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Frontal Sinus Dimensions in the Presence of Persistent Metopic Suture

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Abstract

The frontal sinus (FS) is an air-filled space and usually appears as two irregularly-shaped cavities separated from each other by a septum. The persisting metopic suture (MS) is considered to be a factor influencing the FS development. In this study we aimed to compare the FS dimensions in metopic (n = 50) and control (n = 75) cranial series and thus to assess the relation between MS persistence and FS pneumatization. All skulls were scanned with industrial μCT system and volumetric images were generated. The total FS width and the height and depth of both FS lobes were measured.
The persistent MS was frequently co-occurred with significantly small and underdeveloped FS. The significant and positive correlations between the FS measurements showed that the FS pneumatization is a spatially-coordinated process and its progress is proportionately expressed in both vertical and horizontal plates of the frontal bone.

Key words: frontal sinus, *metopism*, persistent metopic suture, volumetric imaging, μCT scanning

Introduction

The frontal sinus (FS) is an air-filled space and one of the four paranasal sinuses developed as an expansion of the nasal cavities into the adjacent facial and skull bones. Since both lobes of the FS develop independently, they display a high degree of asymmetry attributed to more rapid development on one side at the expense of the other [21, 22, 23]. Commonly the FS appears as two irregularly-shaped cavities separated from each other by a thin bony septum, although many variations have been reported [28, 32, 34]. Furthermore, the FS has been considered to be unique in each person since its shape differs significantly even in monozygotic twins. Thus, due to its uniqueness, protected location, and frequent radiological documentation, the FS is particularly useful for identification of unknown human remains [22, 23].

The metopic suture (MS) lies between the halves of the fetal frontal bone and usually closes at the first or second postnatal year [29]. Failed fusion of the MS leads to condition known as *metopism*, reported to ranges from 0.8% up to 15% in different population groups [3, 5, 6, 12, 26, 35]. The persisting MS is considered to be a factor influencing the FS development [33]. In this study we aimed to compare the FS dimensions in metopic and control cranial series and thus to assess the relation between the MS persistence and FS pneumatization.

Materials and Methods

Material

The FS was investigated in a total of 125 dry adult male crania distributed into two series: a metopic series including skulls with entirely preserved MS (n = 50) and a control one (n = 75). The skulls belonged to soldiers who died in the Balkan Wars and the First World War, and whose bone remains were preserved in the Military Mausoleum with Ossuary at the National Museum of Military History of Bulgaria.

Methods

The scanning was performed using an industrial μCT system Nikon XT H 225 (Nikon Metrology). In order to compare the FS pneumatization when the MS persisted with normally developed FS, the cases of underpneumatized FS were excluded from the control series. Therefore, before scanning, the non-metopic skulls were inspected for FS development using the real time X-ray visualization. The Inspect-X software was used to adjust the settings. The scanning protocol for all of the specimens was as follows: voltage of 100 kV, a power of 10 W, 100 μA tube current and exposure time of 500 ms. A series of 2000 sequential projections were captured while the object was rotated on 360°. The raw data were reconstructed using the software CT Pro 3D with the same parameters and filters and resolution of 97.5 μm with isotropic voxels. The volumetric rendering, inspection in the three orthogonal plains, and FS measurements were accomplished using VG Studio Max 2.2. The total FS width and the height and depth on both FS lobes were measured on tomograms as linear distances between the outermost points (**Fig. 1**). The supraorbital line, tangential to the upper orbital rims, was used as a baseline for measurement of the FS height.

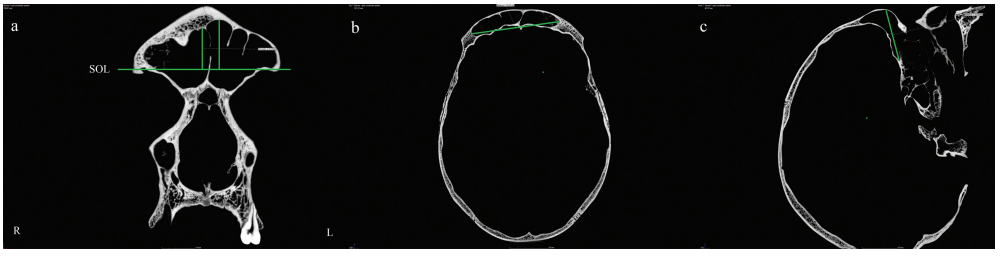

Fig.1. Frontal sinus dimensions: a) Frontal sinus height of right and left lobes measured in the coronal section; b) total frontal sinus width measured in the transversal section; c) frontal sinus depth measured in the sagittal section. Abbreviations: SOL – supraorbital line.

Statistical analyses

The mean, standard deviation (SD), minimum and maximum values were calculated for each measurement in the metopic and control series. The normal distribution of each variable was tested by the Kolmogorov-Smirnov normality test. The statistical significance of intergroup differences was assessed using the independent-samples *t*-test for the normally distributed variables and the Mann-Whiney *U*-test for the non-normally distributed ones. Bilateral differences in the FS height and depth were estimated by the paired *t*-test for the normally distributed variables and the Wilcoxon signed rank test in cases of non-normally distributed ones.

