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Original Article

Determination of Sex of an Individual by Frontal Sinus Using Multidetector Computed Tomography Scan: A Retrospective Forensic Study

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Abstract

Objectives An important aspect of forensic investigation is determining the sex of an unidentified person. The frontal sinus is unique and remains intact, thus making it suitable for forensic analysis. The main objective of this study is to determine the sex of an individual by frontal sinus using a multidetector computed tomography scan.

Materials and Methods A total of 100 patients (50 males and 50 females) were included in the study, and different parameters of the frontal sinus for both sides were analyzed, that is height, width, depth, and total length.

Statistical Analysis Descriptive statistics of all the variables were computed and compared. SPSS version 16 was used to perform the Mann–Whitney *U* test, binary logistic regression, and receiver operating characteristic (ROC) curve analysis on the acquired data.

Results The result suggested that males have higher mean values than females, with the left frontal sinus height being the only variable to be statistically significant ($p < 0.05$). Based on the ROC curve analysis, the optimum cutoff value was 0.489, which means if the predicted probability value was less than 0.489, the individual was considered a male; and if the predicted probability value was $\geq$0.489, the individual was considered a female. The accuracy of the mathematical model based on binary logistic regression analysis for determining sex was 70% for females and 66% for males.

Conclusions The present study plays a significant role in determining sex in the Indian population by using left frontal sinus height measurement through a multidetector computed tomography scan.

Keyword
- demarcation point
- frontal sinus
- multidetector computed tomography
- sex determination

Introduction

Sex determination becomes the first precedence in the process of identification of a person, especially in cases like accidents, natural disasters, ethnic studies, etc.[1] Sex determination is defined as the process of identifying an individual's identity and is commonly required to recognize unknown remains. Many methods may be applied in a venture to identify unknown human remains including fingerprint scanning, deoxyribonucleic acid (DNA) verification, anthropological tests, and radiological techniques.[2] Fingerprinting is a generally accepted procedure for accurately identifying not only the remains of sex but also their identity. However, there are cases in which the collection of a fingerprint has become difficult or impossible due to remains being poorly decayed. DNA analysis is also generally

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accepted; however, this method can be very time-consuming and expensive, and the availabilities of legal laboratories are very low in India.[3] Ontologically there are many probable landmarks that can be used for the identification of an individual, that is, femur, pelvis, scapula, etc. When other means of identification have failed to recognize and only skull remains have been recovered, the frontal sinus can be used for identification. In badly damaged structures, the frontal bone can be recovered intact, making the frontal sinuses within the bone useful in sex determination. This is because the frontal sinus is a particularly strong region of the skull and it can be saved in burnt or disassembled bodies and retrieved after a disaster.[4] Due to its location and diverse clinical manifestations, the frontal sinus is the most complex of the paranasal sinuses (PNSs). This characteristic makes the frontal sinus an important tool in sex determination.[5] The primary goal of the study is to determine the sex of the frontal sinus (FS) using multidetector computed tomography (MDCT) in the Indian populations.

Materials and Methods

The retrospective study was conducted using computed tomography (CT) images of the brain acquired using a 32-slice Siemens Somatom CT scanner. To perform the present study, ethical approval was obtained from the Institutional Ethics Committee of CHARUSAT University (CHA/IEC/ADM/22/02/124).

The minimum sample size was estimated with the following formula:

$$n = 4 \times p \times q / l^2,$$

where prevalence rate p is 0.03; q is equal to 1–p, that is, 0.97; allowable error l^2 is 0.0025.

$$n = 4 \times 0.03 \times 0.97 / 0.0025.$$
$$n = 46.56 \approx 47.$$

This study was conducted between September 2021 and May 2022, with a total of 100 participants (50 males and 50 females). The patients undergoing routine CT of the brain in the age group of 16 to 60 years and without any deformities and pathologies were included in the study. Patients having any systematic bone disease or patients with facial trauma were excluded from this study.

The patients were positioned on the CT table in the supine head first position, with the area coverage from the base of the skull to the vertex. The scan direction was caudocranial with no gantry angulations. A routine CT brain protocol (512 × 512 matrix, field of view [FOV] 250 mm, 120 kVp, 250 mA) was used to acquire raw data. The helical CT scan was carried out and data were acquired in an axial plane with 5-mm slice thickness and 5-mm incrementation. The raw data were reconstructed to the sagittal and coronal plane (1 mm thickness and 1 mm incrementation) by using the multiplanar reconstruction (MPR) technique.

