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A comparative analysis of sphenoid and frontal sinuses using cone beam computed tomography for sex determination

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ABSTRACT

Objectives: This study aimed to evaluate linear measurements of the frontal sinus (FS) and sphenoid sinus (SS) for sex identification on cone beam computed tomography (CBCT) images.

Methods: A comparative CBCT analysis was conducted on 200 full field of view (FOV) scans taken as part of routine dental investigations. Dimensions of the bilateral frontal and sphenoid sinuses were measured. Intra- and interobserver reliability were calculated. Independent t tests were used to compare the various parameters between sexes. Stepwise discriminant function analysis was used to determine sex. Additionally, the receiver operating characteristic (ROC) curve, area under the curve (AUC), sensitivity, and specificity were also determined. A p value < 0.05 was considered significant.

Results: A total of 200 CBCT scans were included in the study. The mean age (±SD) among males was 25.66 (±7.11) and that among females was 24.64 (±5.12). The ROC curve revealed that the right length of the frontal sinus showed the greatest accuracy in sex identification in comparison to other linear measurements of the FS and SS. The results of our study indicated that the equation obtained from stepwise discriminant function analysis can aid in sex determination with an accuracy of 76.5 %.

Conclusion: Our findings support the sexual dimorphism of linear measurements of FS and SS. There was an improvement in the accuracy of sex prediction when the linear measurements of FS and SS were considered in combination rather than in isolation. The derived equation can be an adjunctive tool for sex identification for the representative population.

1. Introduction

Catastrophic events usually result in the deformation of human remains, and the establishment of an individual identity remains the primary and necessary goal of forensic science investigations.[1,2] Sex determination is a critical factor in the reconstruction of an unknown individual's biological profile, and it improves the chance of identification by almost 50 %.[2,3] Sex determination is also a critical step in the age estimation process, as usually the parameters evaluated exhibit sexual dimorphism. Usually, sex determination can easily be performed with forensic analysis of the external and internal genitalia. However, this process can be challenging in cases of intersex sex chromosome variations, advanced stages of soft tissue decay, disfiguration, fragmentation, and skeletonization. In this context, anthropometric and morphometric analyses of skeletal structures can be utilized for sex determination.[4]

The innominate bones are considered the most consistent sexually dimorphic bones in the human skeletal system. Sex can also be identified from the skull and long bones by the identification of discrete features, general dimensions, and various discriminant function tests, depending on the completeness of the material.[3] Usually, the integrity of such bones is compromised because they are either fractured or fragmented. The use

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of skeletal structures that are protected by denser bones, such as the paranasal sinuses and skull base, is now recognized to be more reliable in sex determination.[5] The unique structure and variable shape of the paranasal sinuses make them both common and distinctive. These osteological structures are important in forensics due to their long-lasting attributes.[6]

The frontal sinus (FS) is a paired, irregularly shaped, pneumatized cavity located in the frontal bone deep to the superciliary arch. FS, however, is not distinguishable on a radiograph until three years of age. FSs reach the end of development when individuals are 19 or 20 years old and remain stable until they reach old age.[6–8] FSs have been scientifically proven to be unique to each individual, including monozygotic twins, and are unaffected by lineage. Sex, race, pathologies, environmental conditions, growth, and development influence the configuration of the FS.[8] FS is resistant to decay and damage owing to its bony structure and arch nature and thus is likely to be preserved in human remains.[9,10] Although several studies analysing FS characteristics in various populations have been published, only a few have utilized FS for sex determination, and the results have been variable.[9,10]

The anatomy of other paranasal sinuses, specifically the sphenoid sinuses (SSs), is becoming increasingly popular in forensics.[11] The SS is confined within the sphenoid body, which is part of the base of the skull, and this deep anatomical position makes it difficult to view via two-dimensional imaging.[12] Its anatomic position also protects it from injuries and pathological variation.[13] The development of SS begins around the third to fourth month of intrauterine life, and development is complete by twelve years of age. Studies have shown that SS appears in a variety of shapes and sizes and is generally asymmetric. Recent studies have reported that the average volume of SSs is significantly greater in males than in females. However, unlike those of other paranasal sinuses, very few studies have examined the use of anthropometric measurements of the SS for sex identification, especially three-dimensional imaging.[11,14]

