The frontal sinus morphology in radiographs of Brazilian subjects: its forensic importance

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Abstract

The determination of gender of unknown persons is of vital importance in forensic investigations, such as anthropologic, medical and dental forensic studies, mainly in cases where only fragments of the skull remain and there is no possibility of identification based on the dental arch. The aim of the present study was to develop a mathematical method based on logistic regression analysis capable of determining the gender of individuals using measurements of the frontal sinus. The right and left areas and the maximum height and width of the frontal sinus were determined in 100 radiographs taken by the Caldwell technique of 50 women and 50 men between 20 and 30 years old, with the help of the prog ram SIARCS 3.0 (EMBRAPA). The mean values of the frontal sinus were greater in males and the left area was larger than the right area, based on Student's *t*-test at the 5% level of significance. The mathematical model based on logistic regression analysis gave a concordance index for gender of 79.7% in the cases studied. The areas of the frontal sinus and the logistic regression technique proved to be useful in the determination of gender. (Logit = 1.6905 – 0.5383* left area).

Keywords: forensic identification, sex determination, frontal sinus.

1 Introduction

The frontal sinus is a cavity present inside the frontal bone; among the paranasal sinuses, it is the one that is of most interest and significance in forensic identification due to its irregular shape and because of individual characteristics which make the frontal bone unique for every individual, just as with fingerprints (KULLMAN, EKLUND and GRUNDIN, 1990; REICHS, 1993).

The first studies of the frontal sinus revealed important information about its shape, complexity and individuality, as well as its contribution to human identification, including postmortem cases (SCHULLER, 1921). Since then, complementary studies have been conducted examining the anatomic characteristics and variations of the frontal sinus among the most distinct ethnic groups, for forensic purposes (LIBERSA and FABER, 1958; REVSKOI, 1964).

The correlation of the morphology of the frontal sinus with gender shows that the frontal sinus is smaller in women, an aspect that points out its unique characteristic and importance in human identification, as well as in the determination of age (HANSON and OWSLEY, 1980; SZILVASSY, 1981; FATU, PUISORU, ROTARU et al., 2006).

The use of the frontal sinus for forensic purposes requires a certain amount of precaution. Some environmental factors such as hyperpneumatization due to sport activities, disease, trauma and postmortem changes, and mainly variations in techniques and radiographs, such as distance, angle and orientation of the cranium, can modify the image of the frontal sinus, distorting its anatomic characteristics and impairing the identification of the individual (QUATREHOMME, FRONTY, SAPANET et al., 1996; CAMERIERI, FERRANTE, MIRTELLA et al., 2005).

The aim of the present study was to develop a mathematical method based on logistic regression analysis, capable of determining the gender of individuals from measurements of the frontal sinus.

2 Material and methods

Radiographs of 100 individuals, taken by the Caldwell technique with fronto-nasal support (Figure 1), were evaluated. The sample comprised 50 Caucasian females and 50 males, with a mean age of 25 years, who were previously examined and evaluated with respect to anatomic and physiologic integrity of the frontal sinus. This study was approved by the Committee of Ethics in Research.

Only individuals in perfect health were selected to participate in the present study. Those with a history of orthodontic treatment or orthognathic surgery, trauma, or any surgery of the skull, history or clinical characteristics of endocrine disturbances, nutritional diseases or hereditary facial asymmetries were excluded from the study.

The radiographs were taken by the same radiologist, utilizing Kodak radiographic film, size 18 x 24 cm.

Teleradiography was performed with an Rx Telefunk X-15 apparatus with a distance of 1.52 m from source to film, using an exposure of 80 KVP and time of 1.2 s at 20 mA.

In all the radiographs, the lines that bordered the area of the frontal sinus were determined with the help of a radiograph viewer and tracing paper, where the lower border (superior border of the orbit) of the frontal sinus was previously standardized. Diagram of Caldwell radiographic technique for examination of the frontal sinus is shown in Figure 1, and the following measurements were then taken: right height, left height, right width, left width, total area, left area and right area, obtained only for the portion of frontal sinus projected above the baseline (A). The separation between the left and the right side of the sinus was based on the frontal sinus septum in order to permit quantifying one width only on each side.

The greatest height of each side (B and C) was determined from the maximum distance between the base and upper lines of the frontal sinus, and the largest width (F and G) 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, as illustrated in Figure 1. The linear measurements obtained from each radiograph were expressed in lineal centimeters (cm) and the areas in square centimeters (cm^2).

