

# Middle ear morphology and mastoid pneumatisation: a computed tomography study

Bernardo Alfonso Fernández-Reyes<sup>1\*</sup><sup>®</sup>, Santos Guzmán-López<sup>1\*</sup><sup>®</sup>, Francisco Javier Arrambide-Garza<sup>1</sup><sup>®</sup>, Pamela Garza-Baez<sup>2</sup><sup>®</sup>, Alejandro Quiroga-Garza<sup>1</sup><sup>®</sup>, Mario Campos-Coy<sup>2</sup><sup>®</sup>, Jose Luis Treviño-González<sup>3</sup><sup>®</sup>, Rodrigo Enrique Elizondo-Omaña<sup>1</sup><sup>®</sup>

<sup>1</sup>Universidad Autónoma de Nuevo León, School of Medicine, Human Anatomy Department, Monterrey, Nuevo León, México <sup>2</sup>Universidad Autónoma de Nuevo León, University Hospital "Dr. José Eleuterio González", Radiology and Imaging Department, Monterrey, Nuevo León, México

<sup>3</sup>Universidad Autónoma de Nuevo León, University Hospital "Dr. José Eleuterio González" Ear, Throat and Nose Department, Monterreu, Nuevo León, México

\*Both authors participated equally in the study and are both in the position of first author.

[Received: 10 April 2024; Accepted: 19 May 2024; Early publication date: 21 May 2024]

**Background:** Mastoid pneumatisation 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 analysing computed tomography (CT) scans in which MACS volume and the Eustachian 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  $38.5 \pm 15.3$  years, of which 56 were women and 44 were men. The mean right and left MACS volume were  $5.43 \pm 3.15$  cm<sup>3</sup> and  $5.54 \pm 3.43$  cm<sup>3</sup>, respectively, with an ETL of  $24.55 \pm 3.07$  mm in the right side and  $24.24 \pm 2.60$  mm on the left side, and an aditus ad antrum width of  $2.98 \pm 0.65$  on the right and  $2.98 \pm 0.58$  on the left, and height of  $4.51 \pm 1.05$  and  $4.32 \pm 0.85$ , 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 pneumatisation was greater in men than in 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 pneumatisation of MACS. (Folia Morphol 2025; 84, 1: 108–116)

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

Address for correspondence: Rodrigo Enrique Elizondo-Omaña and Jose Luis Treviño-González, Facultad de Medicina, Universidad Autónoma de Nuevo León, Av. Madero and Dr. Aguirre Pequeño S/N, Col. Mitras Centro, C.P. 64460, Monterrey, Nuevo León, México; e-mail: rod\_omana@yahoo.com jose.trevinog@uanl.mx, tel. +52 1 81 8329 4171, fax: +521 81 8347 7790

This article is available in open access under Creative Common Attribution-Non-Commercial-No Derivatives 4.0 International (CC BY-NC-ND 4.0) license, allowing to download articles and share them with others as long as they credit the authors and the publisher, but without permission to change them in any way or use them commercially.

# 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 pneumatised 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 years in women and 15 years in men [2, 33, 34, 45]. Several factors can influence mastoid air cell system (MACS) pneumatisation: genetics, environment, nutrition, diseases, and anatomical structures [1, 8, 27, 40]. Although MACS function remains unclear, it plays an important role in gas exchange [15, 28, 32, 39, 42].

Mastoid air cell system 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 it 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 becomes obstructed, it could predispose or accentuate middle ear pathologies [3, 23, 24, 44]. Despite their anatomical relationship to middle ear diseases, there is a lack of 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 reporting 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 0.625 mm. 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 visualise the images, a Carestream VUE-PACS (software version 11.2.1.0) 3D workstation was used. CT scans were later uploaded to Lifex software for their segmentation. The images and measurements were assessed independently by 2 radiologists and recorded in a database using millimetres with 2 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 the 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).



