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CBCT based morphometric and volumetric assessment of the mastoid process for gender determination in North Indian

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Abstract:
The predictive ability of CBCT - derived morphometric and volumetric parameters of the mastoid process for gender determination was evaluated in North Indian population. A total of 68 CBCT scans (136 Mastoid Processes) of both sexes aged 18–60 years were retrospectively analyzed and mastoid length, height, width and volume were evaluated bilaterally using customized software, followed by discriminant function analysis. Males exhibited significantly ($P < 0.001$) greater mastoid length, height and volume than females. Volumetric analysis achieved >94 % classification accuracy. Thus, mastoid volume and height appear to be the most informative CBCT derived parameters for forensic gender determination.

Keywords: Cone beam computed tomography (CBCT), gender determination, mastoid height, mastoid length, mastoid process, mastoid volume and mastoid width

Background:
Gender determination from human skeletal remains is the primary requisite for anthropological or forensic investigation. Sexual dimorphism using individual bones has been studied in different population **[1].** Traditionally, the pelvic bone and skull are used. Pelvis is more precise; however, a complete pelvis is not always accessible for analysis **[2].** After pelvis, adult temporal bone shape, especially the mastoid, is recognized as a determinant of sexual dimorphism **[3].** The mastoid process is a conical projection on the inferior temporal bone, situated posterior to the external acoustic meatus and lateral to the styloid process **[4].** The mastoid process develops with the human craniofacial complex, which is influenced by sex **[5]**. Males have an extended growth period that begins later and involves considerable and long-lasting growth spurts **[6].** The mastoid grows in three dimensions: downwards, backwards and outwards and its growth is influenced by the creation of air cells within the mastoid (pneumatization) **[7].** The mastoid region aids gender determination because its protected position resists damage and remains intact with age **[8].** Since the last centuries, various authors have used different methods to study the mastoid process for gender determination. Previous studies on dry skulls showed gender determination by mastoid morphological characters alone and 3D reconstructed skull models from computed tomography (CT) **[9-17].** A study by Passey *et al.* evaluated the effectiveness of mastoid triangle in sex determination using skull lateral radiographs **[18]**. However, limited evidence is available regarding the predictive ability of morphometric and volumetric parameters of the mastoid process using cone-beam computed tomography (CBCT), particularly in the North Indian population. Therefore, it is of interest to report the predictive ability of morphometric and volumetric parameters of the mastoid process for gender determination in north Indian using CBCT.

Methodology:
A retrospective observational study was designed. CBCT scans were collected from Oral Medicine and Radiology department. Ethical approval *was obtained by Institutional Ethics Committee* (IEC/ 01/ 07) and all procedures complied with the ethical standards of the declaration of Helsinki. Sample size was calculated using Epi Info™ software for comparison of two independent means, assuming a 95% confidence interval, 5% level of significance ($\alpha = 0.05$) and 90% power ($\beta = 0.10$). The calculation was based on previously reported mastoid process height values (males: 19.46 ± 3.73 mm; females: 17.33 ± 0.65 mm). The minimum required sample size was estimated to be 34 participants in each group, yielding a total sample size of 68 participants. The study included 68 (136) mastoid CBCT images of North Indian subjects aged 18 – 60 years. Images not showing complete anatomic details of the base or lateral sides of mastoid, trauma cases involving base of skull, developmental anomalies, previous mastoid pathology, otologic surgery history and chronic middle ear disease were excluded. All scans were obtained by PLANMECA ProMax, 3D Mid CBCT with uniform exposure parameters (90 kVp, 11 mA, 18 s) and a field of view of 160 x 160 mm. Patients were positioned in compliance with manufacturer's instructions to ensure consistent head alignment. DICOM images were analyzed using Romexis software, version 3.8.0R. Morphometric (Mastoid length, Mastoid height and Mastoid width) and volumetric measurements (Mastoid volume) were recorded on both sides of mastoid in the axial, coronal and sagittal planes. Frankfort horizontal plane was taken as reference plane and mastoid length was measured on sagittal plane as the widest diameter between prominent anterior and posterior points of mastoid at level of base **(Figure 1).** Height was measured by a perpendicular line from the length to the tip of mastoid process (**Figure 1**). Width was measured on axial plane, between the most prominent lateral and medial aspect of the mastoid at the level of base **(Figure 2)** for mastoid volumetric

