

Radiomorphometric analysis of frontal sinus for sex determination

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Abstract

Context: Sex determination of unknown individuals carries crucial significance in forensic research, in cases where fragments of skull persist with no likelihood of identification based on dental arch. In these instances sex determination becomes important to rule out certain number of possibilities instantly and helps in establishing a biological profile of human remains. **Aims:** The aim of the study is to evaluate a mathematical method based on logistic regression analysis capable of ascertaining the sex of individuals in the South Indian population. **Settings and Design:** The study was conducted in the department of Oral Medicine and Radiology. **Methods and Material:** The right and left areas, maximum height, width of frontal sinus were determined in 100 Caldwell views of 50 women and 50 men aged 20 years and above, with the help of Vernier callipers and a square grid with 1 square measuring 1mm² in area. **Statistical analysis used:** Student's *t*-test, logistic regression analysis. **Results:** The mean values of variables were greater in men, based on Student's *t*-test at 5% level of significance. The mathematical model based on logistic regression analysis gave percentage agreement of total area to correctly predict the female gender as 55.2%, of right area as 60.9% and of left area as 55.2%. **Conclusion:** The areas of the frontal sinus and the logistic regression proved to be unreliable in sex determination. (Logit = 0.924 - 0.00217 × right area).


Key words: Forensic, frontal sinus, sex determination

Introduction

One of the most ancient areas of interest for the forensic sciences is determination of age, sex, race, stature, to create a biological profile,^[1] which when applied in the present day scenario wherein situations like plane crashes lead to fragmentation of individual bones that leads to efforts being directed towards determination of sexual dimorphism via radiological techniques.

French police officer Alphonso Bertillon (1853–1914) created first anthropometric scientific system based on physical measurements for identifying criminals in 1880.^[2]

In the present kaleidoscopic world, mass destruction, or mass fatality incidents are on the rise. Some of these result in the fragmentation of bones of the body and charring and burning of the soft tissues and there is no possibility of identification based on dental arch. In these instances, determination of sex becomes extremely important as it can positively rule out a certain number of possibilities instantly and moreover differentiation of sex in the forensic context is the keystone to establish a biological profile of human remains.^[3,4] The skull, pelvis and femora are most useful for determination of sex. Radiograph of these bones have been exploited and have aided to ascertain or categorize human remains since early 1900's and various skeletal traits have been studied which have contributed to this process.^[5] Particular attention has been paid to the skull where several

Access this article online	
Website: www.jfds.org	Quick Response Code 
DOI: 10.4103/0975-1475.137052	

structures have the potential to identify an individual, including the dentition, cranial suture pattern and the frontal sinuses. Next to pelvis, skull is the most easily sexed portion of the skeleton, but the determination of the sex from the skull is not reliable until well after puberty.^[6,7]

The frontal sinuses are two, in the posterior part of the superciliary arcs, and lies between the external and internal faces of the frontal bone. They are seldom symmetrical; generally, there is a septum between both, which usually deviates from the midline. They point upwards beyond the middle part of the superciliary and backwards to the medial part of the orbital roof.^[8] The significance of frontal sinus in forensic sex determination lies in their unique pattern. The acceptance of the fact that no two frontal sinuses have same pattern is very strong among researchers. The frontal sinus is as unique to each individual as a fingerprint, even in monozygotic twins.^[9] Frontal sinus radiographs may be used because it is commonly exposed in sinus series investigations.^[10] Moreover the outline of the frontal sinus is irregular, and the dimensions of the frontal sinus are more convenient for being exactly measured.^[9] The sinuses develop by the age of two years and grow slowly until puberty, then rapidly until completing growth at approximately 20 years.^[11] Changes in the adult sinuses are rare and they generally remain stable throughout life hence their assessment through linear and area measurements can be carried out in adult male and female subjects.^[12]

Numerous studies have been conducted in the past to evaluate the forensic importance of frontal sinus radiographs.^[9,13,14] Furthermore, it has been suggested that the frontal sinuses have the potential to be used in correctly identifying sex.

