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Parametric measurements of the mastoid process and pneumatization levels in normal Sudanese population using computed tomography

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Abstract

The mastoid portion of the temporal bone has a variety of anatomical and physiological functions, including maintaining the balance of the middle ear pressure and protecting the inner ear. It has also attracted the interest of many investigators as a valuable tool in gender differentiation.

In this study, we examined the mastoid measurements, volume and the degree of pneumatization in relation to age and gender

A cross-sectional study was conducted using computed tomography (CT) scans obtained from the radiology departments of the Military and Al Ragi Hospitals. Six measurements were taken from the mastoid process, the volume was calculated and the pneumatization was assessed on the axial plane at the level of the Sigmoid sinus, three parallel lines were drawn in relation to the sinus to classify the degree of pneumatization into four categories.

The study exhibited that the average mastoid volume in the female was 7.14 mm^3 and 6.62 mm^3 on the right, and the left sides respectively, while in males it was 11.65 mm^3 and 11.63 mm^3 on the right and the left sides respectively. No significant bilateral differences in all measurements were observed in either males or females ($P > 0.05$), except for the oblique coronal diameter (OCD) in male, where a significant difference was found ($P < 0.05$). Male mastoid measurements were significantly greater than those in females ($P < 0.05$), except for the OCD, where no statistically significant difference was found between sexes ($P > 0.05$)

A highly significant inverse association was found between age and the degree of pneumatization ($P<0.05$) indicating a decrease in pneumatization with age. No significant gender differences were observed in degree of pneumatization ($P > 0.05$).

CT scans was proved essential in evaluating the temporal bone's pneumatization. The level of the pneumatization can be assessed by examining the air cells around the sigmoid sinus in axial CT images. Sexual dimorphism was observed in all mastoid process measurements.

Keywords: Mastoid process, Pneumatization, CT Scan, Age, Gender.

Introduction

The mastoid process is a crucial anatomical structure with high significance for radiologists, otolaryngologists, anthropologists, neurosurgeons, anatomists, and forensic specialists. It develops gradually and exhibits a high degree of sexual dimorphism in adulthood [1, 2]. The mastoid process is a part of the temporal bone, and it is grooved on the deep aspect of its base by the digastric notch, which serves as the attachment site for the posterior belly of the digastric muscle [3]. As the mastoid process grows, the cortex is gradually infiltrated by epithelial cells, leading to the formation of air cell chambers lined by these cells; this process is referred to as pneumatization [4].

Developmentally mastoid air cells can be classified into three types: Well-pneumatized (cellular), where the mastoid cells are fully developed with thin intervening septa between them; Diploic, where the mastoid contains fewer air cells; and sclerotic, where no air cells are present [5]. According to the environmental theory, middle ear infections have an impact on mastoid pneumatization, particularly in youngsters, where they may result in inflammatory changes to the ear mucosa that subsequently affect the temporal bone growth. In contrast, the genetic hypothesis suggests that the pneumatization level is primarily dictated by genetics, though it can also be influenced by childhood illnesses [4].

Surgically, the degree of pneumatization of mastoid air cells (MACs) is closely related to postoperative complications following microvascular decompression (MVD) surgery. It has been reported that well-pneumatized MACs increase the risk of cerebrospinal fluid (CSF) leakage and intracranial infection. At the same time, insufficient pneumatization raises the risk of facial paralysis and hearing loss [6]. Clinically, the degree of mastoid pneumatization has also been found to serve as a prognostic indicator in secretary otitis media, with a poor prognosis associated with the sclerotic mastoid [7].

Functionally, the normal air cell system is capable of performing gas exchange independently of the Eustachian tube. The total volume of the air cell system influences the rate of gas exchange [8].

The mastoid process develops as a part of the temporal bone. The petro-squamosal suture may persist as a bony plate (Korner's septum), which separates the superficial squamosal cells from the deep petrosal cells [9]. The normal cell system helps maintain a stable temperature environment, preventing excitation of the vestibular sensors by external temperature changes. Additionally, the gas-to-fluid exchange across the large convoluted mucosal surface of the air cells aids in regulating middle-ear pressure. The volume available for gas within the cell system is not fixed. It can be replaced by fluid in an equal volume, and vice versa, while maintaining the pressure within physiological limits [10].