Figure 1. Representative case of Eustachian tube length measurement. A. Axial view of head CT in bone window, white dotted line marks the measurement used for cartilaginous ETL. B. Schematic illustration of axial view of head. Black dotted line marks the ETL; CT — computed tomography; EAC — external auditory canal; ET — Eustachian tube; ICA — internal carotid artery; IJV — internal jugular vein; NP — nasopharynx.



Figure 2. Representative case of AAH measurement. A. Parasagittal view of head CT — white dotted line marks the measurement used for AAH. B. Schematic illustration of parasagittal view of head — black dotted line marks the aditus ad antrum height. AAH — aditus ad antrum height, An — Antrum; CT — computed tomography.



Figure 3. Representative case of aditus ad antrum width measurement. A. Axial view of head CT in bone window, white dotted line marks the measurement used for of aditus ad antrum width. B. Schematic illustration of axial view of head – black dotted line mark the width of aditus ad antrum. AAW — aditus ad antrum width; An — antrum; Co — cochlea; CT — computed tomography; Oss — ossicles; SC — semicircular canal; TM — tympanic membrane.

### 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 the 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's 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 < 0.5 was considered statistically significant. The database was analysed 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 adhered to the Helsinki Declaration, as well as national and international standards of research. The authors declare no financial or commercial gain for the realisation 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 100 CTs were included, with a mean age of  $38.5 \pm 15.3$  years; 56 were women ( $39.0 \pm 13.9$  years) and 44 were men ( $37.8 \pm 17.2$  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, and 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<sup>3</sup> (range 0.9–16.6 mm) for men and 4.82 cm<sup>3</sup> (range 0.7–12 mm) for women. The mean difference was 1.38 cm<sup>3</sup> (95% CI: 0.15–2.62; p = 0.03). The left MACS volume mean was 6.43 cm<sup>3</sup> (range 0.9–18.1 mm) for men and 4.84 cm<sup>3</sup> (range 1–12.1 mm) for women. The mean difference was 1.59 cm<sup>3</sup> (95% CI: 0.24–2.93; p = 0.03).

Pearson's correlation coefficients 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;  $r^2 = 0.06$ ) was identified.

	Measurement	General (n = 100) Mean ± SD	Women (n = 56) Mean ± SD	Men (n = 44) Mean $\pm$ SD	p-value
	MACS	$5.43\pm3.15$	$4.82\pm2.39$	$\textbf{6.2}\pm\textbf{3.8}$	0.03*
Diaht	ETL	$24.55\pm3.07$	$24.02\pm3.40$	$25.23\pm2.46$	0.05
nıyılı	AAH	4.51 ± 1.05	4.41 ± 1.01	$4.65\pm1.08$	0.26
	AAW	$2.98\pm0.65$	$3.02\pm0.69$	2.92 ±.61	0.44
	MACS	$5.54\pm3.43$	$4.84 \pm 2.48$	$6.43\pm4.21$	0.03*
l offe	ETL	$24.24\pm2.60$	$23.42\pm2.42$	$25.28\pm2.48$	< 0.001*
LUIL	AAH	$4.32\pm0.85$	$4.22\pm0.88$	$4.64\pm0.8$	0.16
	AAW	$2.98\pm0.58$	$2.93\pm0.64$	$3.04\pm0.5$	0.35

 Table 1. Comparison of the measurements stratified by sex.

Values are expressed in millimetres for distances and cubic millimetres for volumes. Independent-sample Student's t-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.

Table 2. Pearson's correlation coefficient bet	tween measurements of the right side.
--	---------------------------------------

	MACS	ETL	ААН	AAW
MACS		0.06	0.26*	-0.13
ETL			-0.10	-0.04
AAH				0.51
AAW				

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

Table 3. Pearson's correlation coefficient between measurements of the left	t side	э.
---	--------	----

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

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

# 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 in Falkenberg-Jensen et al. [14] and Yegin et al. [45], but 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 in 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] — which appears to be more crucial. The degree of middle ear disease affects the variation of mastoid pneumatisation. The exclusion of these patients could improve the understanding of the anatomical factors in mastoid pneumatisation.

