CBCT-BASED MORPHOMETRIC EVALUATION OF MAXILLARY AND SPHENOID SINUSES FOR AGE AND SEX DETERMINATION IN A SOUTH INDIAN POPULATION

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ABSTRACT

Among the paranasal sinuses, maxillary and sphenoid sinuses show considerable anatomical variation and sexual dimorphism, making them useful structures in forensic identification. Cone Beam Computed Tomography (CBCT) allows accurate three-dimensional evaluation of these structures with relatively low radiation exposure. The present study aimed to assess the usefulness of linear and volumetric measurements of the maxillary and sphenoid sinuses obtained from CBCT for age and sex estimation in a South Indian population. A retrospective observational study was conducted using 70 archived CBCT scans comprising 35 males and 35 females between 20 and 70 years of age. Linear measurements including height, width, and length, along with volumetric measurements of the bilateral maxillary and sphenoid sinuses, were obtained using RadiAnt DICOM Viewer and ITK-SNAP software. Independent sample t-test was used for sex comparison, while one-way ANOVA and linear regression analysis were used for age estimation. Receiver operating characteristic (ROC) analysis was performed to evaluate predictive accuracy. Males generally exhibited greater linear and volumetric sinus dimensions than females. Statistically significant differences were observed in left maxillary sinus length ($p = 0.04$), bilateral maxillary sinus volumes ($p = 0.01$ and $p = 0.04$), and bilateral sphenoid sinus volumes ($p = 0.04$ and $p = 0.01$). Among all evaluated parameters, right sphenoid sinus volume demonstrated the highest predictive accuracy for sex estimation, with an accuracy of 80% for males and 68% for females. Significant associations were also observed between sinus height, sinus volume, and age groups ($p < 0.05$). Regression analysis demonstrated that selected maxillary and sphenoid sinus parameters contributed significantly to age estimation.

Keywords: Forensics, disasters, Cone Beam Computed Tomography, maxillary sinus, sphenoid sinus.

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INTRODUCTION

In forensic sciences, personal identification is essential because of its legal, social, and humanitarian significance. Biological profiling in forensic anthropology commonly involves estimation of age, sex, stature, and ancestry, among which sex determination is considered a crucial initial step in narrowing the identification process. In situations such as mass disasters, wars, explosions, and accidents, skeletal remains are often fragmented or damaged, making identification difficult. Therefore, anatomical structures that exhibit sexual dimorphism and

resistance to postmortem destruction are of particular forensic importance.[1,2]

The skull is regarded as one of the most reliable skeletal structures for sex determination after the pelvis because of its durability and preservation even after severe trauma or burning. Among craniofacial structures, the paranasal sinuses demonstrate considerable anatomical variability and sexual dimorphism, making them valuable adjuncts in forensic identification.[3,4] The maxillary and sphenoid sinuses possess unique anatomical contours that differ among individuals and can be reliably evaluated radiographically for age and sex estimation.[5,6]

Cone Beam Computed Tomography (CBCT) has gained importance in forensic odontology because it provides accurate three-dimensional visualization of craniofacial structures with relatively lower radiation exposure and high spatial resolution compared to conventional computed tomography.[4,7] Previous studies have investigated the linear dimensions and volumes of the maxillary and sphenoid sinuses for forensic applications; however, inconsistent findings regarding their reliability for age and sex estimation continue to exist.[8–12] Therefore, the present study aimed to evaluate the usefulness of linear and volumetric measurements of the maxillary and sphenoid sinuses using CBCT for age and sex determination in a South Indian population.

MATERIALS AND METHOD

Study Design and Sample Selection

A retrospective institutional study was conducted in the Department of Oral Medicine and Radiology at Meenakshi Ammal Dental College using archived full skull CBCT scans obtained between 2019 and 2024. Ethical approval was obtained from the Institutional Ethics Committee (Approval No: MADC/IEC/III/109/202).

A total of 70 CBCT scans comprising 35 males and 35 females aged 20–70 years were included using consecutive sampling. The study population was categorized into five age groups: 20–30, 31–40, 41–50, 51–60, and 61–70 years.

CBCT Acquisition Parameters

All scans were obtained using the PLANMECA PROMAX 3D MID PROFACE CBCT machine. Imaging parameters included 90Kvp, 10mA and with large FOV 13x15cm.