Middle ear ventilation is an essential factor in determining the functional outcomes after middle ear reconstruction, as it functions as a buffer to minimize pressure changes and serves as an air reservoir [11]. Assessing the size and degree of pneumatization of the mastoid bone appears to be a valid and straightforward method for predicting surgical success, particularly in terms of tympanic membrane closure during tympanoplasty [12].

The degree of pneumatization plays a critical role in surgical procedures and the management of pathophysiological conditions affecting the temporal bone [13]. The degree of temporal bone pneumatization has been shown to be related to otitis media, with chronic otitis media associated with poorly pneumatized bones and acute otitis media linked to fully pneumatized bones [14].

The mastoid process, one of the sexually dimorphic aspects of the skull, has been used in research on sex differentiation [2, 15, 16]

Mastoid measurements and its degree of pneumatization can vary significantly among individuals and their development changes with age. In Sudan, there is a need for more research and studies focused on these measurements. Such investigations could help prevent complications during mastoid and ear surgeries and assist Otolaryngologists in understanding anatomy-related pathologies in this area. Additionally, correlating these measurements with age and gender could provide valuable insights for forensic and anatomical anthropology.

The lack of specific studies on mastoid measurements and pneumatization for the Sudanese population promoted us to conduct this study, which aimed to investigate these variations and correlate the findings for potential clinical and surgical applications.

Material and Methods

This cross-sectional study was conducted at Omdurman Military Hospital in the radiology department in Khartoum, Sudan, a tertiary healthcare centre, and Al Ragi University Hospital in Khartoum, Sudan, a private tertiary healthcare facility, during a period from 22nd of January to 2nd April 2023. The National University Research Ethics Committee (NU-REC) approved the study on date 02.01.2022 by the number NU-REC 2022/10. The study population consisted of patients attending both hospitals for head and neck CT scans, referred for indications other than mastoid diseases, mainly from

Khartoum state. A total of 101 CT scan images from the normal Sudanese population were collected and analyzed.

The study included Sudanese individuals aged 18-80 with no mastoid pathology affecting their normal appearance. Participants were also required to have no history of head or neck trauma, head or neck tumours, previous temporal bone or skull base surgery, or any positive mastoid pathology. Individuals who had any of these conditions or were aged over 80 or under 18 were excluded from the study.

Demographic Characteristics of The Study Population

The current study uses CT scans of normal Sudanese subjects aged between 18 and 80. The study was carried out on 101 subjects, consisting of 50 males and 51 females, who underwent head CT scans for indications unrelated to mastoid disease. The mean age of male and female participants was 45 and 44 years, respectively.

Data Collection Technique and Equipment

In Omdurman Military Hospital, the CT images were obtained using a General Electric 16-slice machine, following the CT brain helical protocol. The slice thickness was 0.625 mm, with a radiation dose of 120 KV, and the field of view (FOV) was 25 cm. A bone window setting was used for optimal imaging. The patient was positioned supine, with the head first and arms at the sides. In AL Ragi Hospital, the images were taken using a Siemens Scanner, which followed the CT brain helical protocol. The slice thickness was 0.625 mm, with a radiation dose of 130KV, and the field of view was 25 cm. A bone window was used, with the patient positioned in the supine position.

Mastoid Measurements and Degree of Pneumatization

Six measurements were conducted on the bilateral mastoid processes of both sexes. The first, Conventional Mastoid Height (CMH), was measured as a vertical line from the mastoid tip to the Frankfort plane on a 3D image (**Fig 1**). The second, True Mastoid Height (TMH), was measured on the coronal plane as a vertical line from the mastoid tip to the tegmen mastoidium (**Fig. 2**). The third measurement, Oblique Sagittal Diameter (OSD) (**Fig 3B**) was taken on the axial plane at the level of the mastoid groove, using anteroposterior line. The fourth, Oblique Coronal Diameter (OCD) (**Fig 3B**), was also taken on the axial plane at the level of the mastoid groove, using a transverse mediolateral line. The fifth, Maximal Oblique Sagittal Diameter (OSDmax) (**Fig 3A**), was measured on the axial plane at the level of the proximal end of the styloid process using the maximal anteroposterior line. Finally, the sixth measurement, Maximal Oblique Coronal Diameter (OCDmax) (**Fig 3A**), was taken on the axial plane at the level of the proximal end of the styloid process, using the maximal mediolateral line. Mastoid volume was calculated using the following formula: (TMH × OSDmax × OCDmax × 0.52) [17], where TMH represents the true mastoid height, OSDmax is the maximal oblique sagittal diameter, and OCDmax is the maximal oblique coronal diameter. Note that all measurements were performed in millimetres, as in Figures 1. 2, and 3.

