



Are coding systems of frontal sinuses anatomically reliable? A study of correlation among morphological and metrical features

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Abstract

Frontal sinuses are of special interest for personal identification thanks to their high variability. A common procedure for comparing ante-mortem and post-mortem material is based on coding systems classifying frontal sinuses according to their morphological and metrical characteristics. However, the calculation of possible combinations is performed on the hypothesis that all the classified features are independent one from each other. This study aims at analysing the correlation among morphological and metrical characteristics of frontal sinuses. Two hundred CT scans of patients equally divided between males and females were segmented through the ITK-SNAP software. Number of accessory septations, scalloping and supra-orbital cells, side asymmetry and superiority, breadth, height, length and volume were extracted from the frontal sinuses of each subject. A possible relationship among morphological and metrical features was analysed through Pearson's correlation test, Mann-Whitney test or chi-square test according to the type of compared data ($p < 0.05$). In general, a positive correlation was found for all comparisons among metrical measurements (breadth, height, depth and volume) and number of septations, scalloping and supra-orbital cells ($p < 0.05$), but not between the number of scalloping and supra-orbital cells. In addition, side of asymmetry was positively related with side of superiority of the upper profile of frontal sinuses ($p < 0.05$). This study proved that morphological and metrical characteristics of frontal sinuses are strictly related one with each other: therefore, the coding systems based on these features should be applied with caution for personal identification, as the number of possible combinations is lower than reported by literature.

Keywords Forensic anatomy · Personal identification · Frontal sinus · CT scan · 3D segmentation

Introduction

Frontal sinuses (FS) are two pneumatized areas contained into the frontal bone, originating at the root of the nose and expanding into the peri-glabellar region [1]. They develop embryologically from ethmoidal cells and become radiologically visible at the age of 5–6 years [2]; the final configuration

is reached at 15 years according to some authors [3], at 20 years for others [4–6]. FS show a wide variability among different subjects and are different even in homozygotic twins [7].

Thanks to their characteristics of individuality and variability, FS are of special interest for personal identification [8]. In this case, identification is usually performed through the comparison of morphological features found in post-mortem material from an unknown body with similar data from ante-mortem material of possible missing people [9].

Personal identification through analysis of FS can be reached through superimposition methods or coding systems: in the former case, ante-mortem and post-mortem material are compared for what concerns the shape of frontal sinuses, usually including the silhouette of the upper border [6, 10]. The latter ones are based on the characterization of different morphological and metrical features of FS which may then be univocally classified as numerical codes. The advantages of

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coding systems include the chance of quantifying the probability of finding two subjects with the same codes, which cannot be performed in case of morphological comparison through mere superimposition [3, 11]. In literature, several coding systems are available: Schuller first proposed a classification in 1943, based on the observation of main septum deviation, upper border (including scallops/arcades), partial accessory septa, possible ethmoidal and supra-orbital extension, height from planum, total breadth and position of the sinus midline [12].

In 1987, Yoshino et al. elaborated a method based on morphological and metrical characteristics of FS, including surface area size on X-ray, side asymmetry, side superiority of area size, outline of superior borders (including number of scallops/arcades), partial accessory septations and possible supra-orbital cells [4]. In 2005, Cameriere et al. modified the classification by Yoshino et al. adding the ratio between the frontal sinus area and orbital area on the right and left sides instead of the surface area and side asymmetry [9].

In 2007, Tatlisumak et al. defined a novel method of classification, called FSS, based on presence or absence of FS (F), presence of intersinus and intrasinus septations (S) and scalloping (S), together with width, height and antero-posterior length [11].

The possible combinations according to different classifications range between 23,040 [4] and 10^6 [6]. With time, coding systems of FS have been widely experimentally tested, and some authors state that they can be a reliable tool for quantifying probability of identification, based on the high number of supposed available combinations [13].

However, the calculation of the number of possible combinations according to each method is based on the hypothesis that morphological and metrical characteristics included in each coding system are independent one from each other. Surprisingly at the moment, no study has verified the possible correlation among different variables on CT scans so far. Yet, such relationship, if confirmed, would suggest that the number of possible combinations is less than expected, with a decreased applicability of coding systems to personal identification.