analysis, 0.4 mm thick multiple sagittal sections of mastoid process were analyzed by manual segmentation tool. This tool allowed an accurate delineation of mastoid process in each section **(Figure 3 and 4)** and volume of the entire mastoid process could be obtained, as shown by a highlighted area in all sections (sagittal, coronal and axial) and 3D view **(Figure 5).** The morphometric and volumetric measurements were performed on both right and left mastoid process by two experienced radiologists, blinded to each other's findings. One radiologist performed measurements on two separate occasions separated by duration of two weeks. Statistical analysis was performed using IBM SPSS Statistics version 25. Data were expressed as mean ± standard deviation (SD). Differences between males and females were analyzed using the independent sample t-test, while right and left side comparisons within each sex were performed using the paired t-test. Intra- and interobserver reliability was assessed using the intraclass correlation coefficient (ICC). Discriminant function analysis was performed to evaluate the ability of mastoid morphometric and volumetric parameters for sex determination and model performance was assessed using Wilks' lambda, eigenvalues, group centroids and classification accuracy with leave-one-out cross-validation. A p-value <0.05 was considered statistically significant.

Results:

The study analyzed CBCT scans of 68 (136) mastoid process patients aged 18 to 60 years. 35 males (51.47%) had a mean age of 29.30±10.72 and 33 females (48.52%) had a mean age of 27.21±7.10. There was no significant difference in age between males and females (P = 0.35). Males had greater mean values for right and left mastoid length and height than females, indicates significant difference (P < 0.001) whereas mastoid width showed non-significant difference **(Table 1).** Mean mastoid volume showed statistically significant difference (P <0.001), indicating overall greater mastoid volume in males **(Table 2). Table 3** and **Table 4** showed no significant differences in mastoid length, height, width and volume among both sexes. Intraclass correlation coefficient (ICC) was above 0.85 across variables, indicating good intra- and interobserver agreement. Discriminant function analysis showed that most mastoid process parameters exhibited statistically significant sexual dimorphism between males and females. Wilks' lambda values ranged from 0.952 to 0.287, with lower values indicating stronger discrimination. Among linear dimensions, mastoid height (right and left) had better discriminative power than length and width, with lower Wilks' lambda and higher eigenvalues. Right-side width was weaker and not statistically significant (P = 0.072), suggesting limited standalone utility for sex determination **(Table 5).** Volumetric parameters exhibited the strongest discriminatory capacity. Right mastoid volume (Wilks' lambda = 0.316) and left mastoid volume (Wilks' lambda = 0.287) demonstrated very high eigenvalues (2.167 and 2.481, respectively), indicating substantial between-group variance. These parameters achieved excellent classification accuracy, exceeding 94% overall, with male classification accuracy slightly higher than female accuracy. The centroids for volumetric measures showed marked separation between males (positive values) and females (negative values), confirming pronounced sexual dimorphism **(Table 5).** Side-wise comparison showed that right-sided measurements generally performed marginally better than left-sided measurements in terms of eigenvalues and classification accuracy, particularly for length, height and volume. This asymmetry may reflect functional or developmental differences. The overall discriminant model, incorporating bilateral mastoid length, height, width and volume, showed excellent discriminative performance. The model showed Wilks' lambda of 0.147 (P< 0.001) and an eigenvalue of 5.790 indicating strong separation between the sexes. The original classification correctly classified 100% of male and female participants. Leave-one-out cross-validation also yielded 100% classification accuracy, suggesting that the discriminant function was internally stable within the present dataset. Nevertheless, these findings represent performance in the study sample and require confirmation in larger independent populations before broader forensic application.

Table 1: Morphometric parameters of mastoid process in males and females

Parameters	Gender	Mean ± SD (in mm)	P value (t Test)
Right Length	Males	29.27 ± 6.51	<0.001
	Females	23.36 ± 2.21	
Left Length	Males	29.11 ± 8.24	<0.004
	Females	23.89 ± 6.78	
Right Height	Males	22.86 ± 2.69	<0.001
	Females	18.42 ± 2.66	
Left Height	Males	22.61 ± 4.12	<0.001
	Females	18.34 ± 3.27	
Right Width	Males	15.07 ± 2.42	0.06
	Females	16.11 ± 2.22	
Left Width	Males	16.06 ± 2.78	0.07
	Females	17.59± 2.60	

SD - Standard Deviation

Table 2: Volumetric parameters of mastoid process

Parameters	Gender	Mean ± SD (in cm^3)	P value (t Test)
Right volume	Males	13.05 ± 1.66	<0.001
	Females	7.93 ± 1.86	
Left volume	Males	12.92 ± 1.54	<0.001
	Females	7.86 ± 1.71	

