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Frontal Sinus Accuracy in Identification as Measured by False Positives in Kin Groups

ABSTRACT: The aims of this study were to verify if frontal sinuses can uniquely identify individuals belonging to family groups using Cameriere methods and to test if kinship can affect the proportion of erroneous identifications. For this purpose, we compared the proportion of false-positive identifications in a sample of 99 individuals within 20 families with a control sample of 98 other individuals without kinship. The results show that the combined use of SOR and the Yoshino code number allows personal identification with a small probability of false positives ($p < 10^{-6}$), even when kinship is taken into account. The present research confirms the importance of studying anthropological frameworks for identification, which leads to reliable methods and allows for both quick and economic procedures.

KEYWORDS: forensic science, frontal sinus, personal identification, identification probability, forensic anthropology

Radiographic analysis, in which antemortem and postmortem X-rays are compared, is frequently used for human identification purposes. The parts of the body most frequently involved are teeth, frontal sinuses, and vertebrae (1–6). The uniqueness of these parts of the body is one of the most important problems for identification by X-rays, which has become more relevant after the *Daubert* sentence (7–9). The absence of scientifically based methods and techniques has led to rejection of evidence by several judges. Unlike genetics, few papers have been devoted to the study of the uniqueness of the body districts used for X-ray identification.

Frontal sinuses in particular have always been assumed to be different in every person (10–13), although not many studies with large sample populations, especially among relatives, have been carried out.

In 1987, Yoshino et al. (10) proposed a system of classification of the frontal sinuses based on the following seven discrete (categorical, ordinal) variables: area size (left and right), bilateral asymmetry, superiority of area size, outline of superior borders, partial septa, supraorbital cells, and orbital areas. This system assigns a class number to each morphological characteristic, and the frontal sinus patterns of a given person are formulated as a code number obtained by arranging the class numbers in each classification item as serial numbers. If the variables are considered to be independent and uniformly distributed in the population, then there is only a small probability that two different individuals will have identical code numbers. However, area size is considered as a discrete variable, whereas it is in fact a continuous one. Hence, to improve the performance of Yoshino et al.'s method, Cameriere (14) replaced frontal sinus size and bilateral asymmetry by two continuous variables, obtained as ratios SOR_1 (left frontal sinus area/left orbit area) and SOR_2 (right frontal sinus area/right orbit area).

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Christensen recently studied the frontal sinuses of a large sample of 808 individuals by elliptic Fourier analysis (EFA). The EFA method was used to fit the outline of each frontal sinus, yielding an EFA-generated outline which may be represented as a sum of trigonometric functions. The Euclidean distances between pairs of EFA-generated outlines were measured and found to be significantly larger between two different individuals than those between replicates of the same individuals (15). Thus, there is a quantifiable and significant difference between the outlines of individual frontal sinuses.

In a general population, the above methods ensure that the probability of the potential error of positive identification is $< 10^{-5}$. However, in a closely related subpopulation, genetic factors may increase the number of false positives.

To the best of our knowledge, only two works, using historical samples, have tested the possible influence of kinship on the proportion of false-positive identifications in the case of frontal sinuses. Both works evaluated small groups: one refers to possible identification on the basis of epigenetic traits (16); in the second, subjects were not closely related, e.g., they were second cousins (17).

The aims of the present study were to verify if frontal sinuses can uniquely identify individuals belonging to family groups using Cameriere methods (14) and to test if kinship can affect the proportion of erroneous identifications. For this purpose, we compared the frontal sinus pattern of each individual with the frontal sinus pattern of all the others in the sample of 99 individuals within 20 families, estimated the proportion of false positives in the sample, and compared this proportion of false positives with a control sample of 98 other individuals without kinship.

Materials and Methods

Radiographic images of the skulls of 99 individuals belonging to 20 families with a minimum family unit composed of four people residing in Northern Ireland (43 women, 56 men), aged between 15 and 74 years, were analyzed (Fig. 1).