In forensic anthropology, many radiographic imaging techniques, such as conventional radiography, computed tomography (CT), and cone-beam computed tomography (CBCT), have been used to examine skeletal dimensions to determine an individual's sex.[15] Radiographs may yield clear images of skeletal characteristics, especially when the bones are covered with varying degrees of soft tissue, allowing for more accurate bone measurements in sex determination. The complicated anatomy of the paranasal sinuses makes computed tomography (CT) the gold standard for determining the exact anatomy. However, its high cost has restricted its use.[3] CBCT overcomes the limitations of CT and has been shown to deliver accurate and reliable linear measurements for dental and maxillofacial reconstruction and imaging.[16] Over the years, CBCT has rapidly become a useful diagnostic tool in forensic investigations. Presently, numerous studies have highlighted the importance of maxillary sinuses and their role in age and sex determination compared to studies highlighting the role of FS and SS in sex determination, which are far and few in number. Thus, considering the variable results of FS in sex determination and the lack of studies associated with SS, we aimed to evaluate the accuracy of both of these sinuses in determining the sex of an individual. Since measurements in two-dimensional images are not as accurate as those in three-dimensional images, measurements of FS and SS using CBCT images were utilized for better accuracy in the present study.

2. Materials & Methods

A retrospective comparative study was conducted in the Department of Oral Medicine and Radiology from July 2020 to April 2021. Measurements of FS and SS were analysed on full field of view (FOV) (200 × 100 mm) CBCT scans retrieved from the archives. The study was approved by the institutional ethics committee (Protocol no 19128). Additionally, patient consent was sought to reproduce the CBCT images for this paper. Patient details were coded, and the investigators were blinded to the patient details. The sample size was calculated based on the article by Wanzeler et al.,[17] published in 2019, considering the standard deviation (SD) value of the right SS taken from Wanzeler et al.[17] At an alpha error of 1 %, a power of 90 %, and a standard deviation of 2.92, the sample size was calculated to be 100 in each group.

Image Acquisition: CBCT scans were performed using a Planmeca ProMax 3D Mid CBCT machine (Romexis Version 4.6.2 R; Planmeca, Helsinki, Finland). Full field of view (FOV) scans (200 × 100 mm) with a voxel size of 400 μm and exposure parameters of 90 kVp, 5.6 mA, and 18 s were retrieved from the archives. The inclusion criteria for the study were scans of patients above 20 years of age with full complement of teeth. The scans of patients who were less than 20 years of age, subjects who had undergone any SS or FS surgery, images that presented pathologies of the SS and FS, any facial deformity in the field of view, and images with distortions/artifacts were excluded from the study.

Image Analysis: The images were viewed in an HP Compaq 8200 Elite CMT PC x19 inch light-emitting diode backlit liquid-crystal display (LCD) monitor of 48.3 cm (19 inches) with a viewable area display of 1280x1024. Images with a slice thickness and interval of 0.4 mm were utilized for the study. The multiplanar reconstructed images were aligned in three planes such that the axial orientation of the slices was aligned to the Frankfurt horizontal plane. The coronal orientation of the slices was aligned to the plane along the anterior margins of the right and left external acoustic meatus, and the sagittal orientation of the slices was aligned to the mid-sagittal plane as described by Balachandran et al.[18] The landmarks and planes were identified and aligned by correlating the 3D reconstructions as well as multiplanar imaging.

The various parameters were measured in axial and coronal sections. The length and width of the FS and SS were measured in the axial plane for the sections that exhibited the greatest dimensions (Fig. 1a, b, 2a, and 2b). The maximum anteroposterior dimension was considered the greatest length, and the maximum mediolateral dimension was considered the greatest width. The heights of the SS and FS were measured as the maximum distance between the lowest point of the floor and the uppermost point of the roof of the respective sinuses on coronal sections (Fig. 1c and 2c). All measurements were carried out by two experienced maxillofacial radiologists at different time intervals. The radiologists were unaware of the sex of the patient. The principal investigator repeated the measurements of 40 scans after 2 months. Each of the scans was number coded, and the measurements of the scans were correlated to the sex of the individual by another investigator. Intra- and interobserver reliability were calculated.