With this milieu, the present study was undertaken to evaluate a mathematical method based on logistic regression analysis capable of ascertaining the sex of individuals in the South Indian population.

Materials and Methods

The source of data comprised of outpatients visiting our Department. 100 patients consisting of 50 males and 50 females satisfying the following inclusion and exclusion criteria were selected for the study via simple random sampling.

Healthy individuals aged 20 years and above were included to take part in the study, who had formerly been examined and evaluated with respect to the anatomic and physiologic integrity of the frontal sinus.

Individuals with a history of orthodontic treatment or orthognathic surgery, trauma or any surgery of the skull and individuals with history or clinical characteristics

of endocrine disturbances, nutritional disturbances or hereditary facial asymmetry were excluded.

Radiographs of 100 individuals taken by Caldwell technique with frontonasal support were evaluated. The ethical committee at our institution had approved our study. The same maxillofacial radiologist had exposed all the radiographs, using Kodak Radiographic film, size 8 × 10 inches. The source to film distance was kept constant at 1.44 cm and using an exposure of 80 kVp and a time of 2.5 sec the exposures were made using a panoramic machine with Cephalometric function (Rotograph 230 eur (Villa, Italy)[®].

The radiographs were immediately processed in a fully automated extraoral radiographic film processor (Proma × 5 Speed (Chayagraphics [®], India) with auto replenishing feature, set at standard time and temperature throughout the study. Care was taken to obtain radiographs of optimum diagnostic quality.

Following that the perimeter of frontal sinus was mapped out with a lead 0.3 pencil using a view box and tracing paper, where the lower border of the frontal sinus was previously standardized. A tangent line was drawn at 90° to the baseline (A) Figure 1 segmenting the sinus in quadrants. The location of the tangent line was determined by drawing a vertical line at the medial most point of each orbit perpendicular to the baseline, and measuring the distance between the two vertical orbit lines marking the central point of that distance. Subsequently, the following measurements were made namely Maximum right height (C), Maximum left height (B), Maximum right width (G), and Maximum left width (F) with the aid of digital slide callipers and right area, left area, total area by superimposing the traced perimeter on a square grid with

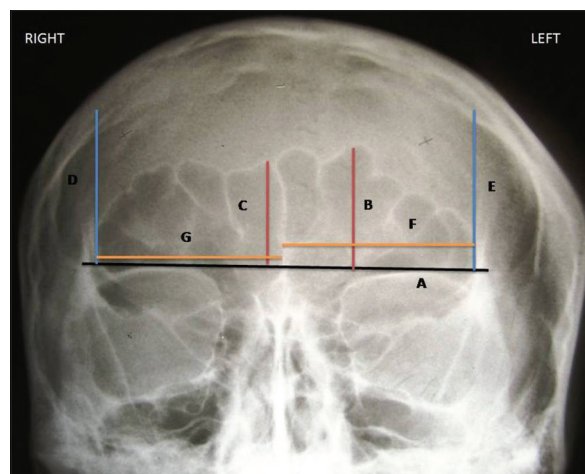


Figure 1: Diagram of Caldwell with the demarcation of the borders of the frontal sinus and identification of the measurements made. (a) Baseline, (b) Maximum left height, (c) Maximum right height, (d) lateral most point of the perimeter on right side, (e) lateral most point of the perimeter on left side, (f) Maximum left width, (g) Maximum right width

1 square measuring 1mm² in area and then counting the number of squares where the perimeter outline crossed totally or more than half and leaving those squares where it traversed through less than half of the square.^[15] All these measurements were obtained only for the portion projecting above the baseline (A). The separation of the left and right side of the frontal sinus was based on the frontal sinus “septum” which denotes the margin between the two main sinus cavities, as it continues from the nasal septum up through the sinuses.^[5] This was done to permit quantifying one width only on each side.^[13]

The greatest height of each side was determined from the maximum distance between the base and upper lines of the frontal sinus, and the largest width of the frontal sinus was determined from the maximum distance between the medial and lateral lines of the right and left side of the frontal sinus.^[13] The linear measurements obtained from each radiograph were expressed in linear millimeters (mm) and the areas in square millimeters (mm²). All the measurements had been adjusted for the radiographic magnification factor.