At the time of investigation, the individuals were living in Northern Ireland. No attempt was made to restrict the selection of the sample from any one area or social class. The families were

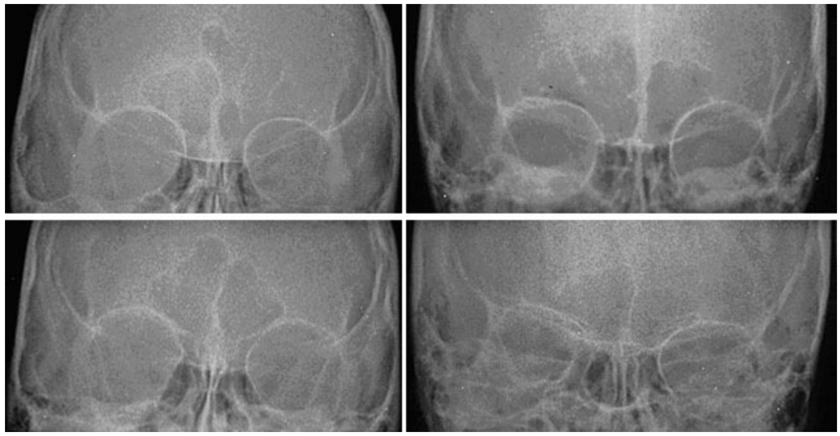

FIG. 1—*Antero-posterior radiographs of frontal sinuses of four individuals belonging to same family.*

identified among those parents who brought their children to the Royal Victoria Hospital in Belfast for orthodontic treatment and who were willing to involve their families in the project.

These data belong to a larger sample of 45 families studied by Brown (18); all subjects being radiographed with their heads in an identically located position, as described in Adams and Brown (19). The positioning of the heads for the anterior/posterior cephalograms was also identical for all the heads aligned on the Frankfurt Plane.

The minimum age was 15 years, when the frontal sinuses are complete (18). X-rays were digitalized and images were recorded on a computer file. Radiographic images of frontal sinuses were processed by a computer-aided drafting program (Adobe Photoshop 7). The Cameriere and Yoshino methods were used to describe both frontal sinuses in 87 individuals, which were subsequently compared, to estimate the proportion of false-positive identifications. Briefly, as reported by Yoshino et al. (10), X-rays were used to evaluate the left and right frontal sinus areas, bilateral asymmetry, superiority of size, outline of the upper border of the left and right sinuses, partial septa, supraorbital cells, and orbital areas. Following Yoshino et al., the frontal sinus pattern of a given person was formulated as a code number, obtained by arranging in the following order: frontal sinus size, bilateral asymmetry, superiority of side (Ss), outline of upper border (left, Ou1; right, Ou2), partial septa (Ps), and supraorbital cells (Sc). To improve the performance of Yoshino et al.'s method for identification of unknown skeletal remains, Cameriere et al.'s method was used to classify the frontal sinus pattern of a given person according to the superiority of area size, outline of superior borders, Ps, and Sc, together with the bivariate continuous variable SOR = (SOR_1, SOR_2), where SOR_1 is the ratio between left frontal sinus area and left orbit area, and SOR_2 is the ratio between right frontal sinus area and right orbit area.

To test for the possible influence of kinship on false-positive identification, a control sample consisting of the X-rays of the skulls of 98 white Caucasian individuals (41 women, 57 men), aged between 17 and 98 years, was also examined.

Statistical Analysis

As SOR values are quantitative continuous characteristics of sinuses and may vary according to skull position at X-ray, we could not conclude that the same skull always gave an identical SOR = (SOR_1, SOR_2).

Therefore, as reported in Ref. (10), in order to identify two images as belonging to the same individual, the following criterion was used: given one image of the frontal sinuses with SOR = (m_1, m_2), we assumed that every image came from the same individual if its SOR values fell within the ellipse of equal probabilities, $G_{1-\alpha}$ ([$1-\alpha$] confidence region):

$$(x_1 - m_1)^2 - 2r(x_1 - m_1)(x_2 - m_2) + (x_2 - m_2)^2 = \sigma^2 d^2$$

where $\alpha = 0.20$, $\sigma = 0.048$, $r = 0.79$, and $d^2 = -2(1-r^2)\ln(1-\alpha)$.