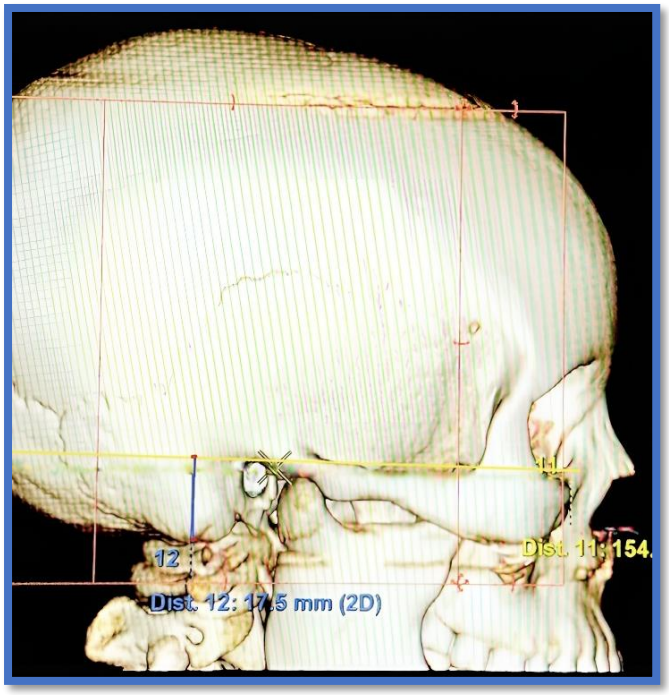

Figure 1. *Measurement of the CMH*

Figure 2*. Measurement of the TMH on the coronal plane.*

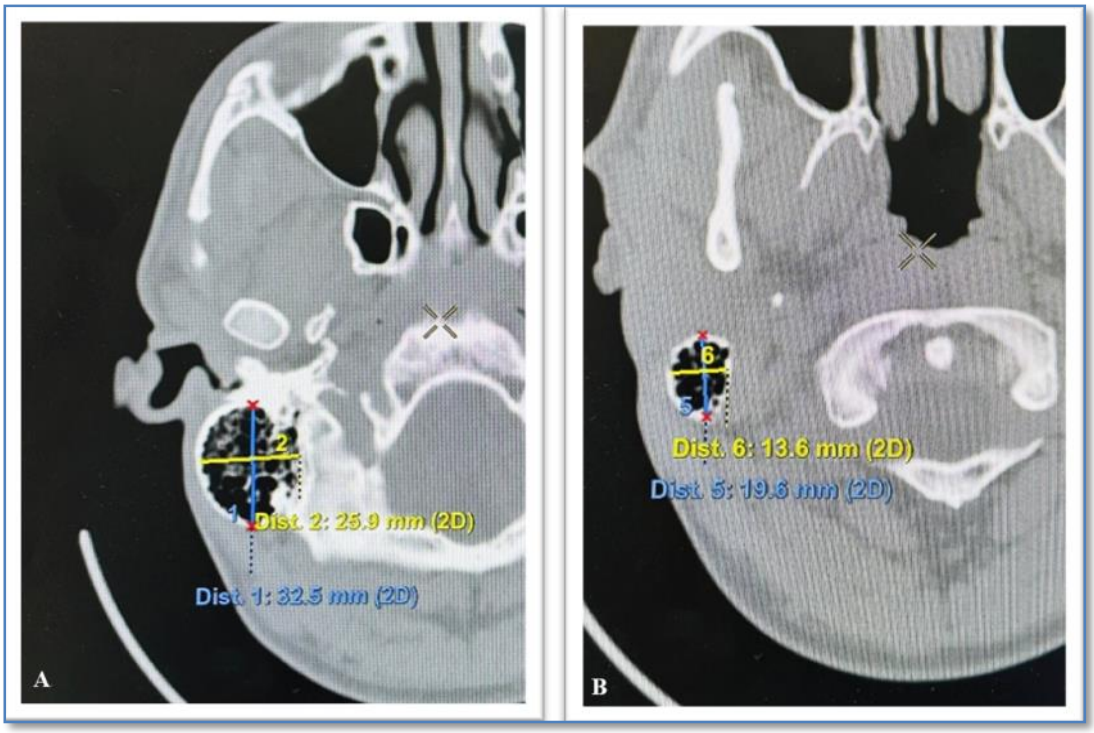

Figure 3. A: *Measurement of the OSDmax and OCDmax on axial plane.* ***B:*** *Measurement of the OSD and OCD on axial plane.*