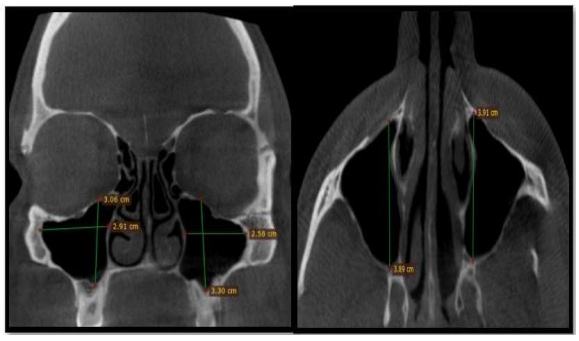
Image Analysis

Linear dimensions were assessed using RadiAnt DICOM Viewer (Version 2025.2), while volumetric analysis was performed using ITK-SNAP (Version 3.8.0). Multiplanar reconstruction views in axial, coronal, and sagittal sections were used for image evaluation and morphometric assessment. All analyses were independently performed by the principal investigator and two experienced Oral and Maxillofacial Radiologists, with repeat evaluation after a two-week interval to assess reproducibility and reliability.

Linear Measurements of the Maxillary Sinus

The maximum width, height, and length of the maxillary sinus were assessed using coronal and axial CBCT sections. Width and height were measured on coronal sections demonstrating the greatest mediolateral and superoinferior dimensions, respectively, while length was measured on axial sections showing the greatest anteroposterior dimension (Figure 1).

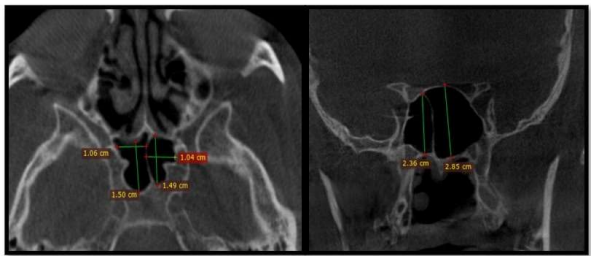
Figure 1. Measurements of right and left maxillary sinus width and height in coronal section and right and left maxillary sinus length in axial section.



Linear Measurements of the Sphenoid Sinus

The maximum length, width, and height of the sphenoid sinus were assessed using axial and coronal CBCT sections. Length and width were measured on axial sections demonstrating the greatest anteroposterior and transverse dimensions, while height was measured on coronal sections showing the maximum vertical dimension (Figure 2).

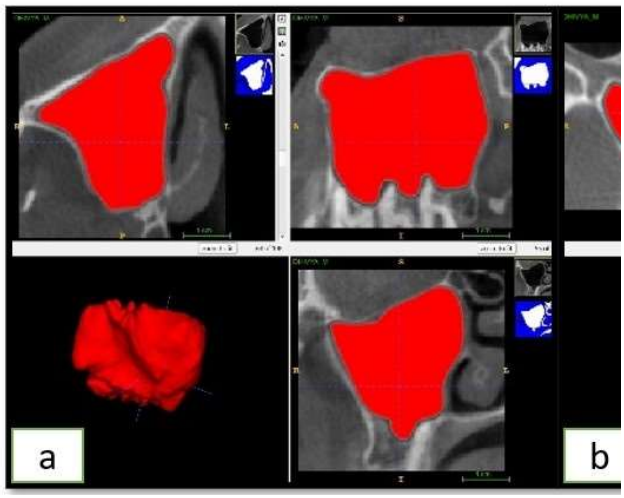
Figure 2. Measurements of right and left sphenoid sinus width and length in axial section and right and left sphenoid sinus height in coronal section.



Volumetric Analysis (Figure 3a,3b)

CBCT DICOM images were imported into ITK-SNAP software for volumetric assessment. The maxillary and sphenoid sinuses were identified in axial, coronal, and sagittal planes. Semi-automatic segmentation was performed using the active contour region-growing tool by placing seed points within the sinus cavity and adjusting threshold values to include air-filled spaces while excluding adjacent anatomical structures. Right and left sinuses were segmented separately. Following segmentation, three-dimensional reconstruction was generated, and sinus volumes were automatically calculated by the software in cubic millimeters (mm^3).

Figure 3: Volumetric filling of a) maxillary and b) sphenoid sinuses in ITK SNAP viewer



Statistical Analysis

Statistical analysis was performed using Statistical Package for Social Sciences (SPSS) software version 27.0. Descriptive statistics including mean, standard deviation, 95% confidence interval, minimum, and maximum values were calculated. Independent sample t-test was used to compare sinus parameters between males and females. One-way ANOVA was used to compare sinus parameters among different age groups. Receiver Operating Characteristic (ROC) analysis was performed to assess the accuracy of sex prediction. Linear regression analysis was used to derive regression equations for age estimation. A p-value of less than 0.05 was considered statistically significant.