The data thus obtained was analyzed by Student’s *t*-test for comparison of the means of the dimensions measured for the two genders. Subsequently, a logistic regression model was developed using Statistical Package for the Social Sciences software (SPSS), based on the logit link function and female sex, whereby parameters of the model were determined that allowed the prediction of probability of relevance of the cranium to female gender.

The stepwise method was used to select the variables and composition of the mathematical model, where the variables were added and removed until the model was defined.

Results

The raw data from the measurements were entered into SPSS for statistical analysis. Among a total of 100 samples taken, 8% had bilateral absence of sinuses which comprised of 4 males and 4 females. So the final data was analyzed for 92 samples. Student’s *t*-test was employed to compare the means of the groups for all the response variables studied. The results obtained are presented in Table 1. There was no significant difference between the mean age group, left width, left height, right width, and right height. But the variables pertaining to the left area, right area, and the total area were found to be statistically significant.

As substantiated in the Figure 2, the means for the measurements for men were consistently greater than those for women. Based on the findings of the Student’s *t*-test the parameters most suited for the determination of an individual’s gender were left area, right area and total area. A logistic regression model was then developed based

on logit link function and the female sex. Parameters of the model were determined that allowed the prediction of probability of relevance of the cranium to the female gender. The stepwise method was used to select the variables and composition of the mathematical model where the variables were added and removed until the model was defined. The study of selection of variables detected that the area (total, right and left) was more suited for determining gender. The results of the analysis with sex as dependent variable are illustrated in Table 2.

-2 log likelihood for left area, right area and total area were 114.1, 115.1, and 113.8, respectively. The percentage agreement of the total area to correctly predict the female gender was 55.2%, of right area was 60.9% and of the left area was 55.2%, respectively. The *P* values for all these variables were significant.

The projected parameters presented in the previous section permitted the construction of the function by which the logit value was obtained which sequentially was used in

Table 1: Means, standard deviation and P value (student’s t-test) for two independent samples for males and females in mm and square mm

Variable	Gender	Mean	Standard deviation	P value (student’s t-test)
Age	Male	28.4	5.97	0.7443
	Female	27.9	7.16	
Left width	Male	32.3	7.98	0.0905
	Female	29.4	7.46	
Left height	Male	20.9	7.96	0.0646
	Female	17.9	6.81	
Left area	Male	564.6	330.09	0.0142
	Female	418.0	202.49	
Right width	Male	30.4	7.82	0.0688
	Female	27.4	7.34	
Right height	Male	19.3	6.63	0.2385
	Female	17.5	7.32	
Right area	Male	477.2	244.84	0.0262
	Female	364.0	221.61	
Total area	Male	1041.8	542.66	0.0114
	Female	783.3	376.35	

Table 2: Results of logistic regression with sex as dependent variable

Model	Independent variables	-2 log likelihood	Chi-square	P value	Cox and snell R square	Percentage agreement
1	Constant only	120.6				
2	Constant and left area	114.1	6.5	0.011	0.072	55.2
3	Constant and right area	115.5	5.1	0.024	0.057	60.9
4	Constant and total area	113.8	6.8	0.009	0.075	55.2