Three parallel lines are drawn on the axial plane in relation to the sigmoid sinus [18, 19] (**Fig 4**): through the anterior margin, through the maximal convexity directed medially, and through the posterior margin of the sinus. The degree of mastoid pneumatization is classified into four groups based on the position of the mastoid cells relative to these lines. Degree 1 (hypo pneumatization) is characterized by mastoid cells lying anteromedial to the most anterior line. Degree 2 (moderate pneumatization) is represented by mastoid cells extending between the first (anterior) line and second (middle) line lines. Degree 3 (good pneumatization) is indicated by mastoid cells extending to the third (posterior) line. Finally, Degree 4 (hyper pneumatization) is represented by mastoid cells extending posterior to the third (posterior) line.

The study variables included gender and age as independent variables, while the degree of pneumatization and mastoid volume were considered dependent variables. Gender and age were analyzed to assess their potential influence on the degree of pneumatization and mastoid volume, with the degree of pneumatization and volume serving as the outcomes to be examined.

Data Analysis

Statistical analysis was conducted using the Statistical Package for Social Sciences (SPSS) version 25 and Microsoft Excel. A p-value of <0.05 was considered statistically significant. The students' t-test was used to compare the right and left mastoid volumes. Pearson's correlation coefficient was applied to examine the relationship between age and mastoid volume. MANOVA with Wilks' Lambda test was used to assess the correlation between gender and mastoid volume. Spearman's test was applied to determine the correlation between age and the degree of pneumatization. Additionally, the Chi-square test was used to evaluate the association between gender and the degree of pneumatization.

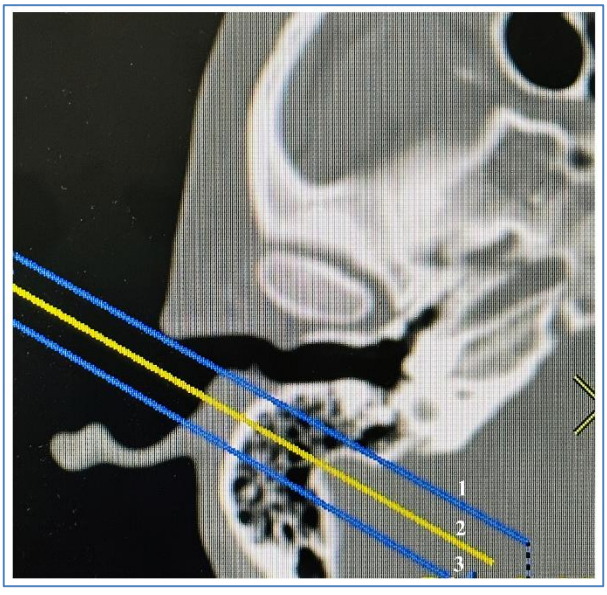

Figure 4. *Axial view showing the degree of pneumatization.* ***Anterior line 1, Middle line 2 and Posterior line 3***

Results

The study investigated the mastoid parameters in CT images belonging to male and female Sudanese individuals. The research looked at the measurements and volume of the right and left mastoid processes, the relationship between age and mastoid measurements and volume, the relationship between gender and mastoid measurements, and the association between age and pneumatization level. The study found significant gender differences in mastoid volume measurements, with males having larger measurements than females. No significant correlation was found between age and mastoid measurements, but a significant gender correlation