This study aims at performing an anatomical study of morphological and metrical features of human frontal sinuses usually included in coding systems and to verify the possible correlation between different variables. The results will be of specific importance in the debate about the application of such classification categories to personal identification.

Materials and methods

Two hundred maxillofacial CT scans of patients (equally divided between males and females) were retrospectively assessed from a hospital database. Age of male and female

population was 53.7 ± 21.6 years and 50.3 ± 20.1 years, respectively. All the chosen subjects were older than 20 years. Possible significant differences of age according to sex were assessed through Student's *t* test ($p < 0.05$).

All the CT scans were performed through a second-generation dual-source scanner, Somatom Definition Flash (Siemens, Forchheim, Germany), with the following parameters of acquisition: kV, 120; mAs, 320; collimation, 40×0.6 mm; tube rotation, 1 s; reconstruction thickness, 3 mm; reconstruction filters, H21s smooth for soft tissues and H60 sharp for bone. CT scans were mainly requested for screening of cranial fractures in trauma (57.3%), sinusitis (20.0%) and neurological symptoms (12.7%).

CT scans of patients showing signs of previous or recent traumatic injuries, pathologies involving the cranial vault, bilateral or monolateral agenesis of frontal sinuses and congenital or acquired cranial deformation were excluded from the study. The study follows international laws and guidelines (Helsinki Declaration) and was approved by the local ethical committee (7331/2019).

From each subject, the 3D model of FS was extracted through the freeware ITK-SNAP software [14]. In detail, a semi-automatic approach was applied: one or more probes or “seeds” were located into each sinus, increasing in size to permeate the entire volume (Fig. 1). Repeatability of the ITK-SNAP software in extracting air spaces has already been tested by literature [15].

From each CT scan, the following morphological features were extracted according to Yoshino et al. [4] (Fig. 2):

- Number of accessory septations within both FS;
- Asymmetry (prevalence in volume of the right or the left side);
- Superiority of the superior border of the FS (on the right or the left side);
- Number of scallops (arcades) on the upper border of both the FS;
- Number of supra-orbital cells.

The 3D models were analysed through a 3D VAM® software (Canfield Scientific Inc.) to automatically measure the total volume of FS. In addition, maximum breadth, height and depth of frontal sinuses were measured on the 3D model. The maximum breadth was measured between the outermost borders of the right and left sinus, respectively. Maximum height was defined as the maximum distance between the upper and the lower border of the sinus. The maximum depth was the distance between the anterior and posterior walls of FS on the sagittal plane [16]. After 4 weeks, the 3D models of FS from 20 individuals were segmented again by the same observer and by another operator: maximum breadth, height, depth and volume were repeated to verify intra- and inter-operator