SD - Standard Deviation

Table 3: Mean value comparison between right and left mastoid process in males

Parameters	Males		P value (t Test)
	Right	Left	
Length(mm)	29.27±6.51	29.11±8.24	0.95
Height(mm)	22.86±2.69	22.61±4.12	0.75
Width(mm)	15.07±2.42	16.06±2.78	0.11
Volume(cm^3)	13.05±1.66	12.92±1.54	0.73

Table 4: Mean value comparison between right and left mastoid process in females

Parameters	Females		P value(t Test)
	Right	Left	
Length(mm)	23.36±2.21	23.89±6.78	0.66
Height(mm)	18.42±2.66	18.34±3.272	0.91
Width(mm)	16.08±2.22	17.09±2.60	0.11
Volume(cm^3)	7.93±1.86	7.86±1.71	0.87

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Table 5: Discriminant function analysis of mastoid process measurements for sex determination

Parameters		Wilks' lambda(p value)	Eigenvalue	Centroids	Accuracy
Length Rt		0.730 (<0.001)	0.371	M: 0.582	M: 60%
	M	D= 1.206 *LengthRt(−18.319)		F: -0.618	F: 87.9%
	F	D= 0.963*LengthRt(−11.968)			Overall: 73.5%
Length Lt		0.891 (0.006)	0.123	M :0.335	M: 65.7%
	M	D= 0.508 *Length Lt (−8.058)		F: -0.355	F: 63.6%
	F	D= 0.471 *Length Lt (−5.700)			Overall:64.7%
Height Rt		0.585 (<0.001)	0.708	M: 0.805	M: 77.1%
	M	D= 3.185 *Height Rt(−37.076)		F: -0.854	F: 81.8%
	F	D= 2.565 *Height Rt(−24.352)			Overall: 79.4%
Height Lt		0.749 (<0.001)	0.336	M: 0.554	M: 68.6%
	M	D= 1.618*Height Lt(−18.960)		F: -0.588	F: 72.7%
	F	D= 1.312*Height Lt(−12.761)			Overall: 70.6%
Width Rt		0.952 (0.072)	0.051	M: -0.215	M: 62.9%
	M	D= 2.774 *Width Rt(−21.575)		F: 0.228	F: 57.6%
	F	D= 2.964 *Width Rt(−24.600)			Overall: 60.3%
Width Lt		0.924 (0.023)	0.083	M: -0.275	M: 68.6%
	M	D= 2.205 *Width Lt(−18.380)		F: 0.292	F: 60.6%
	F	D= 2.415 *Width Lt(−21.974)			Overall: 64.7%
Volume Rt		0.316 (<0.001)	2.167	M: 1.408	M: 97.1%
	M	D= 4.191 *Volume Rt(−28.013)		F: -1.494	F: 90.9%
	F	D= 2.546 *Volume Rt(−10.820)			Overall: 94.1%
Volume Lt		0.287 (<0.001)	2.481	M: 1.507	M: 94.3%
	M	D= 4.859 *Volume Lt)−32.071)		F: -1.598	F: 93.9%
	F	D= 2.956 *Volume Lt)−12.342)			Overall :94.1%
Overall		0.147 (<0.001)	5.790	M: 2.302	M: 100%
	M	D = 2.188 (Length Rt) + 5.970 (Height Rt) + 6.233 (Width Rt) + 4.359 (Volume Rt) + 1.428 (Length Lt) + 2.617 (Height Lt) + 5.223(Width Lt) + 5.873 (Volume Lt) - 306.676		F: -2.441	F: 100%
	F	D = 1.812 (Length Rt) + 5.128 (Height Rt) + 5.804 (Width Rt) + 3.149 (Volume Rt) + 1.241 (Length Lt) + 2.134 (Height Lt) + 4.866 (Width Lt) + 4.237 (Volume Lt) - 222.234			Overall: 100%