A total of seven measurements were acquired using the measurement tool in the DICOM viewer: (1) width of the right frontal sinus, (2) width of the left frontal sinus, (3) height of the right frontal sinus, (4) height of the left frontal sinus, (5) depth of the right frontal sinus, (6) depth of the left frontal sinus, and (7) total frontal sinus length: distance between the lateral margins of the left and right frontal sinuses (►**Fig. 1**).

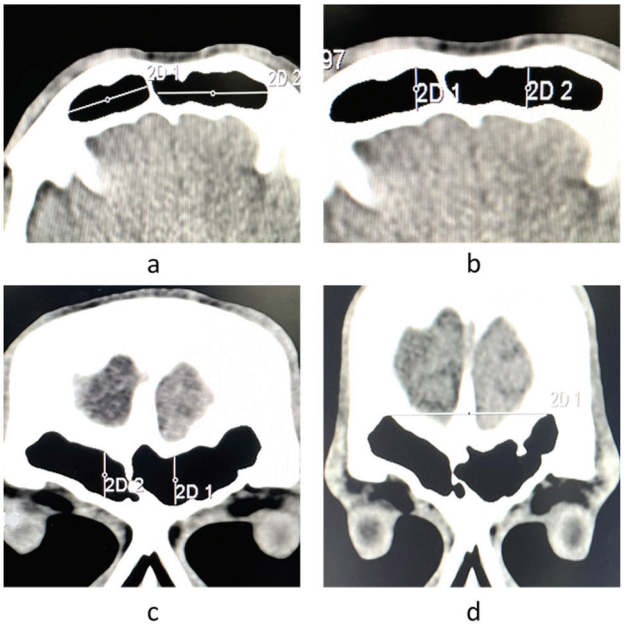

Fig. 1 Measurements of frontal sinus variables. (**a**) Maximum width of the right and left frontal sinuses. (**b**) Maximum depth of the right and left frontal sinuses. (**c**) Maximum height of the right and left frontal sinuses. (**d**) Total frontal sinus length: Distance between the lateral margins of the left and right frontal sinuses.

Statistical Analysis

The Social Package of Statistical Science software (SPSS, version 16.0) was used for the analysis of data. The descriptive statistics were carried out, where the mean and standard deviation were calculated. After that, further analysis was done using the Mann–Whitney *U* test and binary logistic regression.

Results

A total of 100 participants comprising 50 males and 50 females between the ages of 16 and 60 years were included in the study. In the present study, we have used descriptive statistics to assess the mean and standard deviation of the entire population.

The mean measurements of the frontal sinus for both male and female populations that is, height, width, and depth of the right and left frontal sinuses, and the distance between the right and left frontal sinuses, are shown in ►**Table 1**.

Shapiro–Wilk tests were performed to check the normality of the data. In this present study, the data were not normally distributed, so the Mann–Whitney *U* test was used to see if there is any statistically significant difference in the frontal sinus measurements between the sexes. The lower

Table 1 Descriptive analysis of both sexes

Frontal sinus (FS) variables measurements	Sex	Mean	Standard deviation
Right FS height	Male	2.36	0.73
	Female	2.11	0.72
Left FS height	Male	2.49	0.83
	Female	2.07	0.67
Right FS width	Male	1.87	0.72
	Female	1.82	0.73
Left FS width	Male	3.05	11.34
	Female	1.7	0.78
Right FS depth	Male	1	0.306
	Female	0.9	0.27
Left FS depth	Male	1	2.55
	Female	0.99	0.28
Total FS length	Male	5.13	1.15
	Female	4.85	1.24

the *U* statistic value (i.e., *p*-value), the better the results. In this study, the left frontal sinus height shows a statistically significant difference between the two groups, that is, males and females ($p < 0.05$). Other variables were not statistically significant, as shown in ►**Table 2**. All the quantitative variables were summarized as median [Q_1, Q_3] (►**Table 2**).

Furthermore, binary logistic regression was used to determine sex using frontal sinus measurements. It is a regression model with a binary target variable, which means it can take only two values, either 0 or 1. It is used when the response is binary (►**Table 3**).