2.1. Statistical analysis

Statistical analysis of the collected data was performed using SPSS version 2.5 (IBM SPSS® Statistics). The intraclass correlation coefficient was used to determine the inter- and intraobserver reliability. Comparisons of differences between males and females in the examined dimensions of the frontal and sphenoid sinuses were performed using independent t tests. Equations predicting sex differences using the examined parameters were derived via discriminant analysis. Additionally, the receiver operating characteristic (ROC) curve, area under the curve (AUC), sensitivity, and specificity were also estimated. A p value < 0.5 was considered significant.

3. Results

A total of 200 CBCT scans were included in the study. The mean age in years (±SD) among males and females was 25.66 (±7.11) and 24.64 (±5.12), respectively. The intraclass correlation values ranged from 0.7 to 0.9 for intraobserver reliability and 0.6–0.9 for interobserver reliability, indicating good intraobserver and interobserver reliability. Comparisons of various parameters (bilateral, length, width, and height of the FS and SS) between males and females using independent t tests revealed statistically significant differences in relation to all parameters

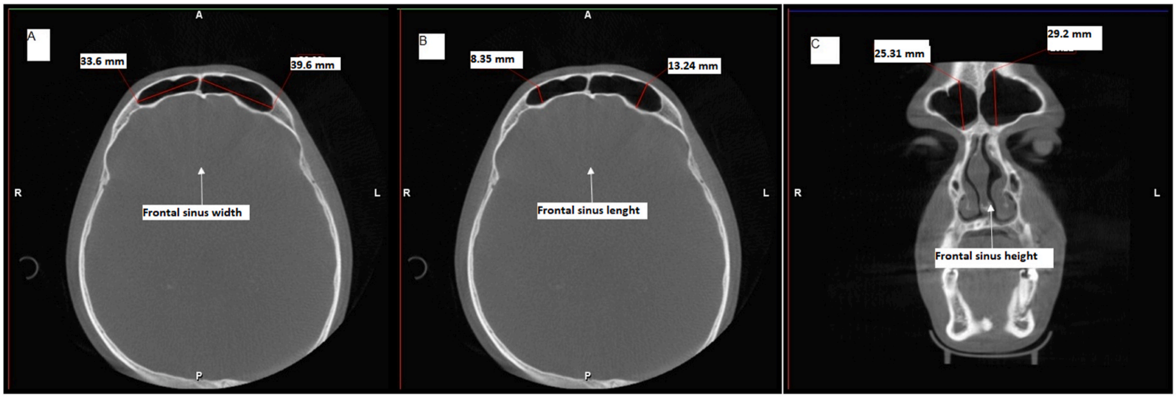

Fig. 1. Linear measurements of the frontal sinus. a- Frontal sinus length; b- Frontal sinus width; c- Frontal sinus height.

