation between the MACS and the aditus ad antrum height, but only in the right side. This could lead us to believe that the ETL does not affect the pneumatization of the MACS

Article information and declarations

Data availability statement

Data and material are available if revision is necessary.

Ethics statement

This study was previously reviewed and approved by the University's Ethics and Research Committees with the registration number AH20-00004, making sure it adheres to the 1964 Helsinki declaration, and national and international standards of research.

Author contributions

All authors contributed to the study conception and design, specifically Bernardo Alfonso Fernández-Reyes, Alejandro Quiroga-Garza, Francisco Javier Arrambide-Garza and Santos Guzmán-López. Material preparation, data collection and analysis were performed by Pamela Garza-Baez, and Francisco Javier Arrambide-Garza. The first draft of the manuscript was written by Santos Guzman-Lopez, Alejandro Quiroga-Garza, and Mario Campos-Coy, and all authors commented on previous versions of the manuscript. All authors read and approved the final manuscript, with the final revision by Alejandro Quiroga-Garza, Jose Luis Treviño-González, and Rodrigo Enrique Elizondo-Omaña.

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Conflict of interest: The authors declare that they have no relevant financial or non-financial interest to disclose.

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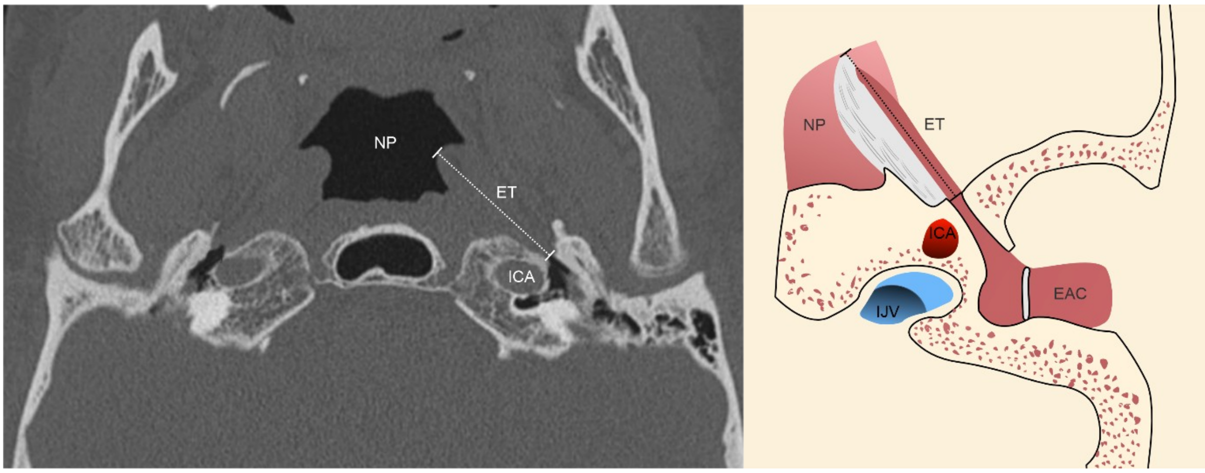

Figure 1. Represantive case of Eustachian tube length Measurment. **A.** Axial view of head CT in bone window, white dotted line marks the measurment used for Cartilaginous ETL. **B.** Schematic Illustration of axial view of head. Black dotted line marks the ETL; EAC — external auditory canal; ET — Eustachian tube; ICA — internal carotid artery; IJV — internal jugular vein; NP — nasopharynx.