Table 1. *Means of Right and Left Mastoid Measurements in Males and Females*

Measurements	Gender	Means Right Mastoid±SD	Means Left Mastoid±SD	Degree of Significance
Conventional Mastoid Height (CMH)	Female	24.45±3.97	23.75±4.70	0.60
	Male	29.85±4.36	29.00±5.90	0.13
True Mastoid Height (TMH)	Female	29.52±5.61	28.98±5.78	0.14
	Male	39.85±5.45	39.51±5.91	0.30
Oblique Sagittal Diameter (OSD)	Female	14.90±3.01	14.79±3.74	0.77
	Male	16.87±2.99	16.27±2.92	0.11
Oblique Coronal Diameter (OCD)	Female	11.02±2.11	10.93±2.84	0.92
	Male	11±1.93	10.68±2.02	0.02*
Maximal Oblique Sagittal Diameter (OSDmax)	Female	24.46±43.59	23.16±4.97	0.20
	Male	27.47±4.50	26.55±4.87	0.14
Maximal Oblique Coronal Diameter (OCDmax)	Female	18.43±4.50	18.32±3.76	0.93
	Male	19.86±3.43	20.06±4.35	0.71
Volume	Female	7.14±3.98	6.624±3.21	0.22
	Male	11.65±4.09	11.63±4.81	0.52

Table 2. *Correlation Between Age and Mastoid Measurements and Volume*

Variable	Correlation	Right CMH	Right OSD	Right OCD	Right mastoid volume	Left CMH	Left OSD	Left OCD	Left mastoid volume
Age	Pearson Correlation	0.173	0.062	-0.128	0.033	0.134	0.155	-0.045	0.051
	Sig. (2-tailed)	0.083	0.539	0.202	0.74	0.178	0.119	0.654	0.611

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

CMH: Conventional Mastoid Height; **OSD**: Oblique Sagittal Diameter; **OCD**: Oblique Coronal Diameter

Table 3. *Comparison of gender and the degree of pneumatization*

Gender		Degree of pneumatization			
		Hypo-pneumatization	moderate pneumatization	Good pneumatization	Hyper-pneumatization
Female	Count	8	10	14	19
	Expected Count	8.6	10.1	11.11	21.21
Male	Count	9	10	8	23
	Expected Count	8.4	9.9	10.9	20.8

was observed in terms of age and the degree of pneumatization.

Right and Left Mastoid Measurements and Volume

The mean mastoid volume for the right and left sides in males was 11.65 mm^3 and 11.63 mm^3, respectively, while for females, it was 7.14 mm^3 on the right side and 6.62 mm^3 on the left side (Table 1). No significant bilateral differences were found in all measurements in either sex ($P > 0.05$) except for the OCD in males, where a significant difference was observed ($P < 0.05$) as indicated by (*) in (table 1).

The Correlation Between Age and Mastoid Measurement and Volume

There was a weak positive correlation between age and all mastoid measurements and volume; this correlation was not statistically significant ($P>0.05$), except for OCD on both sides, where a weak inverse correlation with age was observed; this correlation was also not statistically significant, with the value of $P > 0.05$ for the right side and $P > 0.05$ for the left side (Table 2).

The Correlation Between Gender and Mastoid Measurements and Volume

Male mastoid measurements were higher than females on both sides, except for the OCD, where values were nearly equal. A significant gender difference was observed, with males showing higher values ($P<0.05$), but no significant difference was found between genders for OCD ($P > 0.05$).

Correlation Between Age and The Degree of Pneumatization

A Spearman's rho Correlation was conducted to assess the relationship between age and the degree of pneumatization. It was found that the degree of pneumatization decreases with age, showing a highly statistically significant inverse correlation ($r = -.621$; $P< 0.05$).

The Correlation Between Gender and The Degree of Mastoid Pneumatization

In contrast to age, no significant difference was found between males and females in relation to the degree of mastoid pneumatization ($P > 0.05$) (Table 3).

Discussion

One of the most significant landmarks on the skull is the mastoid process. It is a component of the temporal bone and has spaces called mastoid air cells that are filled with air. From the perspective of surgeons, a normal measurement of the mastoid process is crucial. The purpose of this study was to evaluate the normal dimensions of the mastoid process in the Sudanese population. A multidetector computed tomography (MDCT) study conducted on adult Egyptian individuals reported that the mastoid process volume and all dimensions were higher in males than females, except for the mastoid angles, which were smaller in males than in females. These findings are consistent with our study, as we found that all mastoid measurements and volume were greater in males than in females, with the exception of the OCD, which was almost equal in both sexes [17]. Another CBCT study conducted at the Faculty of Dentistry in Gaziantep reported that mastoid height measured in the coronal sections, as well as the OSD and OCD measured in the transverse sections, were higher in males than in females. These findings are consistent with the results of our study [1]