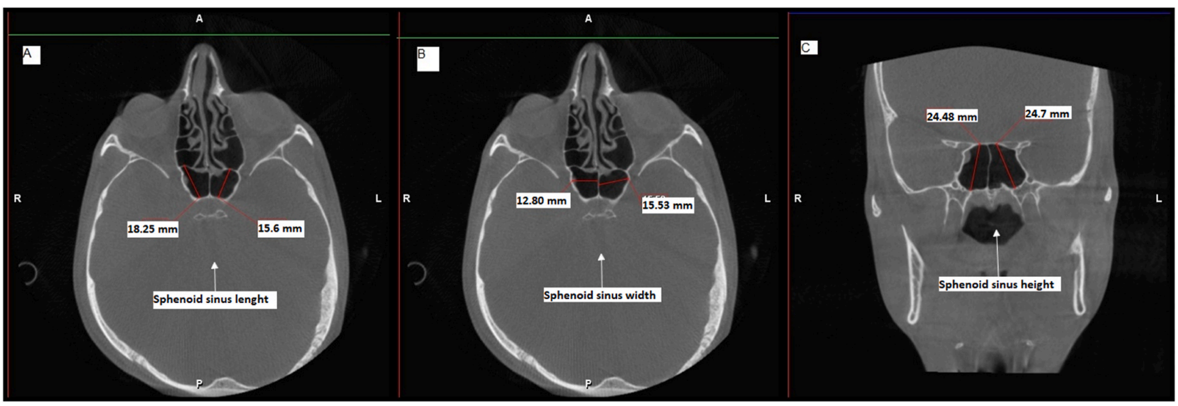

Fig. 2. Linear measurements of the sphenoid sinus. a- Sphenoid sinus length; b - Sphenoid sinus width; c - Sphenoid sinus height.

except the left FS height (Table 1). All parameters showed statistically significant differences except for the right left FS, although the parameters were greater in the male group. Figs. 3 and 4 shows the ROC curve for the various parameters, with the right length of the frontal sinus showing the greatest accuracy in sex identification. The area under the curve (AUC) showed that FS length had acceptable accuracy, with a value of 0.732, compared to other linear measurements of FS and SS (Table 2). The left FS height, left SS height and length had the least accuracy, with AUC values ranging from 0.518 to 0.584. The equation derived through discriminant function analysis for sex determination showed an overall accuracy ranging from 49 % for the right SS length to 75 % for the left FS length. The lowest accuracy was shown by the SS left width and height, with values of 55.10 % and 57.10 %, respectively (Table 3). The highest accuracy of 76.5 % was noted when all the parameters were utilized to derive an equation. The sensitivity and specificity of each cut-off value were calculated (Table 4), with a range of sensitivity from 43 % to 63 % and specificity from 55% to 75 %.

Table 1
Comparison of various parameters between males and females.

Parameters		Male	Female	t	p value
		Mean ± SD (mm)	Mean ± SD (mm)		
FS Length	Left	11.98 ± 2.61	9.85 ± 2.56	5.835	*<0.001
	Right	11.49 ± 2.94	8.7 ± 2.33	7.433	*<0.001
FS Width	Left	34.29 ± 6.62	31.95 ± 6.03	2.614	*0.01
	Right	33.87 ± 6.3	29.93 ± 5.48	4.718	*<0.001
FS Height	Left	30.57 ± 4.54	30.36 ± 4.69	0.309	0.757
	Right	30.61 ± 5.39	28.45 ± 4.44	3.094	*0.002
SS Length	Left	20.12 ± 6.19	18.2 ± 5.07	2.396	*0.018
	Right	19.56 ± 6.84	17.23 ± 4.97	2.75	*0.007
SS Width	Left	15.87 ± 3.95	13.67 ± 4.22	3.799	*<0.001
	Right	16.14 ± 3.29	15.06 ± 3.12	2.366	*0.019
SS Height	Left	27.46 ± 7.08	25.37 ± 6.01	2.25	*0.026
	Right	27.85 ± 5.57	25.39 ± 4.52	3.417	*0.001

Abbreviations SD = standard deviation, FS= Frontal Sinus, SS Sphenoid Sinus. Statistical test: Independent *t*-test B.*Indicates statistically significant value.

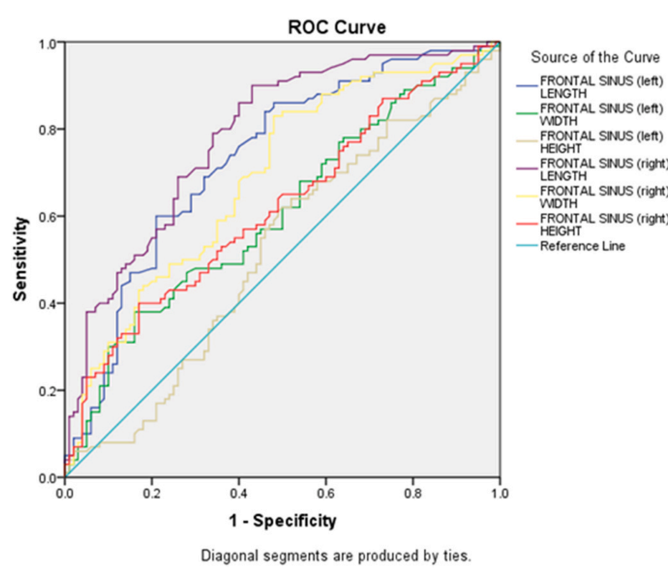

Fig. 3. ROC curve for the various parameters of the frontal sinus.