This criterion was used to estimate the proportion of images of the SOR of two different individuals erroneously identified within each family as belonging to the same individual (false-positive identification). This proportion was then compared with the proportion of the same identification errors made in the control sample by the chi-square test. Statistical analysis was carried out with the S-PLUS® program (release 6.1, for Windows, Professional Edition). A probability value of < 0.05 was considered as significant.

Results

The overall relative frequency of the bilateral absence of frontal sinuses was 10% (11 individuals) (Table 1) and that of the unilateral absence was 2% (2 individuals). In all, we observed 13 individuals with frontal sinus aplasia, which was not statistically significant ($p = 0.08$) with respect to the frequency observed in the control sample (18 individuals).

In the 13 individuals with frontal sinus aplasia, we found only two relatives (a father with his daughter). Consequently, we evaluated the SOR index and Yoshino code number in the remaining 86 individuals.

The comparison of SOR between two individuals within the same family yielded a proportion of 1.17% of false positives (Table 2). Previously (14), SORs were evaluated in a random

TABLE 1—*Relative frequency (proportion) of frontal sinus aplasia in kinship and control samples.*

		Absence of Frontal Sinus		
			Unilateral	
Sample	Number	Bilateral	Left	Right
Kinship	99	11	1	1
Control	98	10	5	3

TABLE 2—*Proportion of false-positive identifications (95% confidence interval) using SOR and SOR plus Yoshino Code Number (YCN) in kinship and control samples (p-values: tests of equal proportions between control and kinship groups).*

Method	Controls	Kinship	*p*-Values
SOR (95% CI)	0.005 (0.0031, 0.0079)	0.0117 (0.0020, 0.0460)	0.515
SOR + YCN	0	0	

sample without kinship, and SOR comparisons between two individuals yielded a proportion of 0.5% of false positives. The difference between these two proportions was not statistically significant ($p = 0.515$).

When the frontal sinus pattern of a given person from the examined 20 families was classified according to the bivariate continuous variable SOR = (SOR_1, SOR_2) and the five discrete variables, Ss, Ou_1, Ou_2, Ps, and Sc, of the Yoshino code number, we did not find any cases of false-positive identification, either in kinship or in control samples.

Discussion

X-ray imaging is certainly a significant method of carrying out proper comparisons and identifications. One of the most widespread anthropological methods for identification purposes is based on X-ray images of frontal sinuses. Verification of identity using frontal sinuses has often been carried out by simply attempting to match the corresponding feature of the antemortem with the postmortem X-ray images (20). Nevertheless, this approach leads to difficulties related to the distance, orientation, and angle of the X-ray equipment. To minimize possible false-negative identification and to find objective criteria for personal identification using frontal sinuses some researchers have proposed classification systems (13,14). The main aim of this research was to evaluate the importance of the features of the frontal sinuses in establishing kinship for identification. Christenson (15), the authors showed that the combined use of SOR and the Yoshino code number allows personal identification with a small probability of false positives ($p < 10^{-6}$), and as our results showed that the proportion of false-positive identification did not increase significantly when frontal sinus patterns were compared between two individuals within the same family, we estimated that the probability of the potential error of positive identification did not change even when kinship is taken into account. As a consequence, although we cannot use frontal sinuses to identify the kinship of an individual, we can identify skeletal remains, even of kin, in poor condition. In our examinations, the number of subjects without frontal sinuses was approximately 10%. This means that, although the absence of frontal sinuses is a marker, which is important for identification, it is not, in itself, a sufficiently reliable index from the viewpoint of identifying individuals (14,21–23). The present research confirms the importance of studying anthropological frameworks for identification, which lead to reliable methods and allow for both quick and economic procedures. In addition, difficult cases of DNA analysis—for example, relatives, twins, or cases of poorly conserved remains—can be resolved more easily.

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