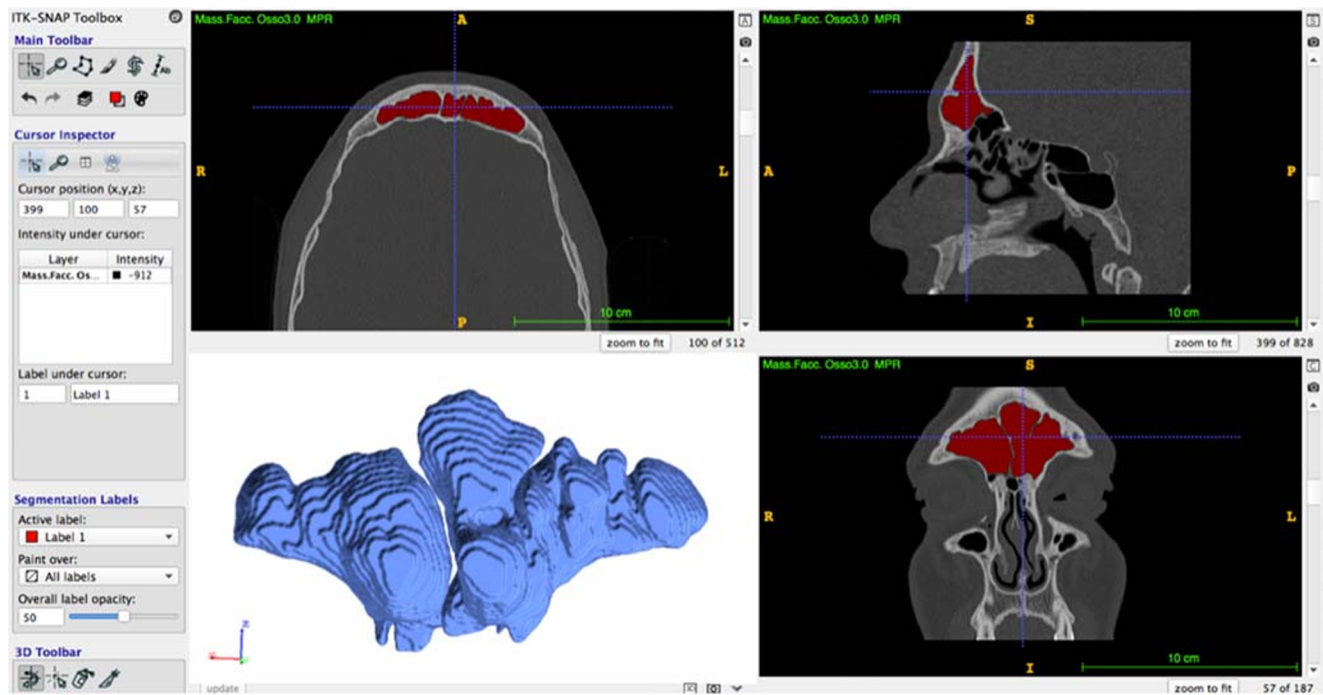


Fig. 1 Example of segmentation of FS through ITK-SNAP: in the lower left box, the obtained 3D model

error, which was calculated through absolute and relative technical errors of measurement (TEM and rTEM, respectively) [17]. Values of rTEM were then classified according to Camison et al., as follows: < 1.0%: excellent; 1.0–3.9%: very good; 4.0–6.9%: good; 7.0–9.9%: moderate; ≥ 10 : poor [18].

Possible relationships among metrical measurements (breadth, height, depth and volume) and between metrical measurements and number of accessory septations, scallops and supra-orbital cells were analysed through Pearson's correlation test ($p < 0.05$).

Statistically significant differences in distribution of metrical measurements according to side asymmetry and side superiority of the upper border were analysed through Mann-Whitney test ($p < 0.05$). Statistically significant differences in distribution of number of septations, scallops and supra-orbital cells according to side asymmetry and side superiority of the upper border were tested through chi-square test ($p < 0.05$). Finally, possible relationship between side asymmetry and side superiority of the upper border was tested through chi-square test ($p < 0.05$).

All the statistical analyses were performed through the SPSS® software.

Results

No statistically significant difference in age was found according to sex ($p > 0.05$).

Data concerning repeatability of continuous variables (maximum breadth, height, depth and volume) are shown in

Table 1: rTEM ranged between 1.0 and 5.8% for intra-operator error, and between 1.6 and 6.8% for inter-operator error, being classified as very good or good for all the measurements.

Overall results are shown in Table 2. On average, males showed higher values for metrical measurements (breadth, height, depth and volume) than females, as well as number of accessory septations (3 on average for males, 2 for females). On the other side, males and females showed similar values for the number of scallops and supra-orbital cells.

Prevalence of morphological features is reported in Table 3. In general, most frequently males showed two or four accessory septations (20% for each group), females one or two septations (26%). On average, most of males and females had five scallops (25% and 21%, respectively). Most of the subjects did not show any supra-orbital cell (74% and 84%, respectively in males and females). Both males and females showed superiority and asymmetry mainly on the left side.