M – Male, F – Female; Rt – Right, Lt – Left

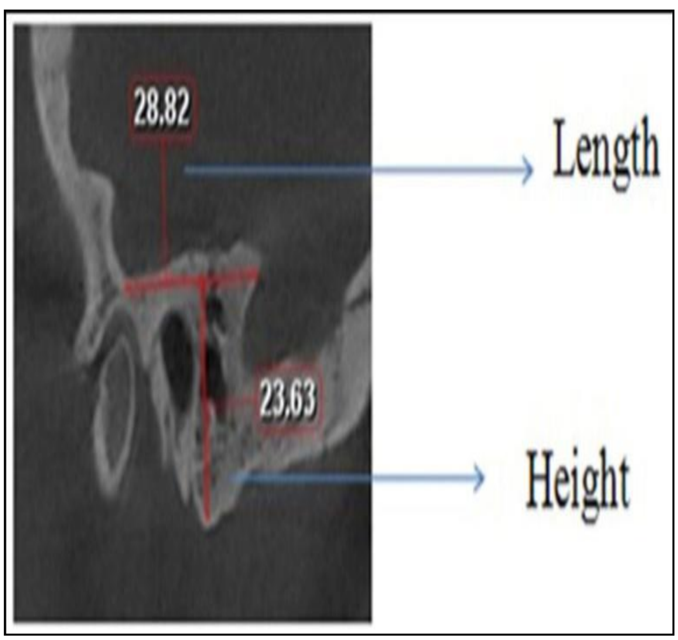

Figure 1: Sagittal section showing length and height of mastoid process

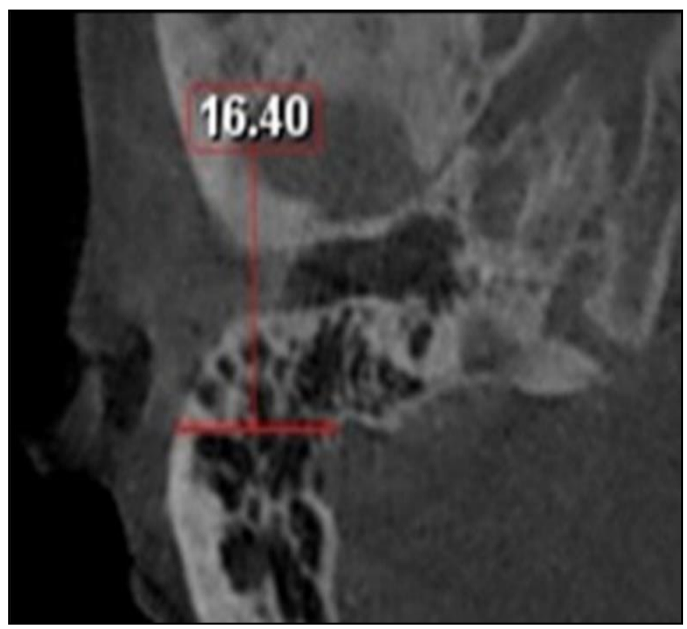

Figure 2: Axial section showing width of mastoid process

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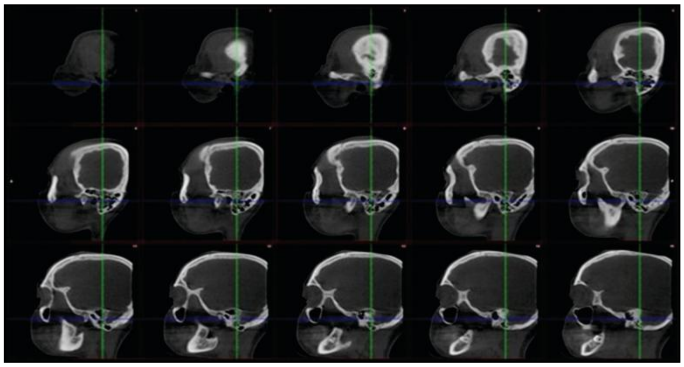

Figure 3: Multiple slices of 0.4 mm thickness of specific (mastoid) area

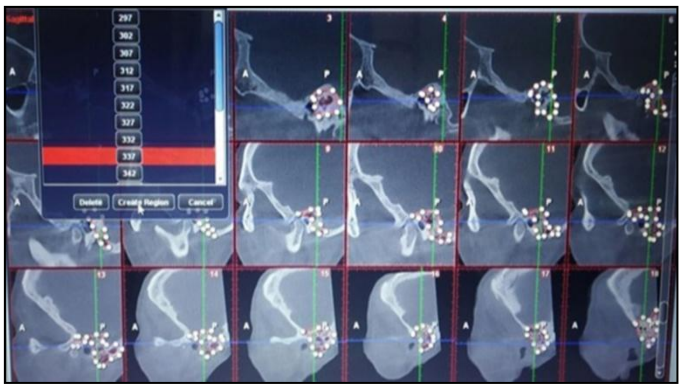

Figure 4: Outline defining of mastoid process on sagittal section by manual segmentation tool