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  $26.8 \pm 2.1$ ,  $26.6 \pm 2.0$ , and  $26.7 \pm 2.1$ mm 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, which may be due to earlier physical growth [5].

Yegin et al. [45] studied the relationship 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 pneumatisation, with similar results. They reported a positive and statistically significant correlation between MACS and ETL (r = 0.159, p = 0.002), and they assumed that MACS is decreased by a shorter ET, similarly to our findings. However, evidence is still lacking, and the correlation between these 2 variables can only be hypothesised.

Takasaki et al. [41] analysed the ETL of normal adults without otitis media with effusion using CT scan in healthy adult ears. ETL was  $42.5 \pm 62.8$  and  $42.9 \pm 62.9$  mm 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]. A study by Csakanyi et al. [9] showed that children with otitis media had a significantly lower volume of MACS when compared with healthy children:  $2.82 \pm 1.51$  vs.  $10.05 \pm 5.3$  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 the ETL of patients with and without otitis media [11]. Even though results demonstrate a positive correlation between MACS and ETL, it is not strong enough to establish an influence in mastoid volume and its possible contribution to the development of disease.

Variations in mastoid pneumatisation, 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 pneumatisation 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 pneumatisation is critical for planning and risk assessment [13, 45]. Surgeons need to anticipate anatomical variations to minimise intraoperative complications and optimise 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 pneumatisation can disturb this balance, potentially resulting in conditions like eustachian tube dysfunction and recurrent middle ear infections [11, 45]. Clinicians must factor in mastoid pneumatisation when devising treatment plans for affected patients. Furthermore, accurate interpretation of radiological findings regarding mastoid pneumatisation 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 because 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 25.28 mm (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 long [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 due to individual variation.

Table 4. Comparison with other authors	S.									
Author, country, year	z	Age	RMV	LMV	RETL	III	RAAH	LAAH	RAAW	LAAW
Colhoun et al., Wales, 1988 [6]	26	NR	8.4 ±	: 3.6*	NR	NR	NR	NR	NR	NR
Isono et al., Japan 1999, [18]	43	NR	5.9	7*	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, [30]	69	NR	$6.63 \pm 2.67$	$6.59 \pm 2.76$	NR	NR	NR	NR	NR	NR
Lee et al., Korea 2005 [26]	102	19-44	7.0	*6	NR	NR	NR	NR	NR	NR
Takaski et al., Japan, 2007 [41]	45	18–82	NR	NR	$42.5 \pm 2.8^{\ddagger}$	$42.9\pm2.9^{\ddagger}$	NR	NR	NR	NR
Csakanyi et al., Hungary 2011, [9]	40	2–18	10.05	± 5.3*	NR	NR	NR	NR	NR	NR
Kim et al., Korea, 2010 [24]	60	18–63	6.239	6.695	NR	NR	NR	NR	NR	NR
Long et al., China 2012 [29]	6	NR	NR	NR	NR	NR	5.74 ±	: 1.16*	5. 19	± 1.39*
Bahgat et al., Egypt 2014 [3]	50	$28.15 \pm 7.62$	NR	NR	NR	NR	7.16(1	.92)*,#	5.16	1.92)*.#
Kaymakçı et al., Turkey, 2015 [23]	30	17–50	9.10 (3.09) <sup>†</sup>	8.62 (2.96) <sup>†</sup>	NR	NR	NR	NR	NR	NR
Cros et al., Denmark, 2016 [8]	8	NR	9.4 (2.7	-13.6)*	NR	NR	NR	NR	NR	NR
Allam et al., Egypt, 2016 [2]	80	32.8 ± 12.98 (M) 28.9 ± 10.1 (F)	13.09 ± 8.43 ±	3.6 (M)* 3.3 (F)*	NR	NR	NR	NR	NR	NR

