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Radiology

Does the presence of persistant metopic suture affect the use of frontal sinus and frontal morphometric measurements in gender identification?

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ABSTRACT

Objectives: One structure capable of use for gender estimation in forensic science is the frontal bone. This study used computed tomography (CT) and investigated whether frontal sinus and frontal morphometric measurements could also be used to identify gender in people with persistent metopic suture (PMS).

Methods: Nine hundred ninety-one patients who underwent brain-paranasal sinus CT for any reason were divided into two groups, PMS and non-PMS. The presence and volume of both halves of the frontal sinus, frontal morphometric measurements including minimum-maximum frontal width, and frontal bone surface length on the outer table surface between the coronal sutures in the axial section were measured.

Results: In the non-PMS group, all quantitative parameters (frontal sinus volume, minimum-maximum frontal width, and frontal bone surface length) differed significantly between the genders ($P<0.05$). However, in the PMS group, only frontal sinus volume and frontal bone surface length differed significantly ($P<0.05$).

Conclusions: Frontal sinus volume, minimum-maximum frontal width and frontal bone surface length measurements exhibited significant sexual dimorphism in the non-PMS group. Since minimum and maximum frontal width do not exhibit significant gender differences in cases with PMS, the presence of PMS should be considered when using these parameters in gender identification.

Keywords: Frontal morphometry, frontal sinus volume, gender identification, persistent metopic suture

Assessing individuals' biological profiles represents a challenge for forensic science. Gender estimation is one of the first and most important steps in such analyses [1]. Anthropologists use the sexual dimorphic features of the human skeleton to distinguish between males and females through visual or metric evaluation [2]. Some authors regard the skull as the second most useful bone structure after the pelvis for gender prediction [3]. Morphometric techniques facilitate the evaluation of differences in the size of structures, thus enhancing objectivity [4].

Gender can be differentiated by measuring features (such as markings, curves, external surfaces or roundness) of cranial bones [5]. The exocranial bone surface exhibits significant gender differences, and success rates in gender prediction increase as a result [6]. One of the cranial structures with high potential in the evaluation of sexual dimorphism is the frontal bone [5]. In addition to the glabella, the most dimorphic and reliable part of the human skull [7], the gen-

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eral shape of the frontal bone and especially the curvature thereof (greater in males), the size of the frontal sinuses (larger in males), and the frontal protrusions (tubera frontalia) (more prominent in females) are other sexual dimorphic features that may be suitable for quantitative evaluation [8]. Sexual dimorphism in the frontal region is due to differences in growth factors and maturation times [9].

The frontal sinuses (FSs), the last paranasal sinuses to develop, exhibit considerable differences in width, height, and volume [10]. These are rudimentary at birth and become radiographically visible at the age of six [11]. The FS exhibits significant inter-individual variability, in the same way that fingerprints differ between monozygotic twins, due to its irregular shape and individual characteristics that make the frontal bone unique to each individual [12].

The physiological closure of the metopic suture (MS) [13], which separates the two halves of the frontal bone, is generally regarded as occurring at eight years of age [14]. If the suture continues to be observed in subsequent years, this is known as a persistent metopic suture (PMS) or 'metopism.' PMS is a factor that suppresses the development of the FS [15]. Pneumatization of the FS may be delayed or completely suppressed if the MS persists [16]. Since pneumatization into the frontal bone represents one of the FS development stages, it may be concluded that a relationship exists between FS and cranial morphometry [17]. In the presence of PMS have been found to exhibit a specific distinctive neurocranial configuration [18] characterized by a broad forehead, greater frontal curvature, and inter-frontal and inter-orbital lengths [19].

Computed tomography (CT) is an excellent imaging modality for identifying human remains and can be used to evaluate the paranasal sinuses and craniofacial bones. It yields valuable and precise measurements of FS dimensions [20].

The purpose of this study was to investigate the effectiveness of FS and frontal morphometric measurements (minimum and maximum frontal width and frontal bone surface length) in gender identification and to investigate the effect of the presence of PMS, with known impacts on frontal bone and frontal sinus development, on the usefulness of these parameters in gender identification.