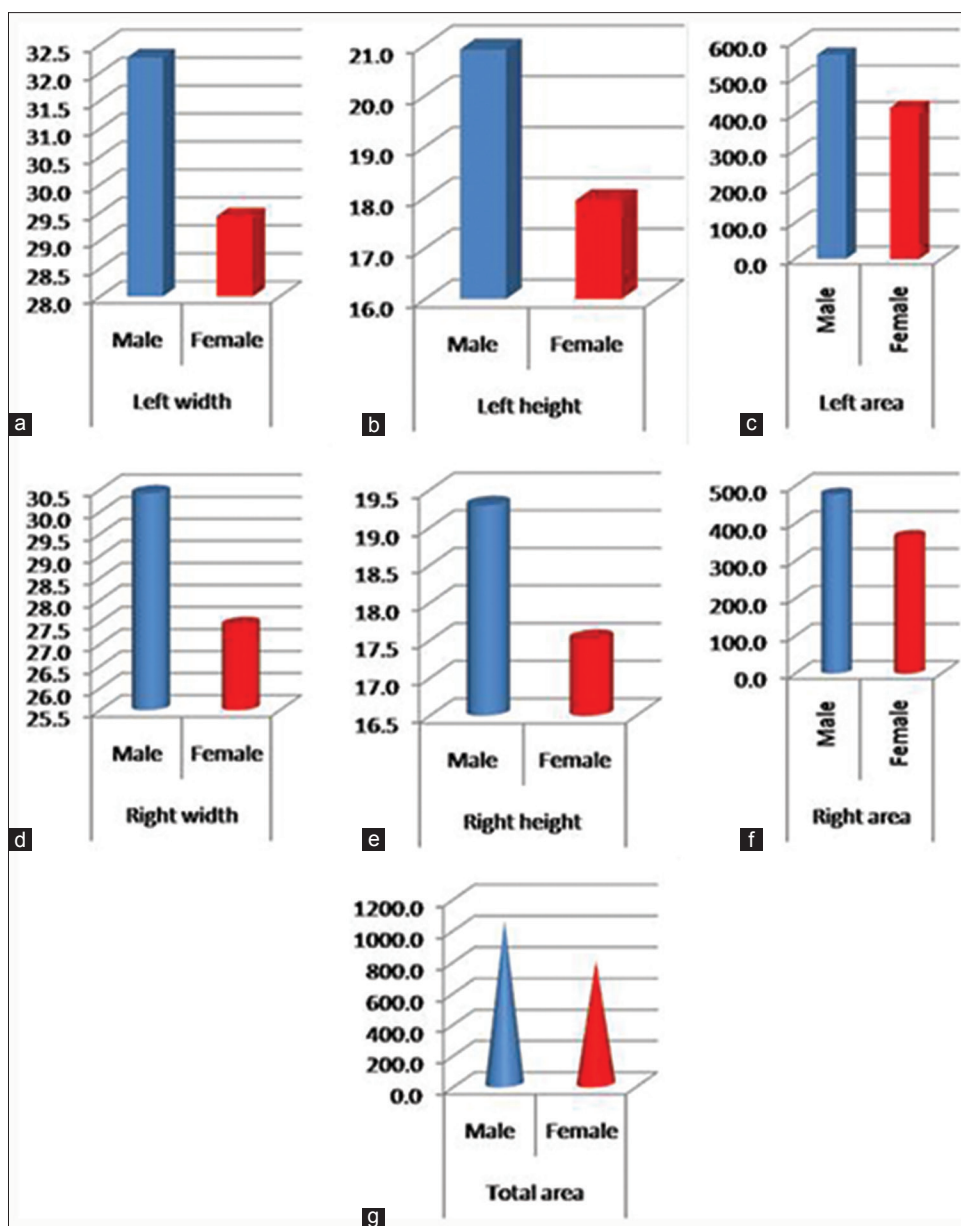


Figure 2: Bar graphs showing differences between the means of the male and female groups for all the response variables studied by Student's t-test

the calculation of the probability of relevance to measure the female cranium.

- $\text{Logit} = 1.708 - 0.00219^* \text{ left area}$
- $\text{Logit} = 0.924 - 0.00217^* \text{ right area}$
- $\text{Logit} = 1.177 - 0.00129^* \text{ total area.}$

For all of these the P value was found to be significant. The use of Wald chi square statistic showed that these parameters were important and significantly influenced the determination of gender. The probability was calculated from the logit value from the preceding equations by the following equation

- $P(\text{female}) = \frac{e^{\text{logit}}}{1 + e^{\text{logit}}}$
- " P " denotes the probability of being a female
- " E " is the mathematical exponential.

The results show that there were approximately 40% erroneous classifications for right area, 45% for left and total area. Nonetheless, this success rate is more favorable than that for the prediction of gender based on chance with 50% probability of error.