Table 4 reports statistical data concerning relationships among different variables. Metrical features (breadth, height, depth and volume) and number of accessory septations were significantly positively related one with each other and with number of scallops in both males and females ($p < 0.01$), with correlation coefficient ranging between 0.27 and 0.83. For what concerns relationship between metrical measurements and supra-orbital cells, a positive significant relationship was found for breadth, depth and volume ($p < 0.05$). Moreover, in males, the same correlation was found between number of septations and supra-orbital cells, and in females between

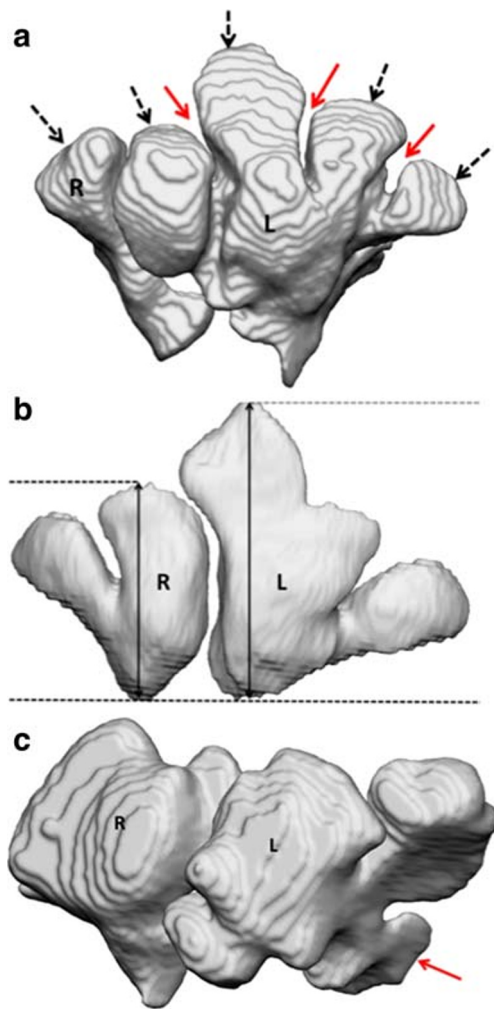


Fig. 2 Morphological features analysed in the present study: **a** accessory septations (indicated by continuous arrows) and scallops/arcades (indicated by dotted arrows); **b** asymmetry of the left sinus (volume 4.5 cm³) and superiority of the upper border of the left sinus in comparison with the right one (volume 3.5 cm³); **c** supra-orbital cells (indicated by continuous arrow)

height and supra-orbital cells ($p < 0.05$). Also, the side of asymmetry significantly corresponded with the side of superiority of the upper edge ($p < 0.01$).

Table 1 Absolute (TEM) and relative (rTEM) technical error of measurement of intra- and inter-operator repeatability for maximum breadth, height, depth and volume of frontal sinuses

	Intra-operator		Inter-operator	
	TEM	rTEM (%)	TEM	rTEM (%)
Breadth	0.6 mm	1.0	1.0 mm	1.6
Height	0.7 mm	2.3	1.4 mm	4.4
Depth	0.6 mm	5.8	0.7 mm	6.8
Volume	0.3 cm ³	4.1	0.5 cm ³	4.8

Table 2 Mean values and standard deviation (among round brackets) of each morphological and metrical characteristic in male and female population

	Males		Females	
No. of septations	2.9 (2.2)		1.8 (1.6)	
Breadth (mm)	56.1 (13.4)		52.7 (11.9)	
Height (mm)	31.2 (7.8)		30.2 (7.9)	
Depth (mm)	11.8 (3.2)		9.0 (2.1)	
Volume (cm ³)	9.0 (5.2)		6.2 (3.8)	
Side asymmetry	Right side	34%	Right side	42%
	Left side	66%	Left side	58%
Side superiority	Right side	30%	Right side	40%
	Left side	70%	Left side	60%
No. of scallops/arcades	4.9 (1.6)		5.1 (1.8)	
No. of supra-orbital cells	0.3 (0.6)		0.2 (0.5)	

On the other side, no significant relationship was found between side asymmetry and superiority of the upper edge and metrical measurement and number of septations, scallops or supra-orbital cells ($p > 0.05$).