 $\rightarrow$ 

	z	Age	RMV	LMV	RETL	LETL	RAAH	LAAH	RAAW	LAAW
Yegin et al., Turkey, 2016 [45]	217	33.14 ± 12.88	$6.52 \pm 2$ $5.64 \pm 1$	.76 (M)* .98 (F)*	46.54 ± 1 42.20 ± 8	0.18 (H)*. <sup>±</sup> 3.42 (M)*. <sup>±</sup>	NR	NR	NR	NR
Falkenberg-Jensen et al., Norway 2018 [14]	29	19–79	NR	NR	$26.6 \pm 2.0$	$26.8 \pm 2.1$	NR	NR	NR	NR
Casale et al., USA, 2020 [4]	23	61 (25–98)	7.1 (0.9	-16.9)*	NR	NR	NR	NR	NR	NR
El- Anwar, Egypt, 2020 [12]	100	$38 \pm 13.29$	NR	NR	$28.15 \pm 3.88$	$28.45 \pm 3.86$	NR	NR	NR	NR
Jarzen-Senn et al., Portugal 2020 [20]	143	4–96	NR	NR	$28.6 \pm 2.5$	$28.5 \pm 2.5$	NR	NR	NR	NR
Søndergaard, Denmark, 2020 [38]	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 [25]	1117	NR	2.77 ± 1.46	$2.24 \pm 1.69$	NR	NR	NR	NR	NR	NR
Epprecht et al., Switzerland (2021) [13]	20	$45 \pm 21$	$1.44 \pm 1.46^{*}$	NR	NR	NR	NR	NR	NR	NR
Magro et al., 2021, USA [31]	20	$52.3 \pm 18.5$	NR	NR	28 (27	1–28)*	NR	NR	NR	NR
Fernández-Reyes et al., Mexico (2024)	100	$38.47 \pm 15.36$	$5.43 \pm 3.15$	$5.54\pm3.43$	$24.55 \pm 3.07$	$24.24 \pm 2.60$	$4.51 \pm 1.05$	$4.32 \pm .85$	$2.98\pm0.65$	$2.98 \pm 0.58$

#### CONCLUSIONS

The volume of the mastoid air cell 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 pneumatisation 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, ensuring 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, and 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 Guzmán-López, 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.

# Funding

This study was funded by Human Anatomy Department of the Universidad Autónoma de Nuevo León.

# **Conflict of interest**

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

# REFERENCES

 Aladeyelu OS, Olaniyi KS, Olojede SO, et al. Temporal bone pneumatization: A scoping review on the growth and size of mastoid air cell system with age. PLoS One. 2022; 17(6): e0269360, doi: 10.1371/journal.pone.0269360, indexed in Pubmed: 35657972.