		Mean	SD	95 % CI	Minimum	Maximum
Width	**Right**	1.59	0.43	1.48 - 1.69	0.82	2.73
	Left	1.70	0.50	1.58 - 1.82	0.68	3.08
Height	**Right**	2.29	0.33	2.21 - 2.37	1.55	3.16
	Left	2.33	0.36	2.25 - 2.45	1.45	3.3
Length	**Right**	2.24	0.61	2.09 - 2.38	1.02	4.02
	Left	2.21	0.67	2.05 - 2.37	0.78	4.05
Volume	**Right**	123.25	16.83	117.31- 139.19	94.62	170
	Left	116.65	10.24	112.12- 130.86	90.02	172

RESULTS

The descriptive statistics of the maxillary sinus parameters are presented in Table 1. The mean maxillary sinus width was slightly greater on the right side (2.48 ± 0.49) compared to the left side (2.45 ± 0.48). In contrast, the left maxillary sinus demonstrated marginally greater mean height (3.69 ± 0.50) and length (2.99 ± 0.50) than the right side (3.62 ± 0.44 and 2.90 ± 0.50, respectively). Volumetric analysis revealed a higher mean volume on the right side (332.86 ± 15.51 mm^3) compared to the left side (310.61 ± 16.70 mm^3). The 95% confidence intervals of the bilateral measurements showed considerable overlap, indicating relatively symmetrical distribution of the linear dimensions.

Table 1: Descriptive statistics of Maxillary sinus parameters.

		Mean	SD	95% CI	Minimum	Maximum
Width	**Right**	2.48	0.49	2.36-2.60	1.47	4.07
	Left	2.45	0.48	2.34-2.57	1.38	3.63
Height	**Right**	3.62	0.44	3.52-3.73	1.99	4.45
	Left	3.69	0.50	3.57-3.81	1.92	4.62
Length	**Right**	2.90	0.50	2.78-3.02	1.96	4.25
	Left	2.99	0.50	2.87-3.11	1.67	4.03
Volume	**Right**	332.86	15.51	314.8-350.8	270.8	407.2
	Left	310.61	16.7	292.3-328.9	258.1	333.6

The descriptive statistics of the sphenoid sinus parameters are shown in Table 2. The left sphenoid sinus exhibited slightly greater mean width (1.70 ± 0.50) and height (2.33 ± 0.36) compared to the right side (1.59 ± 0.43 and 2.29 ± 0.33, respectively). Conversely, the right sphenoid sinus demonstrated marginally greater mean length (2.24 ± 0.61) and volume (123.25 ± 16.83 mm^3) than the left side (2.21 ± 0.67 and 116.65 ± 10.24 mm^3, respectively). The range of linear measurements was comparable between the right and left sphenoid sinuses.

Table 2. Descriptive statistics of sphenoidal sinus parameters

The association between maxillary sinus parameters and gender is presented in Table 3. Males demonstrated higher mean values than females for all evaluated maxillary sinus dimensions. Among the linear measurements, a statistically significant difference was observed only for left maxillary sinus length, which was greater in males (3.10 ± 0.48) than in females (2.88 ± 0.50) (p = 0.04). Bilateral maxillary sinus volumes were also significantly greater in males than females on both the right side (344.92 ± 13.36 vs 320.80 ± 15.76; p = 0.01) and left side (323.51 ± 18.80 vs 297.70 ± 10.79; p = 0.04).

Table 3. Association between maxillary sinus parameters and gender

		Males	Females	p-value
Width	**Right**	2.54±0.51	2.42±0.46	0.28
	Left	2.54±0.50	2.36±0.45	0.12
Height	**Right**	3.69±0.41	3.56±0.46	0.22
	Left	3.75±0.56	3.63±0.44	0.32
Length	**Right**	2.94±0.54	2.86±0.46	0.55
	Left	3.10±0.48	2.88±0.50	**0.04***
Volume	**Right**	344.92±13.36	320.80±15.76	**0.01***
	Left	323.51±18.8	297.7±10.79	**0.04***

Table 4 summarizes the association between sphenoid sinus parameters and gender. Males demonstrated higher mean values than females for all sphenoid sinus measurements. However, statistically significant differences were observed only in volumetric measurements. The mean right sphenoid sinus volume was significantly greater in males (128.61 ± 13.18) than in females (117.89 ± 10.43) (p = 0.04). Similarly,

the left sphenoid sinus volume was significantly greater in males (123.61 ± 14.31) compared to females (109.39 ± 15.90) (p = 0.01).

Table 4. Association between sphenoidal sinus parameters and gender

		Males	Females	p-value
Width	**Right**	1.60±0.47	1.57±0.39	0.77
	Left	1.79±0.50	1.61±0.50	0.13
Height	**Right**	2.29±0.28	2.29±0.37	0.99
	Left	2.39±0.37	2.27±0.34	0.17
Length	**Right**	2.33±0.63	2.14±0.59	0.21
	Left	2.29±0.65	2.14±0.68	0.36
Volume	**Right**	128.61±13.18	117.89±10.43	**0.04***
	Left	123.61±14.31	109.39±15.90	**0.01***

One-way ANOVA demonstrated statistically significant variations in selected sinus parameters across different age groups. Among the maxillary sinus measurements, left maxillary sinus height showed a significant difference between age groups (p < 0.001). In addition, both right and left maxillary sinus volumes demonstrated significant age-related differences (p < 0.001). Similarly, for the sphenoid sinus, left sphenoid sinus height differed significantly across age groups (p = 0.02), while bilateral sphenoid sinus volumes also showed statistically significant variation with age (p = 0.01).