Based on the regression coefficients, a formula was developed to predict the probability of the gender.

$$\text{Predicted probability} = \frac{\exp(3.303 + (0.608 * \text{FS RT height}) + (-1.218 * \text{FS LT height}) + (0.130 * \text{FS RT width}) + (-0.192 * \text{FS LT width}) + (-0.380 * \text{FS RT depth}) + (0.306 * \text{FS LT depth}) + (-0.315 * \text{FS distance}))}{1 + \exp(3.303 + (0.608 * \text{FS RT height}) + (-1.218 * \text{FS LT height}) + (0.130 * \text{FS RT width}) + (-0.192 * \text{FS LT width}) + (-0.380 * \text{FS RT depth}) + (0.306 * \text{FS LT depth}) + (-0.315 * \text{FS distance}))}$$

Table 3 Binary logistic regression for the determination of sex

Measurements of frontal sinus (FS)	Beta coefficients	*p*-value
Right FS height	0.608	0.268
Left FS height	−1.218	0.029
Right FS width	0.130	0.795
Left FS width	−0.192	0.716
Right FS depth	−0.380	0.705
Left FS depth	0.306	0.773
Total FS length	−0.315	0.124
Constant	3.303	0.036

The diagnostic accuracy of the frontal sinus to identify the sex of the individuals was evaluated using the ROC curve. Based on the ROC curve analysis, the present model has an area under the curve of 0.733, indicating the model is a good fit, as shown in ►**Fig. 2**.

The optimum cutoff value for predicted probability was 0.489. If the predicted probability value was less than 0.489, the individual was considered male and if the predicted probability value was ≥0.489, the individual was considered female. The cutoff value (0.489) has 66% correct classification for males and 70% for females (►**Table 4**).

Discussion

Identification of an individual from an incomplete skeleton can be one of the most challenging tasks in the field of forensic science. When a patient's body is burned and an unknown body is recovered in a natural disaster, forensic research and anthropological analysis become critical in identifying the individual. The frontal sinus is chosen because it is rigid and remains intact in human remains, making it suitable for forensic analysis. The present study was conducted on individuals aged ≥16 years as the frontal sinuses are said to attain full maturity by this age.[6]

Tatlisumak et al conducted a study based on gender identification from frontal sinus in Turkish population. They reported that frontal sinus measurements were usually higher in females than in males, especially in the age group of

Table 2 Comparison of outcome variables between the groups

Variables	Male ($n = 50$)			Female ($n = 50$)			*U*statistic (*p*-value)
	Median	Q_1	Q_3	Median	Q_1	Q_3	
Right frontal sinus height	2.35	1.79	2.99	2.05	1.44	2.68	997.50 (0.082)
Left frontal sinus height	2.68	1.76	3.21	2.05	1.54	2.62	853.50 (0.006)
Right frontal sinus width	1.85	1.24	2.42	2.05	1.20	2.29	1,187.00 (0.664)
Left frontal sinus width	1.83	1.36	2.39	1.56	1.05	2.12	996.50 (0.081)
Right frontal sinus depth	0.88	0.77	1.17	0.90	0.73	1.12	1,169.50 (0.579)
Left frontal sinus depth	0.96	0.82	1.25	0.92	0.81	1.15	1,195.00 (0.704)
Total frontal sinus length	5.04	4.16	6.16	4.55	3.86	5.40	998.50 (0.083)

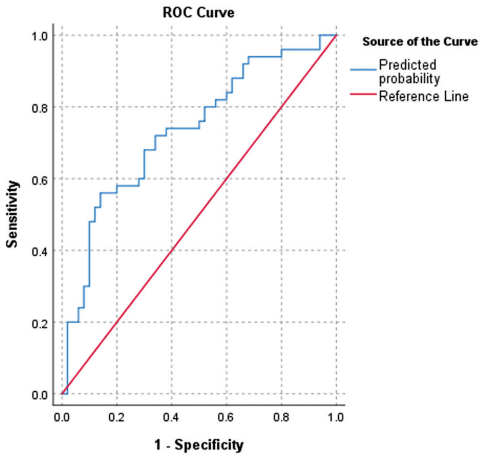

Fig. 2 Receiver operating characteristic (ROC) curve for the predicted probabilities.