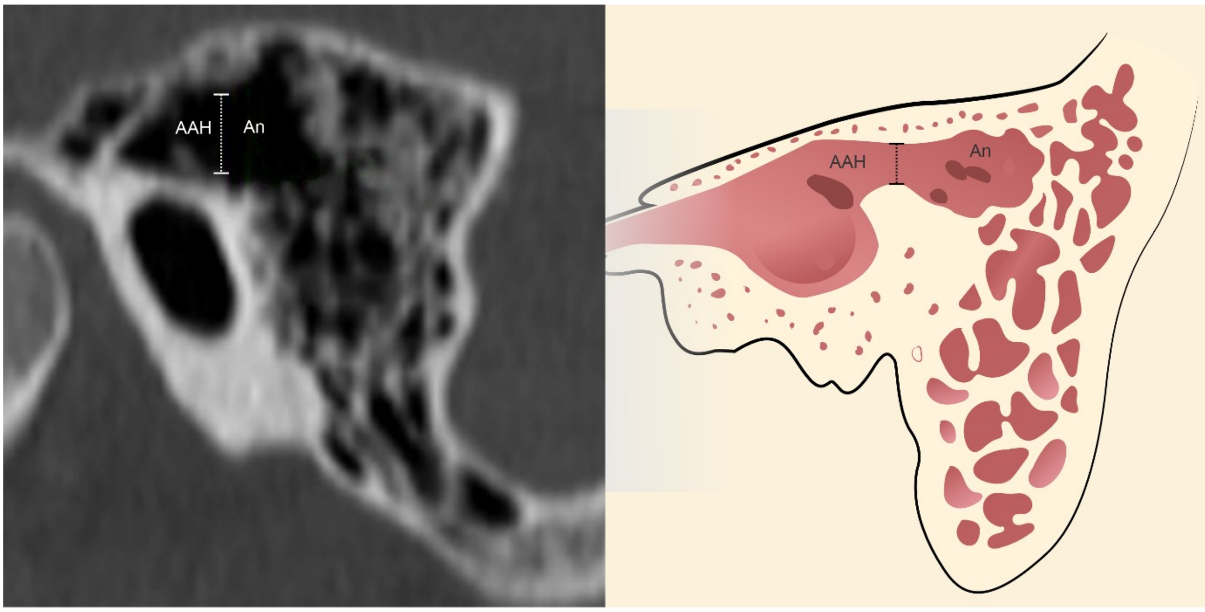

Figure 2. Representative case of aditus ad antrum height measurement. **A.** Parasagital view of head CT, white dotted line marks the measurment used for aditus ad antrum height. **B.** Schematic illustriation of parasagittal view of head black dotted line marks the aditus ad antrum height. AAH — Aditus ad Antrum Height, An — Antrum.

Table 1. Comparative of the measurements stratified by sex

	Measurement	General (n = 100) Mean ± SD	Women (n = 56) Mean ± SD	Men (n = 44) Mean ± SD	P-value
Right	**MACS**	5.43 ± 3.15	4.82 ± 2.39	6.2 ± 3.8	0.03*
	ETL	24.55 ± 3.07	24.02 ± 3.40	25.23 ± 2.46	0.05
	AAH	4.51 ± 1.05	4.41 ± 1.01	4.65 ± 1.08	0.26
	AAW	2.98 ± 0.65	3.02 ± 0.69	2.92 ±.61	0.44
Left	**MACS**	5.54 ± 3.43	4.84 ± 2.48	6.43 ± 4.21	0.03*
	ETL	24.24 ± 2.60	23.42 ± 2.42	25.28 ± 2.48	< 0.001*
	AAH	4.32 ± 0.85	4.22 ± 0.88	4.64 ± 0.8	0.16
	AAW	2.98 ± 0.58	2.93 ± 0.64	3.04 ± 0.5	0.35

Values are expressed in millimeters for distances and cubic millimeters for volumes. Independent-sample T-student tests were used for compared measurements between sexes; *statistically significant ($p < 0.05$); AAH — Aditus ad Antrum Height; AAW — Aditus ad Antrum Width; ETL — Eustachian Tube Length; MACS — mastoid air cell system; SD — standard deviation.

Figure 3. Representative case of aditus ad antrum width measurement. **A.** Axial view of head CT in bone window, white dotted line mark the measurment used for of aditus ad antrum width. **B.** Schematic illustriation of axial view of head black dotted line mark the width of aditus ad antrum. AAW — aditus ad antrum width; TM — timpanic membrane; SC — semicircular canal; An — Antrum; Co — Coclea; Oss — Ossicles.

Table 2. Pearson's correlation coefficient between measurements of the right side

	MACS	ETL	AAH	AAW
MACS		0.06	0.26*	–0.13
ETL			–0.10	–0.04
AAH				0.51
AAW				

*statistically significant.

Table 3. Pearson's correlation coefficient between measurements of the left side

	MACS	ETL	AAH	AAW
MACS		0.05	0.165	0.07
ETL			0.034	0.091
AAH				0.63
AAW				

*statistically significant; AAH — aditus ad antrum height, AAW — aditus ad antrum width; ETL — Eustachian tube length; MACS — mastoid air cell system.