The bordering points of the radiographic images of the frontal sinus were obtained with the help of a transparency plate for an HP Scanner connected to a PENTIUM II computer.

The linear measurements (width and height) and the areas (right and left) of the frontal sinus, were obtained using the program SIARCS 3.0 for Windows, developed by EMBRAPA - São Carlos - São Paulo - Brazil.

The data were 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 SAS, 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.

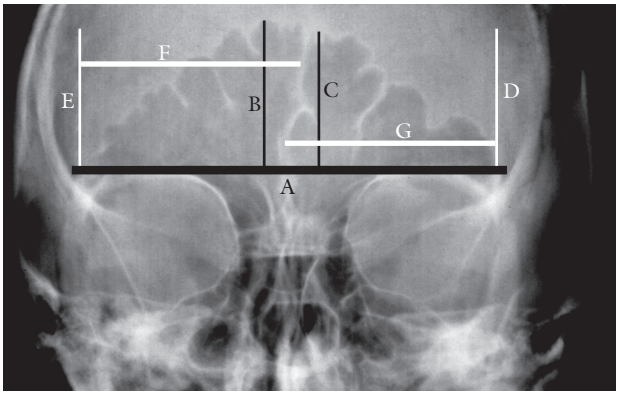

Figure 1. Diagram of Caldwell with the demarcation of the borders of the frontal sinus and identification of the measurements collected with the aid of a reference baseline of 10 cm.

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.

3 Results

3.1 Student's t-test

Student's *t*-test was applied to compare the means of the groups (males and females) for all the response variables studied. And a priori significance level of 5% was established and the Satterweith correction was applied when heteroscedasticity was detected. The results obtained are presented in Table 1.

Student's *t*-test showed strong indications ($p < 0.01$) of differences between the means of the male and female groups for all the response variables studied. As shown in Figure 2, the means for the measurements of the men were consistently greater that those of the women.

3.2 Logistic regression

The study of the selection of variables detected that the left area of the frontal sinus was more suited for the determination of an individual's gender, and the parameters that determined the quality of the work are shown in Table 2.

Table 2 presents the results of the statistical analysis which demonstrate the significance of the independent variables (co-variables) in the model. Based on these criteria, there were strong indications ($p < 0.01$) for the importance of the left area of the frontal sinus in the determination of gender, referred to a model presented in Table 3.

The estimated parameters presented in the preceding section allowed the construction of the function by which the logit value was obtained, which in turn was used in the calculation of the probability of relevance to measure the female cranium.

$$\text{logit} = 1.6905 - 0.5383 * \text{left area} \quad (p < 0.0001)$$

Table 1. Means, standard deviation and p value (Student's *t*-test) for two independent samples, corrected for cases of heterogeneity of variance, when necessary.

Variable	Gender	Mean	Standard deviation	p value (Student)
Right height	Female	0.953	0.729	0.0001
	Male	1.898	1.034	
Left height	Female	1.144	0.718	0.0001
	Male	2.084	1.014	
Right width	Female	1.819	1.109	0.0003
	Male	2.650	1.107	
Left width	Female	2.257	1.063	0.0001
	Male	3.197	0.838	
Total area	Female	3.529	3.018	0.0001
	Male	8.452	5.499	
Right area	Female	1.504	1.468	0.0001
	Male	3.723	2.740	
Left area	Female	2.025	1.692	0.0001
	Male	4.188	2.997	