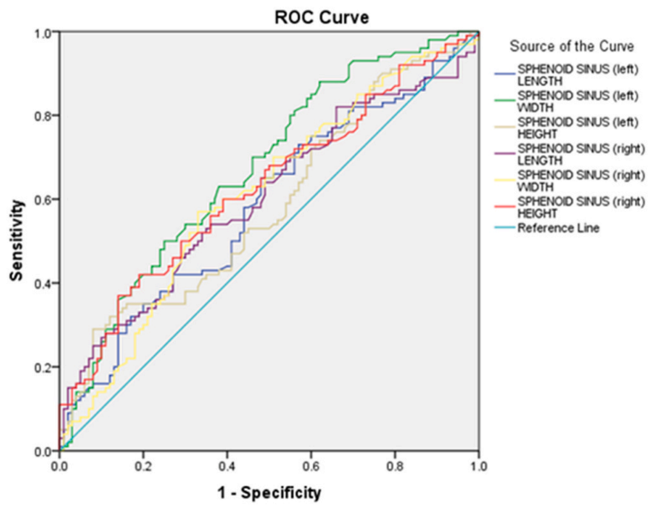

Fig. 4. ROC curve for the various parameters of the sphenoid sinus.

Table 2
Area under the curve of various parameters.

Parameters		Area	Std. Error.[a]	p value	95 % Confidence Interval	
					Lower Bound	Upper Bound
FS Length	Left	0.732	0.036	0.000	0.662	0.802
	Right	0.732	0.032	0.000	0.722	0.848
FS Width	Left	0.605	0.040	0.010	0.527	0.683
	Right	0.690	0.037	0.000	0.617	0.763
FS Height	Left	0.518	0.041	0.655	0.438	0.599
	Right	0.618	0.040	0.004	0.540	0.695
SS Length	Left	0.584	0.040	0.040	0.505	0.663
	Right	0.602	0.040	0.013	0.523	0.680
SS Width	Left	0.671	0.038	0.000	0.597	0.746
	Right	0.609	0.040	0.008	0.531	0.687
SS Height	Left	0.584	0.040	0.040	0.505	0.663
	Right	0.626	0.039	0.002	0.549	0.703

Abbreviations SD = standard deviation, FS= Frontal Sinus, SS Sphenoid Sinus.
Null hypothesis: true area = 0.5.
[a] Under the nonparametric assumption.

4. Discussion

CBCT imaging provides accurate measurements due to its minimal anatomic superimposition and limited magnification, thus improving the applicability of three-dimensional imaging for cranio-morphometric analysis in forensic dentistry. Among the various CBCT measurements explored in our study for assessing sexual dimorphism, FS has been well documented in the literature. However, very few studies have explored the sexual dimorphism of SS, especially using three-dimensional imaging. The results of our study indicated that the equation obtained from stepwise discriminant function analysis can aid in sex determination with an accuracy of 76.5 %.

Sexual dimorphisms related to the skeletal structure emerge during development and during puberty under the influence of hormones.[8] The SS completes its development by the age of twelve[19,] and the FS completes its development by the age of twenty years.[7,8] Hence, in this study, individuals older than 20 years were included. Additionally, it has been postulated that the development of FS and SS is influenced by dentition and the distribution of masticatory forces.[20] Thus, for our study, only dentate individuals with full teeth were included. The reproducibility of the methodology was good considering the interclass correlation values, which is critical for application in the field of forensics.