- Allam F, Allam M. Sex discrimination of mastoid process by anthropometric measurements using multidetector computed tomography in Egyptian adult population. Egypt J Forensic Sci. 2016; 6(4): 361–369, doi: 10.1016/j. ejfs.2016.05.001.
- Bahgat M. Patency of the aditus ad antrum in tubotympanic chronic suppurative otitis media. Otolaryngol Head Neck Surg. 2015; 152(2): 331–335, doi: 10.1177/0194599814559698, indexed in Pubmed: 25422281.
- Casale G, Shaffrey E, Kesser BW. Correlation between hearing loss and middle ear volume in patients with a tympanic membrane perforation. Laryngoscope. 2020; 130(4): E228–E232, doi: 10.1002/lary.28107, indexed in Pubmed: 31173372.
- Cinamon U. The growth rate and size of the mastoid air cell system and mastoid bone: a review and reference. Eur Arch Otorhinolaryngol. 2009; 266(6): 781–786, doi: 10.1007/ s00405-009-0941-8, indexed in Pubmed: 19283403.
- Colhoun EN, O'Neill G, Francis KR, et al. A comparison between area and volume measurements of the mastoid air spaces in normal temporal bones. Clin Otolaryngol Allied Sci. 1988; 13(1): 59–63, doi: 10.1111/j.1365-2273.1988. tb00282.x, indexed in Pubmed: 3370855.
- Conticello S, Saita V, Ferlito S, et al. Computed tomography in the study of the eustachian tube. Arch Otorhinolaryngol. 1989; 246(5): 259–261, doi: 10.1007/BF00463568, indexed in Pubmed: 2590029.
- Cros O, Knutsson H, Andersson M, et al. Determination of the mastoid surface area and volume based on micro-CT scanning of human temporal bones. Geometrical parameters depend on scanning resolutions. Hear Res. 2016; 340: 127–134, doi: 10.1016/j.heares.2015.12.005, indexed in Pubmed: 26701785.
- Csakanyi Z, Katona G, Josvai E, et al. Volume and surface of the mastoid cell system in otitis media with effusion in children: a case-control study by three-dimensional reconstruction of computed tomographic images. Otol Neurotol. 2011; 32(1): 64–70, doi: 10.1097/MAO.0b013e-3181fcec84, indexed in Pubmed: 21068691.
- Cuschieri S. The STROBE guidelines. Saudi J Anaesth. 2019; 13(Suppl 1): S31–S34, doi: 10.4103/sja.SJA\_543\_18, indexed in Pubmed: 30930717.
- Dinç AE, Damar M, Uğur MB, et al. Do the angle and length of the eustachian tube influence the development of chronic otitis media? Laryngoscope. 2015; 125(9): 2187–2192, doi: 10.1002/lary.25231, indexed in Pubmed: 25778737.
- El-Anwar MW, Eldib DB, Nofal AA, et al. Eustachian tube: computed tomography analysis. J Craniofac Surg. 2020; 31(6): 1763–1765, doi: 10.1097/SCS.000000000006548, indexed in Pubmed: 32694471.
- Epprecht L, Qingsong L, Stenz N, et al. Correlation between tympanometry volume and three-dimensional computed tomography mastoid volumetry in tympanoplasty candidates. J Laryngol Otol. 2021; 135(8): 718–722, doi: 10.1017/S002221512100164X, indexed in Pubmed: 34219626.
- Falkenberg-Jensen B, Hopp E, Jablonski GE, et al. The cartilaginous Eustachian tube: Reliable CT measurement and impact of the length. Am J Otolaryngol. 2018; 39(4):

436–440, doi: 10.1016/j.amjoto.2018.04.010, indexed in Pubmed: 29685379.