A CBCT study conducted in India evaluated various measurements of the mastoid process, including length, width, height, angle, area, and intermastoid distance. The findings regarding mastoid height are consistent with our study, as males exhibited greater height than females [20]. A study conducted on adult crania of North Indian subjects measured eight parameters of the mastoid region, including mastoid height. The results revealed significant sexual dimorphism in all evaluated parameters, which is consistent with the findings of this study [2]. A study conducted on normal skulls of both male and female Thais was used for sex determination. The mean mastoid dimensions and mastoid triangular area in males were significantly larger than those in females. These findings are consistent with the results of our study [21].

Another study conducted on CBCT images of Jordanian individuals for osteometric assessment of the mastoids in gender determination found that male measurements were significantly higher than female measurements across all variables, including height, size, surface area, and anteroposterior diameter [28]. These findings are consistent with the results of this study, where males also exhibited higher values than females across all measurements. The larger measurements of the mastoid process in males could be attributed to the attachment and stronger action of muscles, such as the sternocleidomastoid muscle. This may explain the irregular and rougher surface of the mastoid process in males compared to females.

The current study found a significant inverse correlation between age and the degree of pneumatization, with pneumatization decreasing as age increased. However, no significant sex differences were found, which aligns with a

CBCT study conducted in the Department of Radiology at Manipal College of Dental Sciences, which also found no significant association between the grade of pneumatization and sex. However, while their study reported no association between the grade of pneumatization and age, we observed a significant negative correlation between age and the grade of pneumatization [22]. Another CBCT study conducted in the Department of Dentomaxillofacial Radiology at Gazi University's Faculty of Dentistry found no significant relationship between the degree of pneumatization and either age or gender. This finding is consistent with our study in terms of gender but differs regarding age, as we observed a significant negative correlation [23]. A CT study conducted to assess mastoid pneumatization found that mastoid pneumatization was greater in men than in women. This finding is inconsistent with our study, as we observed no significant gender differences [24]. A study conducted on 3D reconstructed CT images of mastoid pneumatization and volume variation across different age groups found that the mastoid pneumatization volume rises quickly from birth until the beginning of the second decade. Afterwards, the rate of increase slows, peaking in the third decade. Following the third decade, there is a slight decrease in volume, with a more significant decline occurring after the seventh decade. These findings highlight the substantial impact of age on pneumatization in older individuals, which is consistent with the results of our study, as it also observed a decline in pneumatization with advancing age; additionally, no significant differences were observed between sides (bilateral) or between sexes, and the findings regarding gender differences are consistent with this study [25].

This is in contrast to a study conducted in Korea [19], which found that mastoid pneumatization increases with age and peaks in the third decade of age, then decreases dramatically in the seventh decade, which is in agreement with the findings of our current study. Magnuson B. [10], on the other hand, it was reported that temporal bone pneumatization correlated poorly with age and that the number of air cells varied substantially, which might be attributed to ethnic differences.

Moreover, the mastoid process plays a crucial role in clinical practice; its size and pneumatization may be influenced by otitis media where the study demonstrated that Otitis media with effusion may impact the development of mastoid in children [26]. Another study evaluated the function of mastoid pneumatization in terms of maintaining important temporal bone structures during direct lateral trauma. It showed that the mastoid portion of the temporal bone influences the dispersion and absorption of kinetic energy during direct lateral trauma to the temporal bone, lowering the risk of fracture associated with direct trauma [18]. It has been suggested that the mastoid portion of the temporal bone has a pneumatic structure similar to that of the paranasal sinuses and protects important structures like the facial nerve, blood vessels, and central nervous tissue by dispersing energy [27].

Limitations of The Study

Since the primary aim of this study was to evaluate mastoid process measurements and the degree of pneumatization, it did not focus on using these features for age estimation. As a result, we were unable to assess the accuracy or potential impact of the mastoid process in determining age. Additionally, the study focused exclusively on individuals from Khartoum, which may not fully represent the diversity of Sudanese populations. Therefore, findings related to gender differences and pneumatization may not be generalizable to other ethnic groups in Sudan.