The individual distinctiveness of the frontal sinuses (FS) has made it popular for human identification. A recent systematic review revealed that the accuracy rates of FS for human identification ranged from 13 % to 100 %.[21] Although FS has shown excellent capabilities for individual identification, its potential for gender discrimination has been relatively less accurate. The potential difference in the configuration of FSs between males and females was evaluated by Goyal et al.[22] The authors found it to be statistically insignificant when examined on a conventional two-dimensional paranasal sinus radiograph. Sex was correctly identified with an accuracy of 60 % using multivariate logistic regression equations. Uthman et al.,[23] considered linear measurements of FS using CT images for sex identification and noted a 76.5 % accuracy. The results improved to 85.9 % when the linear measurements of FS were considered with other measurements of the skull. Rao et al.,[24,] in their study among a population in Saudi Arabia, reported that linear CBCT measurements of the frontal sinus had an accuracy of 63.1 %. Moreover, the width of the FS significantly differed from the height of the FS between males and females. In a similar CBCT study, Sangavi et al.[25] reported that the left FS length and left FS height were significantly different between sexes according to multivariate logistic regression, with p values of 0.011 and 0.002, respectively. Motawie et al.,[26] in their study among the Egyptian population, found similar results with statistically significant differences in linear measurements of FS, with an accuracy of 76.7 % for sex identification. Apart from the width of the left FS, our study revealed significant differences in all other dimensions measured between males and females, which is similar to the findings of studies in the literature[27,28] The accuracy rates for sex determination were better, with the length of the left and right FS showing the highest accuracy of 75.50 % and 71.40 %, respectively, followed by 69.40 % for the right FS width.

To date, the literature has utilized linear and volumetric measurements of the SS for sex identification using three-dimensional imaging. Ramos et al.,[29] in their study on the Brazilian population, found no statistically significant differences in the linear measurements of SS between males and females. However, they found statistically significant results in volumetric measurements of the SS. In addition to linear measurements, pneumatization, morphological characteristics and the volume of the SS have been studied as parameters for individual and sex identification. The variation in results in the literature can be attributed to the varied ethnicity of the population under study and methodological variations. To the best of our knowledge, measurements of SS thus far have not been analysed for predicting sex in the Indian population. The present study revealed significant differences in the length, width, and height of the SS between males and females. The height of the right SS showed the highest accuracy of 71.40 % for sex determination.

The present study shows that the accuracy of linear measurements of FS is better than that of SS, with FS length showing better results. Additionally, it can be noted that the accuracy of the discriminant function equation is improved when the linear measurements of FS along with SS are taken into consideration, which is one of the strengths of this study. The parameters evaluated in this study have shown good results for sex determination and can be considered an adjunctive tool in sex determination. Additionally, this study supports the use of CBCT for imaging FS and SS for sex determination. CBCT images with large FOVs allow for clear imaging of multiple bony structures in the head and neck region. Measurements and evaluations of multiple parameters for the purpose of sex determination can be performed without any additional radiation exposure or cost. Thus, CBCT images allow us to develop sex determination models using multiple parameters to improve accuracy, which can be explored in future studies. Some of the limitations of the study include the exclusion of patients with variations in anatomy (unilateral agenesis, etc.) and pneumatization of the frontal region and SSs. Additionally, the study did not evaluate the presence or pattern of sinus septa for sex determination due to differences in FS and SS septal patterns. Thus, the applicability of these methods for sex identification under such conditions is limited. The results are presently applicable to

Table 3
Equations derived through discriminant function analysis for determining sex.