Table 4. Comparison with other authors

Author, Country, Year	N	Age	RMV	LMV	RETL	LETL	RAAH	LAAH	RAAW	LAAW
Colhoun et al., Wales, 1988 [31]	26	NR	$8.4 \pm 3.6^{*}$		NR	NR	NR	NR	NR	NR

Isono et al., Japan 1999, [32]	43	NR	5.97*		NR	NR	NR	NR	NR	NR
Park et al., Korea, 2000 [33]	24	20–53	10.43 ± 4.66*		NR	NR	NR	NR	NR	NR
Luntz et al., Israel, 2001, [34]	69	NR	6.63 ± 2.67	6.59 ± 2.76	NR	NR	NR	NR	NR	NR
Lee et al., Korea 2005 [26]	102	19–44	7.09*		NR	NR	NR	NR	NR	NR
Takaski et al., Japan, 2007 [28]	45	18–82	NR	NR	42.5 ± 2.8‡	42.9 ± 2.9‡	NR	NR	NR	NR
Csakanyi et al., Hungary 2011, [29]	40	2–18	10.05 ± 5.3*		NR	NR	NR	NR	NR	NR
Kim et al., Korea, 2010 [35]	60	18–63	6.239	6.695	NR	NR	NR	NR	NR	NR
Long et al., China 2012 [25]	90	NR	NR	NR	NR	NR	5.74 +/– 1.16*		5. 19 +/– 1.39*	
Bahgat et al., Egypt 2014 [19]	50	28.15 ± 7.62	NR	NR	NR	NR	7.16(1.92)*, #		5.16 (1.92)*, #	
Kaymakçı et al., Turkey, 2015 [36]	30	17–50	9.10 (3.09)†	8.62 (2.96)†	NR	NR	NR	NR	NR	NR
Cros et al., Denmark, 2016 [37]	8	NR	9.4 (2.7–13.6)*		NR	NR	NR	NR	NR	NR

Allam et al., Egypt, 2016 [38]	80	32.8 ± 12.98 (M) 28.9 ± 10.1 (F)	13.09 ± 3.6 (M)* 8.43 ± 3.3 (F)*		NR	NR	NR	NR	NR	NR
Yegin et al., Turkey, 2016 [4]	217	33.14 ± 12.88	6.52 ± 2.76 (M)* 5.64 ± 1.98 (F)*		46.54 ± 10.18 (H)*, ‡ 42.20 ± 8.42 (M)*, ‡		NR	NR	NR	NR
Falkenberg-Jensen et al., Norway 2018 [24]	29	19–79	NR	NR	26.6 ± 2.0	26.8 ± 2.1	NR	NR	NR	NR
Casale et al., USA, 2020 [39]	23	61 (25–98)	7.1 (0.9–16.9)*		NR	NR	NR	NR	NR	NR
El- Anwar, Egypt, 2020 [13]	100	38 ± 13.29	NR	NR	28.15 ± 3.88	28.45 ± 3.86	NR	NR	NR	NR
Janzen-Senn et al., Portugal 2020 [40]	143	4–96	NR	NR	28.6 ± 2.5	28.5 ± 2.5	NR	NR	NR	NR
Sondergaard, Denmark, 2020 [41]	23	20–79	5.71 ± 2.98*		NR	NR	NR	NR	NR	NR
Ratag et al., Indonesia 2020 [34]	58	11–60	NR	NR	26.6	26.9	NR	NR	NR	NR
Koç et al., Turkey 2021 [43]	1117	NR	2.77 ± 1.46	2.24 ± 1.69	NR	NR	NR	NR	NR	NR

Epprecht et al., Switzerland (2021) [44]	20	45 ± 21	1.44 ± 1.46*	NR	NR	NR	NR	NR	NR	NR
Magro et al., 2021, USA [45]	20	52.3 ± 18.5	NR	NR	28 (27–28)*		NR	NR	NR	NR
Fernande-Reyes et al., Mexico (2024)	100	38.47 ± 15.36	5.43 ± 3.15	5.54 ± 3.43	24.55 ± 3.07	24.24 ± 2.60	4.51± 1.05	4.32 ± .85	2.98 ± .65	2.98 ± .58

*Measurement was done in both sides; ‡measurement was done in the cartilaginous and bony portion of Eustachian tube; #measurement was done with surgical instruments; †median and IQR; M — males; F — females; NR — not reported; N — sample; RMV — right mastoid volume; LMV — left mastoid volume; RETL — right Eustachian tube length; LETL — left Eustachian tube length; RAAH — right aditus ad antrum height; LAAH — left aditus ad antrum height; RAAW — right aditus ad antrum width; LAAW — left aditus ad antrum width.