METHODS

Patients and Study Design

The study commenced following receipt of approval from the Süleyman Demirel University non-interven-

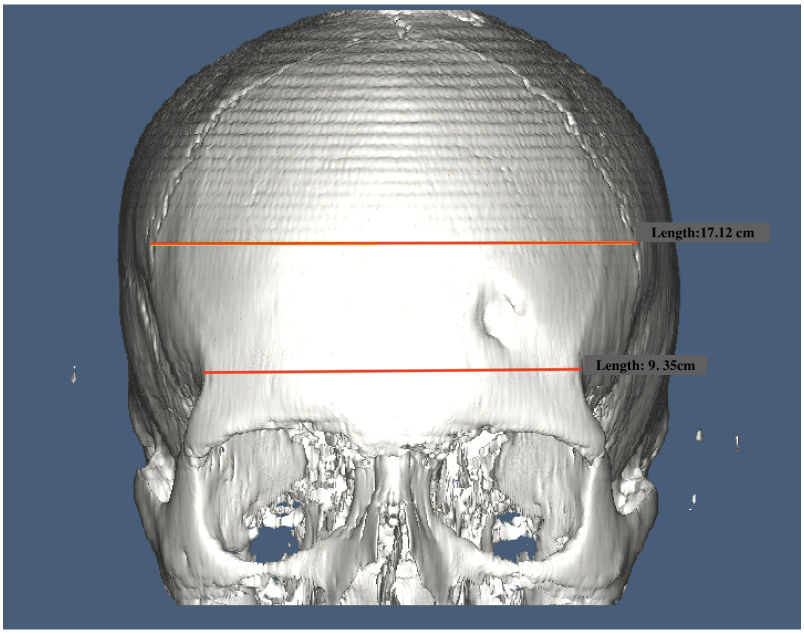

Fig. 1. Maximum horizontal width between both coronal sutures(upper horizontal line) and minimum horizontal width between both frontotemporal lines(lower horizontal line) on "volume rendering" CT images.

tional clinical research ethics committee (decision dated 30.12.2020 and numbered 72867572-050.01.04-15964). Paranasal sinus or brain CT images obtained for any reason between April and December 2018 were evaluated in this retrospective study. Nine hundred ninety-one patients met the inclusion criteria (age 18 years or over, cases in which the entire frontal region was included in the examination, and cases without a history of surgery or trauma in the frontal region). The presence or absence of PMS was recorded in these cases. All cases were divided into two groups, PMS and non-PMS. In both groups, the presence and volume of FS were recorded separately on the right and left sides, and frontal bone morphometric measurements (frontal bone surface length, minimum and maximum frontal width) were performed.

Technical Parameters

Brain and paranasal sinus CT scans were performed with a 128 cross-section CT device (Definition AS, Siemens Medical Solutions, Forchheim, Germany). The detector in the multi-section CT device possessed 64 rows of 0.6 mm elements and 128 independent data acquisition channels. The pitch value was adjusted automatically by the device and was set to 1.5 for brain CT and 1.0 for paranasal sinus CT. The gantry rotation time was 0.5 sec. Parameters were 120 kVp, 350 mA, reconstruction slice thickness 3 mm, and acquisition slice thickness 0.6 mm (WW:1500, WL:450) for brain tomography. For paranasal sinus CT, recordings were made using 80 kVp, with a 120 mA, 1 mm slice thickness, and a 0.6 mm acquisition slice thickness (WW: 1500, WL: 450) protocol.

Evaluation of Images

The presence of incomplete or complete MS in cases aged over 18 was recorded as PMS. FS volume calculations were performed separately for both halves of the FS through manual segmentation by OsiriXTM