Equation Discriminant function = constant + coefficient x parameter	Percentage of males correctly classified	Percentage of females correctly classified	Overall Accuracy	male Centroid	female Centroid	Demarcating point
Discriminant function (D) = -4.218 + (0.386) x (FS Left Length)	63	71	75.50 %	0.413	−0.413	10.92746
Discriminant function (D) = -5.232 + (0.158) x (FS Left Width)	52	58	55.10 %	0.185	−0.185	33.11392
Discriminant function (D) = -6.599 + (0.217) x (FS Left Height)	48	56	67.30 %	0.022	−0.022	30.41014
Discriminant function (D) = -3.808 + (0.377) x (FS Right Length)	60	75	71.40 %	0.526	−0.526	10.1008
Discriminant function (D) = -5.406 + (0.169) x (FS Right Width)	55	65	69.40 %	0.334	−0.334	31.98817
Discriminant function (D) = -5.982 + (0.203) x(FS Right Height)	55	61	61.20 %	0.219	−0.219	29.46798
55 61 61.20 % −0.219 0.219						
Discriminant function (D) = -3.387 + (0.177) x (SS Left Length)	43	64	61.20 %	0.169	−0.169	19.13559
Discriminant function (D) = -3.61 + (0.244) x (SS Left Width)	54	66	55.10 %	0.269	−0.269	14.79508
Discriminant function (D) = -4.023 + (0.152) x (SS Left Height)	50	56	61.20 %	0.159	−0.159	26.46711
Discriminant function (D) = -3.075 + (0.167) x (SS Right Length)	51	66	49.00 %	0.194	−0.194	18.41317
Discriminant function (D) = -4.864 + (0.312) x (SS Right Width)	57	67	57.10 %	0.167	−0.167	15.58974
Discriminant function (D) = -5.243 + (0.197) x (SS Right Height)	52	67	71.40 %	0.242	−0.242	26.61421
Discriminant function = -5.452 + 0.197(FS left length -0.063 (FS Left Height) + 0.202 (FS Right Length) + 0.081(SS Left Width) + 0.074 (SS Right Height)	70	83	76.5 %	0.666	−0.666	Na

The Sectioning point was zero or close to zero with regard to all the parameters.
All values are higher in males than in females.
Abbreviations SD = standard deviation, FS= Frontal Sinus, SS Sphenoid Sinus.

Table 4
Sensitivity and specificity for the value of the discriminating point of various parameters.

Parameters		Sensitivity (%)	Specificity (%)
FS Length	Left	63	71
	Right	60	75
FS Width	Left	52	58
	Right	55	65
FS Height	Left	49	55
	Right	55	60
SS Length	Left	43	63
	Right	50	66
SS Width	Left	54	66
	Right	57	67
SS Height	Left	50	56
	Right	52	67

Abbreviations SD = standard deviation, FS= Frontal Sinus, SS Sphenoid Sinus.

the local population only, and future studies need to be planned with linear and volumetric measurements using CBCT images with larger sample sizes for better generalization. CBCT images can be used for versatile analysis of craniofacial structures, including shape and variations and for linear craniometric and volumetric analysis, which could lead to better clinical applicability. Further studies can evaluate the morphological variations and sex determination correlated with cephalometric measurements[30] and additionally explore the scope of artificial intelligence in sex determination.[31]

5. Conclusion

The present study highlights the importance of using CBCT for craniometric analysis in forensics and supports the sexual dimorphism of linear measurements of FS and SS. The results of our study indicated that the equation obtained from stepwise discriminant function analysis can aid in sex determination with an accuracy of 76.5 %. There was an improvement in the accuracy of sex prediction when the linear measurements of FS and SS were considered in combination rather than in isolation. There are very few studies that evaluate linear measurements of FS and SS using CBCT for sex determination, and further studies need to be performed to establish references for different subpopulations.

Authors' contributions

JA: Conception, design of the work; the acquisition, interpretation of data; substantively revised it, approved the submitted version.

N: Conception, design of the work; the acquisition, drafted the work interpretation of data; preparation of tables and figures, substantively revised it, approved the submitted version.

NS*: the acquisition, Analysis, interpretation of data; preparation of tables and figures, substantively revised it, approved the submitted version.

NS: Conception, design of the work, drafted the work, substantively revised it, approved the submitted version.

SN: Conception, design of the work, Statistical analysis, drafted the work substantively revised it, approved the submitted version.

AM: the acquisition, Analysis, interpretation of data; substantively revised it, approved the submitted version.

AS: design of the work, interpretation of data, drafted the work substantively revised it, approved the submitted version.

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Declaration of competing interest

No conflict of interest exists.

We wish to confirm that there are no known conflicts of interest associated with this publication and there has been no significant financial support for this work that could have influenced its outcome.

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None.

List of abbreviations

CT	computed tomography
CBCT	cone-beam computed tomography
FS	Frontal sinus
SS	Sphenoid sinus
FOV	Field of View
ROC	Receiver Operating Characteristic
AUC	Area under the curve

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