Discussion

The morphological and metrical uniqueness of FS is well known in literature: the first report about the high variability of these anatomical structures dates back to 1875 [8]. As early as Schuller focused on the importance of this anatomical structure for forensic purposes in 1921, the comparison of FS for personal identification has been extensively studied [19]. Literature agrees in recognizing that the assessment of frontal sinus morphology represents a reliable approach to human

Table 3 Distribution of male and female population according to number of accessory septations, scallops and supra-orbital cells

	No. of septations		No. of scallops		No. of supra-orbital cells	
	Males	Females	Males	Females	Males	Females
0	11	23	-	-	74	84
1	17	26	-	-	18	13
2	20	26	8	8	8	3
3	13	14	10	12	-	-
4	20	6	24	16	-	-
5	7	3	25	21	-	-
6	5	-	19	20	-	-
7	4	1	9	15	-	-
8	1	-	4	5	-	-
>8	2	1	1	3	-	-

Table 4 Statistical results expressed as *p* value about the relationship between different morphological and metrical features in male (light grey) and female (white) population; among round brackets the correlation coefficient (where available)

	N° supra-orbital cells	N° scallops	Side superiority	Side asymmetry	Volume	Depth	Height	Breadth	N° septations
N° septations	<0.01* (0.26)	<0.01* (0.73)	0.740	0.619	<0.01* (0.48)	<0.01* (0.45)	<0.01* (0.57)	<0.01* (0.51)	
Breadth	0.032* (0.22)	<0.01* (0.65)	0.601	0.546	<0.01* (0.70)	<0.01* (0.54)	<0.01* (0.64)		<0.01* (0.60)
Height	0.322 (0.10)	<0.01* (0.59)	0.562	0.091	<0.01* (0.77)	<0.01* (0.58)		<0.01* (0.69)	<0.01* (0.69)
Depth	<0.01* (0.26)	<0.01* (0.49)	0.122	0.156	<0.01* (0.77)		<0.01* (0.52)	<0.01* (0.56)	<0.01* (0.27)
Volume	0.012* (0.25)	<0.01* (0.50)	0.408	0.312		<0.01* (0.70)	<0.01* (0.81)	<0.01* (0.83)	<0.01* (0.63)
Side asymmetry	0.917	0.553	<0.01*		0.513	0.267	0.887	0.824	0.646
Side superiority	0.537	1.000		<0.01*	0.313	0.181	0.586	0.955	0.811
N° scallops	0.268 (0.11)		0.900	0.974	<0.01* (0.58)	<0.01* (0.35)	<0.01* (0.62)	<0.01* (0.71)	<0.01* (0.64)
N° supra-orbital cells		0.031* (0.22)	0.307	0.424	<0.01* (0.55)	<0.01* (0.43)	<0.01* (0.34)	<0.01* (0.41)	0.15 (0.15)

*Statistically significant differences ($p < 0.05$)

positive scientific identification [7]. As method for identification, the comparison of FS has the great advantages of being applicable in cases where genetic procedures cannot be easily used, for example in charred [20] or skeletonized samples [11].

Among the various method for personal identification based on FS, the morphological and metrical classifications have known a wide diffusion, thanks to their easy applicability and the chance of translating a shape into a code which can be compared with other codes deriving from ante-mortem or post-mortem material. The high number of possible combinations is usually considered by literature sufficient to justify personal identification through the comparison of codes [4, 6, 13]. The use of a code for classifying FS is suggested also because it is inalterable, highly specific and of unlimited duration [9]. In addition, the code systems are considered more feasible than superimposition methods which are often hampered by possible discordances in orientation between the X-ray image of frontal sinuses in ante-mortem and post-mortem material [9].

However, surprisingly, very few authors pointed out the chance of possible dependence among metrical and morphological features; for example, Buyuk et al. found a relationship

between measurements of FS and cranial measurements, including the antegonial and the nasal widths [21]. These results suggest that the code of each FS depends upon the general cranial size, as well. Cameriere et al. found a possible correlation among some morphological items of Yoshino's classification, but did not report the significance of such correlations [9]. For this reason, they suggested a novel system including also the ratio between the frontal sinus area and the orbit area on the right and the left sides, to reduce the number of repetitions of codes [9].