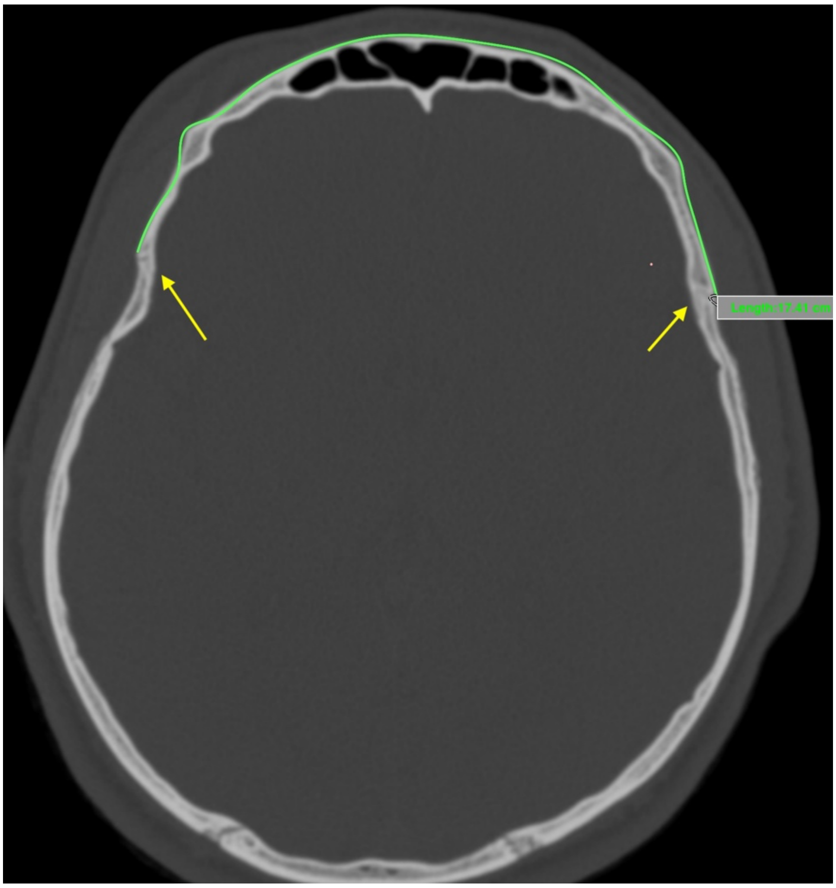

Fig. 2. **External tabular surface length (green line) measurement between both coronal sutures in the axial section passing through the junction of both coronal sutures with the sphenosquamous and sphenofrontal sutures (yellow arrow).**

software, including the entire FS lumen up to the frontonasal recess. In cases with 'Multifidus FS', defined as the presence of air cells that open into the ethmoid infundibulum and can be confused with the frontal sinus, the volume of this was included in the ipsilateral sinus volume. In coronal ‘volume rendering’ images, the maximum frontal width between both coronal sutures in the frontal bone and the minimum frontal width between both frontotemporal crests were measured in cm, as described by Valloise [21] (Fig. 1). In the axial images, the 'frontal bone surface length' was recorded in cm on the outer table surface between the bilateral coronal sutures in the section passing through the junction of both coronal sutures with the sphenosquamous and sphenofrontal sutures (Fig. 2).

Statistical Analysis

The Kolmogorov-Smirnov test showed that, with the exception of the 'frontal bone surface length,' quantitative data did not comply with normal distribution. Parametric tests were therefore applied for 'frontal bone surface length' measurements and non-parametric tests for other quantitative data. In order to examine the effects of PMS on quantitative data and to evaluate the practicability of quantitative data in distinguishing between the genders in both groups, Student's t test was performed for the 'frontal bone surface length' measurement, while the Mann Whitney U test was applied for other quantitative data. Data were analyzed on IBM SPSS Statistics for Windows software (Version 21.0, Armonk, NY, USA IBM Corp.). Statistical significance was set at $P<0.05$.

RESULTS

A total of 1156 cranial and paranasal sinus CT scans were initially evaluated. However, 165 cases met the exclusion criteria, and the CT scans of 991 patients, 452 women and 539 men, were finally included in the study. The average age of the cases was 53.7 years. Women represented 425 (45%) of the non-PMS cases and 517 (55%) men.

PMS was present in 49 (4.9%) cases, 22 (44%) of which were female and 27 (56%) were male. Surface length, minimum and maximum frontal width variables were found statistically significantly higher in PMS group ($P<0.05$). An analysis of the relationship between PMS and frontal sinus volume and other morphometric measurements is given in Table 1.

The practicability of the use of quantitative data in gender identification in the PMS and non-PMS case groups was subjected to analysis. In the non-PMS group, all quantitative variables exhibited statistically significant gender differences ($P<0.05$) and lower values were detected in women than in men in all parameters (Table 2).

In the PMS group, only the gender differences in frontal bone surface length and FS volume measurements emerged as statistically significant. Other quantitative variables (minimum and maximum frontal width) exhibited no significant gender differences in the PMS group, in contrast to the non-PMS group. In the PMS cases, frontal bone surface length was significantly lower in women than in men ($P=0.037$). FS volume values were also lower in women than in men

Table 1. Comparison of quantitative parameters between PMS and non-PMS groups

Variables	PMS group (n=49)	Non-PMS group (n=942)	t or z	P value
Surface length (cm)*	17.7426±1.0324	16.7257±1.1877	-5.257	**<0.001**
Right FSV (cm^3)	2.61 (0.38-16.71)	3.35 (0.09-37.87)	-1.819	0.069
Left FSV (cm^3)	2.24 (0.24-17.91)	3.80 (0.14-25.95)	-2.787	**0.005**
Min. Frontal width (cm)	10.00 (9.22-12.57)	9.64 (8.10-13.85)	-4.769	**<0.001**
Max. Frontal width (cm)	12.57 (10.23-13.66)	23.75 (9.06-43.78)	-3.475	**0.001**