Discussion

Frontal sinus uniqueness was initially observed by Zukerkandl (1875) who called attention to its asymmetric morphology.^[16] The first human identification through morphologic analysis of the frontal sinus to be accepted in a court case in the United States was described by Culbert and Law in (1927).^[17] Since then research on various aspects of frontal sinuses has come a long way.^[17] Previous studies have

focused upon taking multiple measurements of the sinuses and combining the probabilities of each measurement for analysis.^[12,18,19] Probability analysis supports the strength of metric differentiation of the frontal sinus.^[20] In concordance with all these studies our study used skull radiography with Caldwell View and results analyzed through logistic regression analysis.

The sample size used was 20 years and above, as the frontal sinus completes its growth in both the sexes by that age. This selection confirmed to earlier studies by Porbonikova S.^[8] Camarago *et al.*,^[13] David *et al.*,^[14] In our study the overall percentage of bilateral frontal sinus absence was 8%. Whereas Tang *et al.*, had reported non-existence of 16.6%.^[9] White and Pharoah have mentioned absence of frontal sinus at 4%.^[21] Similarly, David *et al.*, have also reported non-existence of 4%. Ponde *et al.* had found non-existence of 24.7% in their study.^[8] In our study no significant difference was found between the absences of sinuses between both sexes.

Schuller (1943) has verified in radiological studies that the frontal sinuses are bigger in males than in females.^[11] Ponde *et al.*, had also arrived at the same conclusions.^[8] Our study was in accordance with their findings and the mean area of males were significantly larger than females i.e. 0.0142 for left area, 0.0262 for right area and 0.0114 for total area. Brown reported that the sagittal diameter is significantly larger in males i.e. an average of 32.6 mm in males.^[8] Similar finding was observed by Camarago *et al.*,^[13] whereas in our study even though the right and the left sagittal diameters of males were larger than those for females but were not statistically significant. The morphological differences in the cranium between the two sexes are determined mainly by genetic factors, more so than nutritional, hormonal, and muscular.^[22] Such attributes can explain why the frontal sinus of male is larger than that of female.

The need to set up a reliable, low-cost and easily reproducible method for human identification prompted elaboration of technical and accessible parameters, such as evaluation of area, symmetry and shape of the frontal sinus.^[13] Christenson 2005 used comparison of Euclidian distances by elliptical Fourier analysis but it was very complex and required a lot of resources.^[23] So our study also aims at the same goal of developing a low-cost system in the Indian scenario so that it is more suited to the monetary constraints that often plague the disaster management bodies in our country.

The logistic regression analysis used in this study exploits three dependent variables (left area, right area and total area of frontal sinus) and an independent variable (sex). Our study has the precision of 61% for sex prediction with the right area in comparison to Camarago *et al.*,^[13] which gave a correct prediction of 71% when the left area of sinuses was considered as the dependent variable.

The study has several limitations. Firstly, this analysis is limited by age of the individuals, because we are only considering age group from 20 and above due to the varying size of the sinuses in childhood because of their development. Secondly, the laws of radiology should be aptly adhered to at the time of exposing the radiographs for the bone remnants which could turn out to be taxing in some settings. Thirdly, the area was measured by a mathematical method employing square grids for research purpose. To employ it in the field, a more precise measuring tool should be used with the least margin for error and it should not be subjected to inter or intra observer variations.

To conclude, the right area variable of frontal sinus yielded the greatest precision i.e., of 61% for determining sex radiographically, but it is not acceptable by forensic standards. Logistic regression analysis was found to be an unreliable method to determine sex based on the frontal sinus in adult individuals. However, to concretely ascertain the model we recommend further studies, with enactment of new parameters for sex determination and the use of larger samples which would be more representative of the Indian population.

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How to cite this article: Verma S, Mahima VG, Patil K. Radiomorphometric analysis of frontal sinus for sex determination. *J Forensic Dent Sci* 2014;6:177-82.

Source of Support: Nil, **Conflict of Interest:** None declared

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