ROC analysis demonstrated that right sphenoid sinus volume showed the highest predictive accuracy for sex estimation, with 80% accuracy for males and 68% accuracy for females at a cutoff value of 107.22 (Table 5).

Table 5. Accuracy of gender prediction using maxillary sinus and sphenoidal sinus parameters using ROC analysis

	Cut-off value	**Area under the curve**	**Accuracy in Prediction of males**	**Accuracy in Prediction of females**
Maxillary sinus Length (Left)	2.77	0.62	70%	65%
Maxillary sinus Volume (Right)	268.35	0.59	75%	60%
Maxillary sinus Volume (Left)	286.70	0.56	65%	62%
Sphenoidal sinus Volume (Right)	107.22	0.53	**80%**	**68%**
Sphenoidal sinus Volume (Left)	119.52	0.54	75%	63%

Linear regression analysis demonstrated that maxillary sinus height, bilateral maxillary sinus volume, left sphenoid sinus height, and bilateral sphenoid sinus volume contributed significantly to age estimation (p = 0.006). The derived regression equation for age estimation was as follows:

Age = 74.98 − (0.38 × Maxillary sinus height) − (0.07 × Right maxillary sinus volume) + (0.003 × Left maxillary sinus volume) − (13.78 × Left sphenoid sinus height) + (0.05 × Right sphenoid sinus volume) + (0.05 × Left sphenoid sinus volume)

Age-related variations in sinus morphometry demonstrated statistically significant differences in selected parameters. Left maxillary sinus height showed a progressive decrease with advancing age (p < 0.001). Bilateral maxillary sinus volumes were highest in the younger age groups and gradually decreased with age, with a slight increase observed in the 61–70 years age group (p < 0.001). Similarly, left sphenoid sinus height demonstrated significant variation across age groups (p = 0.02). Bilateral sphenoid sinus volumes also showed significant age-related differences, with relatively higher values observed in younger individuals and in the older age group of 61–70 years (p = 0.01).

DISCUSSION

The paranasal sinuses, among other craniofacial structures, are considered valuable forensic markers because of their anatomical variability, resistance to postmortem destruction, and preservation even after severe trauma or burning. Cone-beam computed tomography (CBCT) enables accurate three-dimensional evaluation of these structures with lower radiation exposure and improved image quality with minimal distortion.

In the present study, males demonstrated greater mean values than females for most maxillary and sphenoid sinus parameters. However, statistically significant sexual dimorphism was observed mainly in the volumetric measurements, particularly bilateral maxillary and sphenoid sinus volumes, as well as left maxillary sinus length. These findings suggest that volumetric analysis may provide greater reliability for sex estimation than linear measurements alone.

Tambawala et al.[13] reported maxillary sinus height as a reliable indicator for sex determination, with larger values in males. Although the present study also demonstrated greater dimensions in males, significant differences in height and width were not observed, possibly due to ethnic and methodological variations. The present findings are consistent with Deshpande AA et al.[14] and Demiralp KO et al.[15] who reported significantly greater left maxillary sinus length and sphenoid sinus volumes in males, supporting the greater discriminatory value of volumetric analysis.

ROC analysis in the present study demonstrated moderate predictive accuracy for sinus morphometry. Among all evaluated parameters, right sphenoid sinus volume showed the highest predictive accuracy, with 80% accuracy for males and 68% for females. These findings are comparable with those of Uthman et al.[16] who also highlighted the forensic utility of sphenoid sinus morphometry using CBCT.

With respect to age estimation, significant age-related variations were observed in left maxillary sinus height and bilateral maxillary and sphenoid sinus volumes. Maxillary sinus volumes were highest in younger individuals, gradually decreased with age, and showed a mild increase in older age groups. Similar observations were reported by Jasso-Ramirez et al.[17] and Chandran et al.[18] The increase in sinus volume among older individuals may be associated with alveolar bone resorption, posterior tooth loss, and secondary pneumatization of the maxillary sinus.

We conclude that the present study supports the utility of CBCT-based morphometric evaluation of the maxillary and sphenoid sinuses for forensic age and sex estimation, with volumetric parameters demonstrating greater discriminatory potential than linear dimensions. Limitations of the study include the relatively small sample size and restriction to a single South Indian population, which may limit generalizability. Further multicentric studies with larger sample sizes are recommended to improve reproducibility and forensic applicability.

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