Data are shown as mean±standard deviation or median (minimum-maximum). PMS=Persitent metopic suture, FSV=Frontal sinus volume, Min=minimum, Max=maximum

t=independent sample t test, z=Mann Whitney-U test,

*Frontal bone surface length

Table 2. Comparison of quantitative data between genders in the non-PMS group

Variables	Non-PMS group Males (n=517)	Females (n=425)	t or z	P value
Surface length(cm)*	17.09±1.15	16.28±1.07	10.573	**<0.001**
Right FSV (cm^3)	4.36 (0.20-37.87)	2.48 (0.09-21.92)	-9.909	**<0.001**
Left FSV (cm^3)	4.73 (0.19-25.95)	2.80 (0.14-20.67)	-9.558	**<0.001**
Min. Frontal width (cm)	9.82 (8.13-13.85)	9.45 (7.10-12.35)	-8.584	**<0.001**
Max. Frontal width (cm)	12.44 (9.51-43.78)	12.02(9.06-14.69)	-9.595	**<0.001**

Data are shown as mean±standard deviation or median (minimum-maximum). PMS=Persitent metopic suture, FSV=Frontal sinus volume, Min=minimum, Max=maximum
t=independent sample t test, z=Mann Whitney-U test,
*Frontal bone surface length

on both sides (right and left), and the findings were statistically significant (P=0.006 and P=0.002, respectively) (Table 3).

DISCUSSION

Analyses of teeth, fingerprints, and DNA profiles are among the most reliable methods for identification in forensic medicine. However, radiological examinations are important without such samples [22]. Radiology is important in forensic science as it permits non-invasive and objective evaluation. In particular, radiology helps identify human remains in forensic investigations [23]. Details such as volume, size, shape, and the individual characteristics of bones represent consistent evidence, and this can be used to identify bodies [24]. Sexual dimorphism is evident in various anatomical features of the skull [25], one of the most sexually dimorphic regions of the human skull being the frontal bone [26].

The practicability of using the FS in distinguishing between the genders has previously been investigated using various morphometric and morphological methods. The purpose of this study was to evaluate the usefulness of minimum and maximum frontal width measurements, volumetrically evaluated FS, and also 'frontal bone surface length' measurement, used for the first time in the present study according to our scan of the literature and also to investigate whether gender differences exist in these parameters in cases with PMS too.

Table 3. Comparison of quantitative data between genders in the PMS group

Variables	PMS group Males (n=27)	Females (n=22)	t or z	P value
Surface length (cm)*	18.05±0.97	17.37±0.99	2.162	**0.037**
Right FSV (cm^3)	1.60 (0.49-6.66)	1.60 (0.49-6.66)	-2.704	**0.006**
Left FSV (cm^3)	3.99 (0.60-17.91)	1.57 (0.24-6.28)	-2.986	**0.002**
Min. Frontal width (cm)	10.10 (9.22-10.78)	9.94 (9.26-12.57)	-1,719	0.088
Max. Frontal width (cm)	12.86 (11.94-13.66)	12.48 (10.23-13.65)	-1.057	0.294

Data are shown as mean±standard deviation or median (minimum-maximum). PMS=Persitent metopic suture, FSV=Frontal sinus volume, Min=minimum, Max=maximum
t=independent sample t test, z=Mann Whitney-U test,
*Frontal bone surface length

The prevalence of PMS in this research was 4.9%. Bilateral FS aplasia was observed in 10 (20%) of the PMS cases. Numerous studies [27, 28] have investigated the prevalence of PMS, and our findings were generally compatible with those.

In Atalay and Eser's [29] comparison of FS volumes between PMS and non-PMS groups, the two halves were not evaluated separately, although total FS volumes were lower in the PMS cases. Grine *et al*. [30] compared the CT findings of a PMS group and a control group in a South African population in terms of FS volumes. Those authors divided their PMS cases into partial and complete groups. While a decrease was observed in FS volumes in the complete PMS cases compared to the control group, an increase in FS volume was detected in partial PMS cases compared to the control group. In the present study, bilateral FS volumes in the PMS group were lower than those in the non-PMS group. This may be attributable to the suppressive effect of PMS on the development of FS, a phenomenon confirmed by previous research, and may possibly also be due to the number of complete and incomplete PMS cases. Further studies, distinguishing between complete and incomplete PMS cases, are now needed on this subject. Our scan of the literature revealed no similar studies comparing frontal morphometric measurements between PMS and non-PMS groups. In the present study, all three frontal morphometric length measurements were higher in PMS cases compared to the non-PMS group, confirming the functions of the sutures in bone growth.