Conclusion

The current study concluded that males have significantly greater mastoid process measurements and volume compared to females. In contrast, no statistically significant variation in mastoid measurements was observed with age. Additionally, the study found no significant difference in the degree of pneumatization between males and females. However, the degree of pneumatization, was found to decrease with age. All measures in both sexes showed no discernible bilateral variations, with the exception of the oblique coronal diameter in males. CT scans are an essential and effective tool for evaluating and measuring bone structures. This study provides a preliminary reference for mastoid measurement in the Sudanese population. However, it is important to view these results as exploratory, as further extensive studies are needed to support these findings.

Ethics Committee Approval

National University Research Ethics Committee (NU-REC) approved the study on date 02.01.2022 by the number NU-REC 2022/10.

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Conflicts of Interest

The authors have no conflicts of interest associated with the publication of this article.

Author Contributions

All of the authors declare that they have all participated in the design, execution, and analysis of the paper and that they have approved the final version.

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References

1. İnceoğlu A, Bahşi İ, Orhan M, Yalçın ED, İnceoğlu F. The Radiological Evaluation of the Mastoid Process and Its Implications for Surgical Approaches. Cureus. 2021:13(7):e16101. https://doi.org/10.7759/cureus.16101
2. Saini V, Srivastava R, Rai RK, Shamal SN, Singh TB, Tripathi SK. Sex estimation from the mastoid process among North Indians. J Forensic Sci. 2012:57(2):434-439. https://doi.org/10.1111/j.1556-4029.2011.01966.x
3. Çalışkan S, Akkaşoğlu S, Sargon MF, Demiryürek MD. Mastoid process morphometry on dry skulls. Kırıkkale Üniversitesi Tıp Fakültesi Dergisi. 2020:22(1):58-63 https://doi.org/10.24938/kutfd.649170
4. Khan FQ, Deshmukh PT, Gaurkar SS. Pneumatization Pattern and Status of the Mastoid Antrum in Chronic Otitis Media: A Review. Cureus. 2022:14(7):e27068. https://doi.org/10.7759/cureus.27068
5. Hindi K, Alazzawi S, Raman R, Prepageran N, Rahmat K. Pneumatization of Mastoid Air Cells, Temporal Bone, Ethmoid and Sphenoid Sinuses. Any Correlation?. Indian J Otolaryngol Head Neck Surg. 2014:66(4):429-436. https://doi.org/10.1007/s12070-014-0745-z
6. Zhou J, Shi Q, Jiang L, Xie Y, Deng B, Zhan, Y. Association study of the pneumatization degree of mastoid air cells and postoperative complications after microvascular decompression in hemifacial spasm. Acta Neurochir (Wien). 2022:164(6)1543-1550. https://doi.org/10.1007/s00701-022-05155-4
7. Bayramoğlu I, Ardiç FN, Kara CO, Ozüer MZ, Katircioğlu O, Topuz B. Importance of mastoid pneumatization on secretory otitis media. Int J Pediatr Otorhinolaryngol. 1997:40(1):61-66 https://doi.org/10.1016/s0165-5876(97)01505-x
8. Park MS, Yoo SH, Lee DH. Measurement of surface area in human mastoid air cell system. J Laryngol Otol. 2000:114(2):93-96. https://doi.org/10.1258/0022215001904969
9. Przewoźny TT, Kosiński A, Markiet K, Sierszeń W, Kuczkowski J, Kuryłowicz J, Skorek A. Körner's septum (petrosquamosal lamina): the anatomical variant or clinical problem?. Folia Morphol (Warsz). 2020:79(2):205-210. https://doi.org/10.5603/FM.a2019.0079
10. Magnuson B. Functions of the mastoid cell system: auto-regulation of temperature and gas pressure. J Laryngol Otol. 2003:117(2):99-103. https://doi.org/10.1258/002221503762624512
11. Sethi A, Singh I, Agarwal A, Sareen D. Pneumatization of Mastoid Air Cells: Role of Acquired Factors. International Journal of Morphology. 2006:24(1)35-38