- Gaihede M, Dirckx JJJ, Jacobsen H, et al. Middle ear pressure regulation complementary active actions of the mastoid and the Eustachian tube. Otol Neurotol. 2010; 31(4): 603–611, doi: 10.1097/MAO.0b013e3181dd13e2, indexed in Pubmed: 20393372.
- Hasebe S, Takahashi H, Honjo I, et al. Mastoid condition and clinical course of cholesteatoma. ORL J Otorhinolaryngol Relat Spec. 2001; 63(3): 160–164, doi: 10.1159/000055733, indexed in Pubmed: 11359094.
- Hernandez-Trejo AF, Cuellar-Calderon KP, Treviño-Gonzalez JL, et al. Prevalence of facial canal dehiscence and other bone defects by computed tomography. Eur Arch Otorhinolaryngol. 2020; 277(10): 2681–2686, doi: 10.1007/ s00405-020-06013-8, indexed in Pubmed: 32383094.
- Isono M, Murata K, Azuma H, et al. Computerized assessment of the mastoid air cell system. Auris Nasus Larynx. 1999; 26(2): 139–145, doi: 10.1016/s0385-8146(98)00055-8.
- Jackler RK, Schindler RA. Role of the mastoid in tympanic membrane reconstruction. Laryngoscope. 1984; 94(4): 495–500, doi: 10.1288/00005537-198404000-00013, indexed in Pubmed: 6708693.
- Janzen-Senn I, Schuon RA, Tavassol F, et al. Dimensions and position of the Eustachian tube in humans. PLoS One. 2020; 15(5): e0232655, doi: 10.1371/journal. pone.0232655, indexed in Pubmed: 32365086.
- Jun BC, Song SW, Cho JE, et al. Three-dimensional reconstruction based on images from spiral high-resolution computed tomography of the temporal bone: anatomy and clinical application. J Laryngol Otol. 2005; 119(9): 693–698, doi: 10.1258/0022215054797862, indexed in Pubmed: 16156909.
- Kawase T, Hori Y, Kikuchi T, et al. The effects of mastoid aeration on autophony in patients with patulous eustachian tube. Eur Arch Otorhinolaryngol. 2008; 265(8): 893–897, doi: 10.1007/s00405-007-0560-1, indexed in Pubmed: 18180937.
- Kaymakçı M, Yanık B, Erel F, et al. Association between atopy, mastoid pneumatization and tympanometric findings. Eur Arch Otorhinolaryngol. 2015; 272(1): 15–21, doi: 10.1007/s00405-014-3006-6, indexed in Pubmed: 24647495.
- 24. Kim J, Song SW, Cho JH, et al. Comparative study of the pneumatization of the mastoid air cells and paranasal sinuses using three-dimensional reconstruction of computed tomography scans. Surg Radiol Anat. 2010; 32(6): 593–599, doi: 10.1007/s00276-009-0618-4, indexed in Pubmed: 20047049.
- 25. Koç A, Kaya S. Prevalence of foramen Huschke: evaluation of the association between mastoid pneumatization volume and the existence of foramen Huschke using cone beam computed tomography. Eur Arch Otorhinolaryngol. 2021; 278(3): 791–796, doi: 10.1007/s00405-020-06296-x, indexed in Pubmed: 32813172.
- 26. Lee DH, Jun BC, Kim DG, et al. Volume variation of mastoid pneumatization in different age groups: a study by three-dimensional reconstruction based on computed tomography images. Surg Radiol Anat. 2005; 27(1): 37–42, doi: 10.1007/s00276-004-0274-7, indexed in Pubmed: 15349696.

- Lee DH, Jung MK, Yoo YH, et al. Analysis of unilateral sclerotic temporal bone: how does the sclerosis change the mastoid pneumatization morphologically in the temporal bone? Surg Radiol Anat. 2008; 30(3): 221–227, doi: 10.1007/ s00276-008-0310-0, indexed in Pubmed: 18246294.
- Lima MA, Farage L, Cury MC, et al. Mastoid surface area-to-volume ratios in adult Brazilian individuals. Braz J Otorhinolaryngol. 2013; 79(4): 446–453, doi: 10.5935/1808-8694.20130080, indexed in Pubmed: 23929144.
- 29. Long X, Feng X, Zhu J. Normal anatomy of aditus of antrum and antrum on high-resolution CT and three--dimensional reconstruction. Lin Chuang Er Bi Yan Hou Tou Jing Wai Ke Za Zhi. 2012; 26(16): 747–750, indexed in Pubmed: 23213756.
- Luntz M, Malatskey S, Tan M, et al. Volume of mastoid pneumatization: three-dimensional reconstruction with ultrahigh-resolution computed tomography. Ann Otol Rhinol Laryngol. 2001; 110(5 Pt 1): 486–490, doi: 10.117 7/000348940111000516, indexed in Pubmed: 11372935.
- Magro I, Pastel D, Hilton J, et al. Developmental anatomy of the eustachian tube: implications for balloon dilation. Otolaryngol Head Neck Surg. 2021; 165(6): 862–867, doi: 10.1177/0194599821994817, indexed in Pubmed: 33620272.
- Miura M, Takahashi H, Honjo I, et al. Influence of the gas exchange function through the middle ear mucosa on the development of sniff-induced middle ear diseases. Laryngoscope. 1998; 108(5): 683–686, doi: 10.1097/00005537-199805000-00011, indexed in Pubmed: 9591546.
- Park MS, Yoo SH, Lee DH. Measurement of surface area in human mastoid air cell system. J Laryngol Otol. 2000; 114(2): 93–96, doi: 10.1258/0022215001904969, indexed in Pubmed: 10748822.
- Ratag Y, Asriyani S, Murtala B, et al. Anatomical measurement of normal Eustachian tube on the temporal bone computed tomography imaging. Jurnal Kesehatan Andalas. 2020; 9(3): 276, doi: 10.25077/jka.v9i3.1323.
- 35. Shewel Y, Bassiouny M, Ebrahim M. Endoscopic assessment of the isthmus tympanicum and tensor tympani fold and their relationship with mastoid pneumatization in chronic otitis media. J Int Adv Otol. 2020; 16(2): 227–233, doi: 10.5152/iao.2020.7507, indexed in Pubmed: 32209517.
- 36. Sirikci A, Bayazit YA, Bayram M, et al. Significance of the auditory tube angle and mastoid size in chronic ear disease. Surg Radiol Anat. 2001; 23(2): 91–95, doi: 10.1007/ s00276-001-0091-1, indexed in Pubmed: 11462868.