Table 4 Table depicts the prediction accuracy of sex for frontal sinus

		Predicted sex	
		Male	Female
Prediction of sex based on a cutoff of 0.489	Male ($N = 50$)	33 (66%)	15 (30%)
	Female ($N = 50$)	17 (34%)	35 (70%)
Total		100%s	100%

40 to 49 years, but lower in females than in males in the age group of 60 to 69 years.[7] Similar studies have been conducted by Chowdhuri et al,[8] Belaldavar et al,[9] and Soman et al.[10] They also stated that the frontal sinus was larger in males than in females. In our present study, it was found that the overall mean values collected from the frontal sinus were greater in males than in females.

Several authors performed the study on frontal sinus and have reported that the left frontal sinus was measured to be larger than the right.[7,10–13] Our study is also congruent with these studies, as it also showed the mean measurement of the left frontal sinus to be greater than that of the right side.

In previous studies, Belaldavar et al showed that the left sinus height was the most accurate compared to other variables.[9] Eboh et al carried out a study on the Nigerian population and reported that the left frontal sinus width and height were statistically significant.[14] In the present study also, the left frontal sinus height was statistically significantly difference ($p < 0.05$) between males and females, while there was no significant difference in the other variables ($p > 0.05$).

Chowdhuri et al[8] conducted a study based on the frontal sinus in which they interpreted the cutoff point of 0.3795 for human identification. Hence, above the 0.3795 cutoff point, the cases were males and below 0.3795 the cases were females, and their gender identification model had an 86.7% accuracy.[8] Similarly, Eboh et al[14] performed a study based on sex determination of frontal sinus on which a cutoff value of 0.5 was established, which meant that when it was ≥0.5, the individuals were classified as males and if it was less than 0.5 it was female.[14] According to the present study, an ROC curve analysis was used and the area under the curve of our model was 0.733. The optimum cutoff value for predicted probability was 0.489 (►**Table 4**). If the predicted probability value was less than 0.489, then the individual was identified as a male and if the predicted probability value was ≥0.489, then the individual was considered a female.

Uthman et al conducted a study to estimate the frontal sinus size of 90 patients in spiral CT scanning to identify the sex; they measured the width, length, height, and total distance of the frontal sinuses. They created a model for sex prediction based on the left frontal sinus height, with an overall accuracy of 76.9%.[15] Belaldavar et al performed a study based on frontal sinus sex estimation among Indian adults using digital radiographs and observed an overall accuracy rate of 64.6% while utilizing the right and left frontal sinus height, right and left frontal sinus width, and right and left frontal sinus area.[9] Nethan et al conducted a study with 100 digital PNS radiographs to determine gender. They found that the accuracy of their predictions was 62% for females and 46% for men.[16] Sheikh et al conducted a study with 100 patients to identify the sex of an unknown individual using the frontal sinus. They measured the following variables for their study: right frontal sinus height, right frontal sinus width, left frontal sinus height, and left frontal sinus width from the PNS radiographs. They achieved an overall accuracy of 58%.[17] In the present study, a total of 100 participants were included and a total of seven measurements were taken from MDCT scan, which included maximum width and depth of the frontal sinus derived from axial images and maximum height and distance between the two frontal sinuses taken from coronal images. It was observed that the left frontal sinus height was better at predicting sex, with an accuracy of 66% in males and 70% in females. The discrepancy between these studies of sexual dimorphism could be attributed to the vast difference in parameters used for sex determination. Also, the higher accuracy rates in other studies could be attributed to the methods used.

Limitations

In this study, interobserver variation could not be accounted for as all measurements were obtained by a single person. The study's sample size and time constraints are two significant limitations; if a larger sample size had been used, the accuracy would have improved. Further study can be conducted with a greater data set to overcome the present limitation.

Conclusion

Sex determination is the key point of forensic evaluation. In the present study, several measurements of the frontal sinus were taken and it was observed that the size of the frontal sinus was relatively greater among males than females. The left frontal sinus height can be used in sex determination ($p < 0.05$). These findings can be helpful in determining sex in violent crimes, disasters, accidents, or cases where the body

has terribly deteriorated. The present study concluded that the frontal sinus can be one of the promising landmarks in determining the sex of incomplete skeleton remains in the Indian population.

Ethical Approval

The present study protocol was reviewed and approved by the institutional review board of CHARUSAT University (CHA/IEC/ADM/22/02/124).

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None.

Conflict of Interest

None declared

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