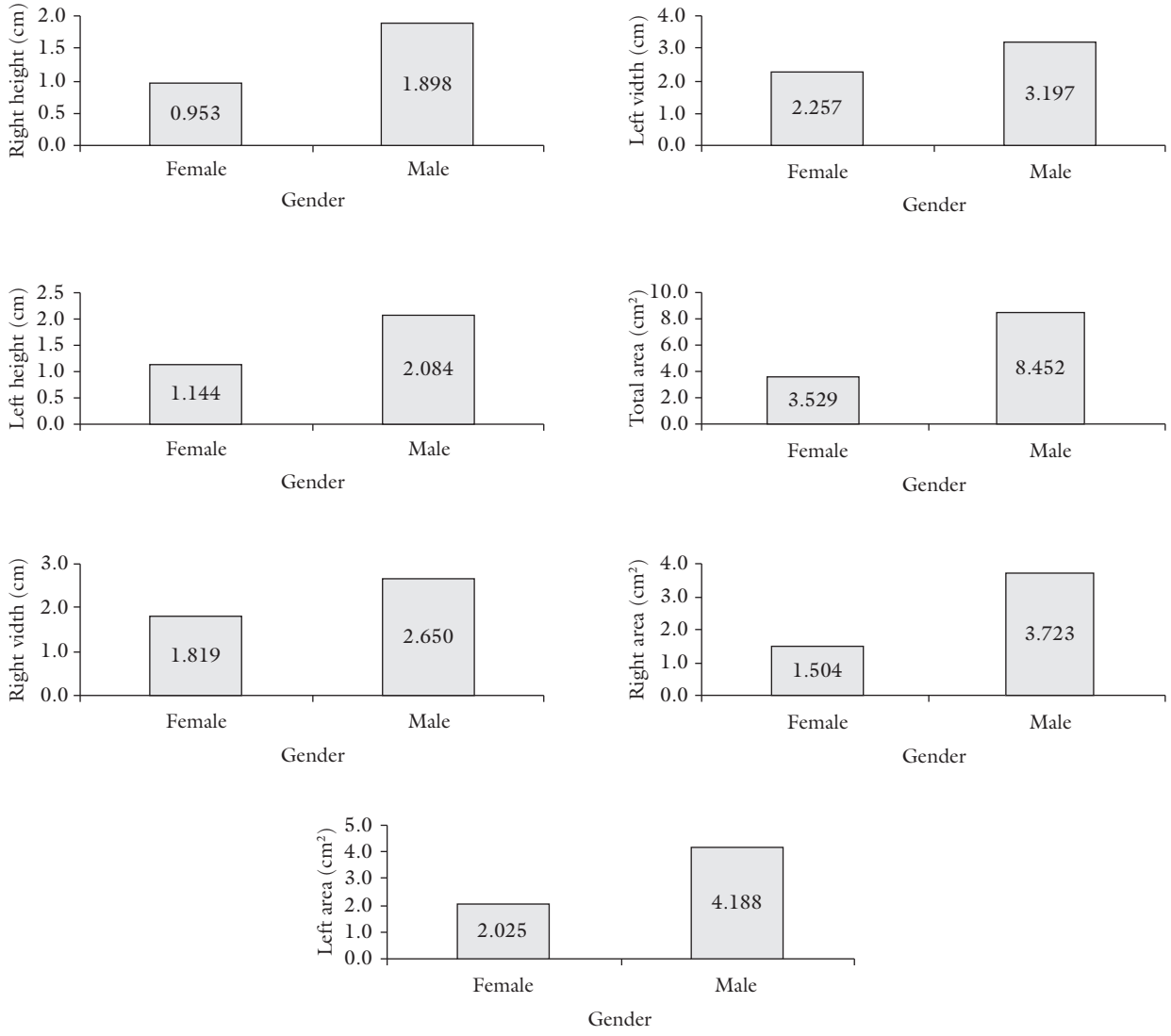

Figure 2. The differences between the means of the male and female groups for all the response variables studied by Student's t-test ($p < 0.01$).

Table 2. Criteria to evaluate the adjustment of the logistic regression model, obtained from the selection of data by the Stepwise method.

Criterion	Intercept only	Intercept and co-variables	Chi squared
AIC	140.629	112.247	
SC	143.235	117.457	
–2 LOG L	138.629	108.247	30.383 with 1 DF (p, 0.0001)

The use of the WALD chi squared statistic showed that the parameter was important and significantly influenced the determination of gender.

The probability was calculated from the logit value (p) from the preceding expression by the following Equation 1:

$$P(\text{female}) = \frac{e^{\text{logit}}}{\left(1 + e^{\text{logit}}\right)} \quad (1)$$

The measurements of association between estimated probability and observed responses (Table 4) were important to determine the prediction capacity of the proposed model. In order to access the process of prediction, the cut-off probability of 50% was selected and the data was reclassified through the model and the predictive capacity was measured and presented in Table 4 as a concordance criterion.

A concordance index of 79.7% was found, which indicated a model that demonstrates an excellent association between predicted response and observed gender. An also important value and commonly associated with accuracy is the c statistic (0.798) corresponding to the area under the ROC curve which was very close to 80%.