- Smith ME, Weir AE, Prior DCC, et al. The mechanism of balloon Eustachian tuboplasty: a biomechanical study. Med Biol Eng Comput. 2020; 58(4): 689–699, doi: 10.1007/ s11517-020-02121-z, indexed in Pubmed: 31953796.
- Søndergaard N, Nyengaard JR, Bloch SL. Stereologic investigation of mastoid air cell geometry: volume, surface area, and anisotropy. Otol Neurotol. 2020; 41(5): e630– -e637, doi: 10.1097/MAO.00000000002583, indexed in Pubmed: 32032296.
- Takahashi H, Sato H, Nakamura H, et al. Correlation between middle-ear pressure-regulation functions and outcome of type-I tympanoplasty. Auris Nasus Larynx. 2007; 34(2): 173–176, doi: 10.1016/j.anl.2006.09.007, indexed in Pubmed: 17055205.
- 40. Takahashi M, Yamamoto Y, Koizumi H, et al. A quantitative study of the suppression of the development of the mastoid air cells by the presence of congenital cholesteatoma. Acta Otolaryngol. 2019; 139(7): 557–560, doi: 10.1080/0 0016489.2019.1606439, indexed in Pubmed: 31050578.
- 41. Takasaki K, Takahashi H, Miyamoto I, et al. Measurement of angle and length of the eustachian tube on computed tomography using the multiplanar reconstruction technique. Laryngoscope. 2007; 117(7): 1251–1254, doi: 10.1097/MLG.0b013e318058a09f, indexed in Pubmed: 17603324.
- Tanabe M, Takahashi H, Honjo I, et al. Factors affecting recovery of mastoid aeration after ear surgery. Eur Arch Otorhinolaryngol. 1999; 256(5): 220–223, doi: 10.1007/ s004050050145, indexed in Pubmed: 10392294.
- Tapia-Nañez M, Quiroga-Garza A, Guerrero-Mendivil F, et al. A review of the importance of research in Anatomy, an evidence-based science. Eur J Anat. 2022; 26(4): 477–486, doi: 10.52083/evza1394.
- Thomassin JM, Dessi P, Danvin JB, et al. Anatomía del oído medio. EMC - Otorrinolaringología. 2008; 37(3): 1–20, doi: 10.1016/s1632-3475(08)70301-1.
- 45. Yegin Y, Çelik M, Şimşek BM, et al. Correlation between the degree of the mastoid pneumatization and the angle and the length of the Eustachian tube. J Craniofac Surg. 2016; 27(8): 2088–2091, doi: 10.1097/SCS.000000000003071, indexed in Pubmed: 28005759.
- 46. Yegin Y, Çelik M, Şimşek BM, et al. Impact of the degree of the mastoid pneumatization on cartilage type 1 tympanoplasty success. J Craniofac Surg. 2016; 27(7): e695– -e698, doi: 10.1097/SCS.000000000003022, indexed in Pubmed: 27564066.