In their study investigating the contribution of FS to sexual dimorphism, Tatlısumak *et al*. [31] compared FS volumes according to age and gender, and both FS values were significantly higher in men than in women. Wanzeler *et al*. [32] did not examine both halves of the FS separately but reported a significantly higher total FS volume in men than in women. Michel *et al*. [33] reported similar results to those of Wanzeler *et al*. [32]. However, the presence of PMS and its effect on the usefulness of this parameter in sexual dimorphism was not evaluated in those studies. Atalay and Eser [29] observed significantly lower FS volumes in women compared to men in both the control and PMS groups. In the present study, both halves of the frontal sinus were evaluated separately and, in agreement with Atalay and Eser [29], FS volume was significantly lower in the PMS group than in the non-PMS group. In terms of gender, bilateral FS volumes in both groups were significantly lower in women than in men. Our findings were compatible with the above study and supported the assumption that metopic suture persistence suppresses the development of the FS. The results also showed that both halves of the FS can be used in gender identification.

Various studies have examined the use of cranial morphometry in gender identification. Several different landmarks and methods have been used in the frontal bone. Del Bove *et al*. [34] used various landmarks on the skull to evaluate the surface shape of the frontal bone through a special software program. Those authors investigated whether the surface shape would differ between the genders. They concluded that the most accurate results in terms of gender identification were 'evaluation of the supraorbital part shape'. Since the difference in bone surface shape can also affect the measurements performed on the bone surface, this may explain the difference between genders in the length of the frontal bone surface, one of the measurements made in the present study. Čechová *et al*. [35] examined differences in frontal bone external surface area and shape, frontal sinus volume, and surface area by gender, and reported that frontal sinus measurements and frontal bone surface area measurements differed significantly between the sexes. Cekdemir *et al*. [36] investigated the usefulness of cranial morphometry in gender dimorphism and reported that, similarly to the present study, minimum frontal width was significantly higher in men than in women. However, no evaluation in terms of the presence of PMS was conducted. Consistent with Cekdemir *et al*. [36], minimum frontal width and all other parameters (maximum frontal width, frontal sinus volumes, and frontal bone surface length) in the non-PMS group in the present study exhibited significant differences between the genders and were capable of use in gender identification. However, in the PMS group, and in contrast to Cekdemir *et al*. [36], the difference between the genders in minimum frontal width and maximum frontal width measurements was not significant. This showed that the presence of persistent metopic suture should be taken into consideration when performing gender analysis using frontal morphometric parameters.

Limitations

There are a number of limitations to this study, including its retrospective and single-center character, the small number of PMS cases, and the lack of distinction between complete and partial PMS. Other limitations are that the effects of parameters affecting skeletal development, such as environmental, metabolic, and nutritional factors and ethnicity, could not be determined. Patients under the age of 18 were not included in the study due to skeletal development continuing during childhood and adolescence. Separate studies are therefore needed for that age group.

CONCLUSION

In conclusion, in addition to the frontal morphometric parameters currently used for gender identification, a highly important subject for forensic sciences, the 'frontal bone surface length measurement' performed in the present study may be useful in gender estimation as it exhibits significant gender differences. In addition, some of the frontal morphometric measurements (minimum and maximum frontal width) exhibit no gender difference in the presence of PMS, and caution should therefore be exercised when using these parameters in cases with PMS.

Authors' Contribution

Study Conception: AS, NO; Study Design: AS, NO; Supervision: NO; Funding: N/A; Materials: N/A; Data Collection and/or Processing: AS; Statistical Analysis and/or Data Interpretation: AS, NO; Literature Review: AS; Manuscript Preparation: AS and Critical Review: AS.

Ethical standards

Approval for the research was received from the Clinical Research Ethics Committee of Süleyman Demirel University Faculty of Medicine (decision dated 30.12.2020 and numbered 72867572-050.01.04-15964).

Conflict of interest

The authors disclosed no conflict of interest during the preparation or publication of this manuscript.

Financing

The authors disclosed that they did not receive any grant during conduction or writing of this study.

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