12. Costa JR, Sousa F, Costa S, Soares T, Meireles L. Role of mastoid pneumatization in predicting tympanoplasty results: Will it have the same importance in different age groups?. Am J Otolaryngol. 2023:44(1):103680. https://doi.org/10.1016/j.amjoto.2022.103680
13. Khosravi M, Jabbari Moghaddam Y, Esmaeili M, Keshtkar A, Jalili J, Tayefi Nasrabadi H. Classification of mastoid air cells by CT scan images using deep learning method. Journal of Big Data 2022:9(1):62. https://doi.org/10.1186/s40537-022-00596-1
14. Aoki K, Esaki S, Morikawa K, Kikuthi Y, Honda Y. [The size of the mastoid pneumatization and otitis media with effusion in children]. Nihon Jibiinkoka Gakkai Kaiho. 1989:92(6):893-898. https://doi.org/10.3950/jibiinkoka.92.893
15. Passey J, Pandey S, Singh R, Singh S. Morphometric Study of the Mastoid Triangle for Sexual Dimorphism of Dry Skulls in the North Indian Population. Cureus. 2021:13(5):e14859. https://doi.org/10.7759/cureus.14859
16. Fonseca MT, Siqueira LFR, Belo IS, Rodrigues LG, de Torres É, M, Franco A, Silva RF. Anatomy of the mastoid triangle and morphometric sex differences. Morphologie. 2023107(357):252-258. https://doi.org/10.1016/j.morpho.2022.11.003
17. Allam F.A.F.A.B., and Allam, M.F.A.B. Sex discrimination of mastoid process by anthropometric measurements using multidetector computed tomography in Egyptian adult population. Egyptian Journal of Forensic Sciences. 2016:6(4):361-369 https://doi.org/10.1016/j.ejfs.2016.05.001
18. Ilea A, Butnaru A, Sfrângeu SA, Hedeşiu M, Dudescu CM, Berce P, Chezan H, Hurubeanu L, Trombiţaş VE, Câmpian RS, Albu S. Role of mastoid pneumatization in temporal bone fractures. AJNR Am J Neuroradiol. 2014:35(7)1398-1404. https://doi.org/10.3174/ajnr.A3887
19. Han SJ, Song MH, Kim J, Lee WS, Lee HK. Classification of temporal bone pneumatization based on sigmoid sinus using computed tomography. Clin Radiol. 2007:62(11):1110-1118. https://doi.org/10.1016/j.crad.2007.04.019
20. Gopal SK, Sushmitha S, Kumar M. Mastoid and magnum-hidden key in forensics-a retrospective threedimensional cone-beam computed tomographic study. Int J Forensic Odontol. 2020:5:62
21. Manoonpol C, and Plakornkul V. Sex determination using mastoid process measurement in Thais. J Med Assoc Thai. 2012:95(3):423-429
22. Pingili S, Ahmed J, Ongole R, Denny C, Shenoy N, Sujir N. Evaluation of Mastoid Pneumatization Using Cone-beam Computed Tomography: A Retrospective Study. World. 2023:14(3):228-232. https://doi.org/10.5005/jp-journals-10015-2201
23. Demirel O, Kaya E, Üçok CÖ. Evaluation of mastoid pneumatization using cone-beam computed tomography. Oral Radiology. 2014:30:92-97. https://doi.org/10.1007/s11282-013-0150-4
24. Fernández-Reyes BA, Guzman-Lopez S, Arrambide-Garza FJ, Garza-Baez P, Quiroga-Garza A, Campos-Coy M, Treviño-González JL, Elizondo Omana RE. Middle ear morphology and mastoid pneumatization: a computed tomography study. Folia Morphol (Warsz). 2024. https://doi.org/10.5603/fm.100190
25. Lee DH, Jun BC, Kim DG, Jung MK, Yeo, SW. 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. https://doi.org/10.1007/s00276-004-0274-7
26. Chen, N, Hou Q, Cui Z, Wang L, Zhou S, Li J., Feng Z, Deng Z. Effect of otitis media with effusion and its clinical intervention on the development of mastoid in children. Acta Otolaryngol. 2014:134(5):481-484. https://doi.org/10.3109/00016489.2013.878810
27. Kellman RM, and Schmidt, C. The paranasal sinuses as a protective crumple zone for the orbit. Laryngoscope. 2009:119(9):1682-1690. https://doi.org/10.1002/lary.20583
28. Amin W, Saleh MW, Othman D, Salhab D, Thunaibat H. Osteometric Assessment of the Mastoids for Gender Determination in Jordanians by Discriminant Function Analysis. American Journal of Medical and Biological Research. 2015:3(4):117-123. https://doi.org/10.12691/ajmbr-3-4-7