The present study significantly improved the knowledge concerning relationship among morphological and metrical traits of FS, through a systematic analysis of correlation between different variables: results highlighted first that metrical data (breadth, height, depth, volume) are significantly related one with each other, as expected. Size of FS is usually included in coding system, as surface area: however, literature reported that surface area of FS recorded on X-ray is strongly correlated with their volume ($r = 0.9769$) [22].

Secondarily, results showed that several morphological features (number of accessory septations, scallops and supra-orbital cells) are positively related one with each other, and with metrical measurements: this means that the larger the FS,

the higher the number of accessory septations and scallops and supra-orbital cells. On the other side, the smaller the FS, the lower the number of accessory septations, scallops and supra-orbital cells. This result proves that morphological and metrical features of FS are anatomically linked and cannot be considered independent variables, especially in coding systems.

Finally, the side of FS superiority is usually the same where the superior border is mostly protruding. Again, this is an important information for coding systems, as most of the subjects are expected to show the same code for both the variables.

The present article therefore suggests caution in using coding systems of FS for personal identification purposes, as the repetitions of possible combinations cannot be reliably predicted. Therefore, they do not describe in detail the anatomical variability of FS, as also hypothesised by Cox et al. who suggested that codification methods may provide, at best, a way to perform a preliminary elimination of non-matches [1]. Interestingly, a similar conclusion was reached by Adams in a study focusing on dental features, which highlighted that dental markers are not independent across the teeth, although the combination of missing, filled and unrestored teeth was found to be very individualistic [23].

Therefore, other methods should be used for reaching a personal identification through the morphological analysis of FS. For example, the elliptical Fourier analysis (EFA) of the superior border has been first suggested by Christensen in 2005, as it provides a quantitative support to the assessment of uniqueness of such structures [24, 25]; on the other side, this type of procedure requires several software programs and complex calculations, with consequent limits in its applicability. In addition, the mathematically derived EFA coefficients are fairly abstract and often problematic to be explained in a courtyard discussion [1].

In the last years, the development of methods of 3D segmentation from CT scan has allowed the operators to obtain three-dimensional models of FS: this novel technology has enabled the superimposition of 3D models, and no longer of their 2D silhouettes extracted from X-rays. Gibelli et al. first applied 3D-3D superimposition method to the comparison of 3D FS models [26]; the main advantage is that the superimposition is no longer dependant upon FS orientation (as they are obtained from a CT scan and provide information about the entire 3D surface). In addition, the procedure gives a quantification of personal identification, expressed as root mean square of the mean point-to-point distance between the two models, able to fully distinguish matches from mismatches [26]. In addition, the same method for personal identification has been tested with success also to sphenoid sinuses [27]. In the next future, with the progressive increase of CT scans as ante-mortem material, the use of 3D-3D superimposition methods will become a reliable alternative for reaching a

personal identification with a quantification of the obtained results.

A limit of the present study concerns the use of CT scans which are currently unlikely to be used as ante-mortem data in a case of personal identification: however, the same is not valid for the next future, if we consider the widespread diffusion of CT scan technology in the world and the progressive reduction of required radiations for each exam. In EU, the number of CT scans is constantly increasing in almost all the countries: in 2017 amounted up to 14,845 exams per 100,000 inhabitants in Germany, 18,973 in France, 20,054 in Belgium [28]. Therefore, the research focusing on this type of material is urging and fundamental to adequately face the future issues of personal identification.

In conclusion, the present article shows that the existing coding systems based on morphological and metrical features of FS should be applied with caution, as the number of possible combinations is probably lower than reported by literature because of the high correlation among different variables. They may be used as preliminary methods but they cannot replace other techniques, based on the geometrical analysis of the silhouette of the FS, or the promising 3D-3D superimposition of models segmented on CT scans.

Compliance with ethical standards

Conflict of interest The authors declare that they have no conflict of interest.

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