The results show that there were only 26% wrong classifications, and if the cases of ties were included, the number of unsatisfactory results in the classification would rise to 29%. Still, this success rate is more favorable than that for the prediction of gender based on chance with 50% probability of error. It is noted that 39 women and 32 men were correctly

Table 3. Analysis of estimates of maximum verisimilitude and p value calculated from the Wald chi squared test for the parameters determined for the logistic regression model.

Variable	DF	Parameter estimated	Standard error	$Pr > \chi^2$	Standardized estimates
Intercept	1	1.6905	0.4283	0.0001	
Left area	1	–0.5383	0.1262	0.0001	–0.830536

Table 4. Measurements of association between estimated probabilities and observed responses.

Concordance	79.7%	Somers'D	0.596
Discordance	20.2%	Gamma	0.596
Ties	0.1%	Tau-a	0.301
(25000 pairs)		C	0.798

classified by the model developed which gives a total of 71% correct predictions.

4 Conclusions

The need to establish a reliable, low-cost and easily reproducible method for human identification prompted the elaboration of technical, precise and accessible parameters, such as the evaluation of the area, asymmetry and shape of the frontal sinus. For these, systems of numerical combinations (YOSHINO, MIYASAKA, SATO et al., 1987) and of comparison of Euclidian distances by elliptical Fourier analysis (EFA) (CHRISTENSEM, 2005) were developed, along with other programs with the same aim (RIEPERT, ULMECKE, SCHEWEDEN et al., 2001).

With the same purpose in mind, the SIARCS 3.0 (EMBRAPA) software employed in this study differs from others by being easy to operate. Although it is not exclusively for anthropometric measurements, it also proved to be useful to evaluate and demonstrate differences between the right and left areas of the frontal sinus between genders. Besides, it provided a reliable variable without subjective influences in the determination of gender.

Different methods and statistical techniques are used to measure the frontal sinus to determine gender, race and stature, among other characteristics used for human identification (CHIBA and TERESAWA, 1998; TOWNSEND, RICHARDS and CARROL, 1982; HSIAO, CHANG and LIU, 1996). The logistic regression technique used in this study uses a dependent (left area of the frontal sinus) and an independent (gender) variable. Even when using one variable, this analysis provides a 79.7% precision in the determination of gender, while other studies that used the same mathematical calculation and worked with multiple variables, only obtained a precision of 76.06 to 95.8% in samples (DURAY, MORTER and SMITH, 1999; TORWALD and HOPPA, 2005).

The use of only one variable for postmortem identification has advantages in cases of disasters of large proportion, war crimes, and air travel accidents, situations where the body is badly burned, fragmented or decomposed, making identification difficult (EDITORIAL, 2001; CATTANEO, 2007). This method is also prominent because of its low cost which is more suited to the limited socio-economic conditions of Latin America (ÍSCAN and OLIVERA, 2000).

The morphological differences in the cranium between the two genders are determined mainly by genetic factors, more so than nutritional, hormonal or muscular (QUATREHOMME, FRONTY, SAPANET et al., 1996; PATIL and MODY, 2005). Such aspects can explain why the frontal sinus of men is on average larger than that of women (SZILVASSY, 1981).

In this study, the use of the left area of the frontal sinus was used as a parameter to establish a mathematical model to determine sex based on the results of the analysis and comparison of the width and height of the frontal sinus; this showed a tendency for the left side of the frontal sinus to be larger than the right, in agreement with results from another study (GULISANO, PACINI and ORLANDINI 1978). The existence of one side larger than the other is due to their independent development (NAMBIAR, NAIDU and SUBRAMANIAM, 1999).

The use of this analysis is limited by the age of the individuals, because between the age of five and six the frontal sinus, although radiographically visible, undergoes morphological changes, as well as in puberty, the period of its development, and at advanced age, due to bone resorption (CAMERIERI, FERRANTE, MIRTELLA et al., 2005; YOSHINO, MIYASAKA, SATO et al., 1987; MONTOVANI, NOGUEIRA, FERREIRA et al., 2006).

The left area of the frontal sinus morphology is the variable most suited to determine gender.

Logistic regression analysis is a simple, low-cost and reliable method to determine gender based on the frontal sinus in adult individuals.

The program SIARCS 3.0 (EMBRAPA) is a useful tool to measure the area of the frontal sinus.

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