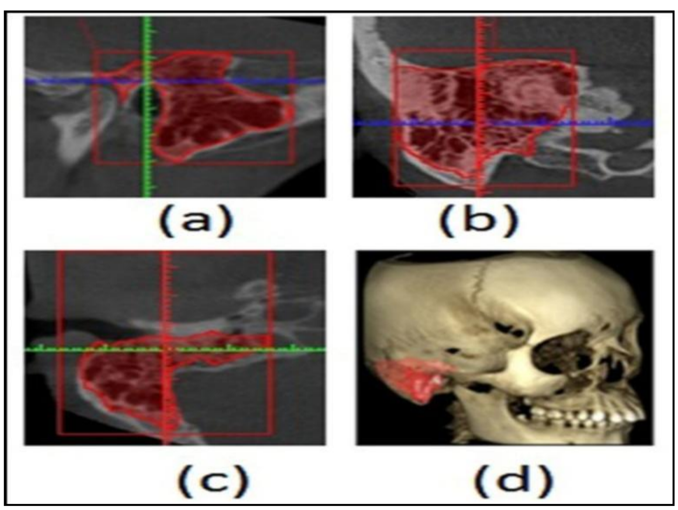

Figure 5: Volume measurement for the segmented area visible in (a) sagittal, (b) coronal, (c) axial and (d) 3D view

Discussion:

In this study, mastoid measurements in males were greater than females and all parameters showed significant difference between sexes except mastoid width which was non-significant. The morphometric parameter results of present study, are in accordance with Bernard and Kristen and Amin CBCT images of Jordon and Indian population respectively **[3, 16].** Compared with the current study, Indian dry skulls studies by Sumati *et al.* and Passey *et al.* revealed lower mastoid length and width, but higher height **[5, 12].** The different methodologies *i.e.* skull verses radiographic details could be the factor responsible for this difference. Apart from morphometric parameters, mastoid volume measurement has significant forensic applications, particularly in the identification of unknown human remains when conventional identification methods are unavailable **[19]**. Mastoid volume may improve the accuracy of gender discrimination, thereby enhancing the identification process **[20]**. A study on multidetector CT used mathematical formula to evaluate mastoid volume to discriminate gender and revealed greater volume in Egyptian male than female **[21].** Assessment of mastoid air cell volume using CBCT provides an objective and reproducible parameter that can aid in gender estimation **[22]**. To the best of our knowledge, this study is the first to use a manual segmentation tool to measure the mastoid process volume using a CBCT DICOM image, showing a statistically significant difference between males and females. Mean mastoid volumes of present study were comparable to Allam *et al.* (mean value 13.09±3.6 in males and 8.43±3.3 in females) **[15].** A study by Koc *et al.* on high resolution computed tomography measuring the normal mastoid air cell system in Turkey population revealed the normal range of mastoid volume from 6 to 10 cm^3, almost similar to the result of present study **[23].** The present study provides baseline values for mastoid process volume to correlate with any alterations in size and volume of mastoid processes, which are frequently affected by trauma and ear diseases. Turgut and Tos assessed reduced mastoid length in pathologic eardrum and middle ear adhesion specimens **[24].** Mastoid cell volume is affected by middle ear damage in children, including recurrent acute otitis media or otitis media with effusion **[25].** Trauma can so pacify of mastoid air cells thus inhibiting the growth of mastoid process **[26].** As volumetric assessment studies of mastoid process by CBCT have not been done earlier therefore its comparison with other studies could not be done. For the same reason future research in this aspect in addition to morphometric analysis between different and larger populations would help to get standard cutoff values. These values could then be helpful for estimating gender by the forensic physician. The slight side-wise asymmetry observed in the present study, may reflect normal biological variation in mastoid development, influenced by temporal bone pneumatization, middle ear health during childhood, functional loading and muscle attachments, including those of the sternocleidomastoid muscle; however the exact mechanism remains uncertain and require further investigation **[27]**.

Conclusion:

CBCT-based morphometric and volumetric assessment of the mastoid process showed significant sexual dimorphism in the North Indian population. The derived discriminant function equations further emphasize that mastoid volume and height contribute most strongly to sex discrimination, followed by width and length parameters. These findings underscore the forensic relevance of the mastoid process, particularly volumetric assessment, as a reliable indicator for sex determination.

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