The Pearson bivariate correlation analysis was applied to evaluate the strength and direction of the relationships between the FS measurements. The strength of the correlations was classified according to the absolute values of correlation coefficients as follows: "very weak" (0.00-0.19), "weak" (0.20-0.39), "moderate" (0.40-0.59), "strong" (0.60-0.79), and "very strong" (0.80-1.00). A positive value denoted a positive correlation and a negative one indicated a negative correlation.

The intraobserver reliability was assessed by Intraclass correlation coefficient (ICC). For this purpose, the FSs of 20 randomly selected skulls were measured twice by one observer with a time interval of 4 months. The significance level of all statistical tests was set at $p<0.05$.

Results

The intraobserver reliability for all FS measurements was excellent (≥0.990).

All FS measurements were significantly larger in the control series, except for the depth of the left FS lobe (**Table 1**), which was insignificantly smaller in the metopic skulls. The control series did not show considerable bilateral differences in the FS measurements, whereas in the metopic skulls the depth of the left FS lobe was significantly

Table 1. Comparison between the frontal sinus dimensions in the metopic and control series

Measurements	Metopic series					Control					t-test / Mann-Whitney U-test
	n	mean	SD	min	max	n	mean	SD	min	max	
Frontal sinus width	50	46.57	14.27	19.26	74.50	75	54.19	14.01	30.78	85.67	U = 1394.50 (p = 0.016)*
Frontal sinus height R	37	13.68	6.63	3.52	28.89	75	17.31	8.10	2.69	48.76	U = 1018.50 (p = 0.023)*
Frontal sinus height L	46	14.42	6.23	1.74	27.80	75	17.06	6.50	4.11	36.88	t = -2.206 (p = 0.029)*
Frontal sinus depth R	49	23.70	8.16	10.49	46.23	75	27.16	8.01	5.55	45.03	t = -2.332 (p = 0.021)*
Frontal sinus depth L	50	26.08	7.89	10.08	44.08	75	26.94	8.99	7.40	52.67	t = -0.549 (p = 0.584)

* The significance level was set at $p<0.05$

larger compared to the right one (**Table 2**). In the metopic series, the FS aplasia was observed in 26% (n = 13) as in 8% (n = 4) it was bilateral and in 18% (n = 9) it was unilateral and entirely right-sided.

In both series, all correlations between FS measurements were positive and significant. In the metopic series, the FS width correlated strongly with the height and depth of both FS lobes. Furthermore, strong correlations were observed between the height and depth of right FS lobe as well as between the depths of both FS lobes (**Table 3**). In the control series, the FS width correlated strongly with the heights of both FS lobes. The depths of both FS lobes correlated very strong with one another (**Table 4**).

Table 2. Bilateral differences in the frontal sinus dimensions in the metopic and control series

Measurements	Series	Right					Left					paired t-test / Wilcoxon signed rank test
		n	mean	SD	min	max	n	mean	SD	min	max	
Frontal sinus height	Metopic	37	13.68	6.63	3.52	28.89	37	14.98	6.46	1.74	27.80	t = -1.153 (p = 0.256)
	Control	75	17.31	8.10	2.69	48.76	75	17.06	6.50	4.11	36.88	Z = -0.079 (p = 0.939)
Frontal sinus depth	Metopic	49	23.70	8.16	10.49	46.23	49	26.38	7.67	10.08	44.08	Z = 2.611 (p = 0.009)*
	Control	75	27.16	8.01	5.55	45.03	75	26.94	8.99	7.40	52.67	t = 0.354 (p = 0.724)

The significance level was set at $p<0.05$

Table 3. Correlations between the frontal sinus measurements in the metopic series

	FS width	FS height R	FS height L	FS depth R	FS depth L
FS width	1	0.769*	0.660*	0.767*	0.671*
FS height R		1	0.448*	0.604*	0.385*
FS height L			1	0.452*	0.492*
FS depth R				1	0.686*
FS depth L					1

* The significance level was set at $p<0.05$

Table 4. Correlations between the frontal sinus measurements in the control series

	FS width	FS height R	FS height L	FS depth R	FS depth L
FS width	1	0.730*	0.774*	0.596*	0.546*
FS height R		1	0.682*	0.391*	0.307*
FS height L			1	0.420*	0.391*
FS depth R				1	0.807*
FS depth L					1

* The significance level was set at $p<0.05$

Discussion

It has already been established that metopic skulls possess specific distinctive characteristics in the configuration of the cranium [1, 7, 13, 15-21, 23, 31, 35]. The established greater widths of the forehead and the orbital region could be attributed to the MS persistence, which allows excessive bone growth perpendicular to it [31].The significantly broad and high forehead in the MS series, however, is not related to a greater FS pneumatization. It is known that in metopic skulls both lobes of the FS develop separately on either side since the persistent MS precludes the likelihood of development of the sinus beyond the median plane [8, 28, 21, 23].This entity is useful in clinical practice for differentiation of a persistent MS from a fracture of the frontal bone on a radiograph [4].

The supposed influence of *metopism* on the general FS pneumatization has not been synonymous. It has been suggested that the persistence of MS inhibits the FS pneumatization [10, 27] due to the simultaneous FS development and frontal bone growth. Hence, the bipartite frontal bone and persistent MS could retarded or entirely suppressed the FS pneumatization [30]. The considerably frequent FS underdevelopment in metopic skulls has been established in some previous studies [2, 9, 18, 21, 25, 32, 33], whereas in others such a correlation has not been found [4, 11, 14, 24].

Our previous morphometric investigation performed on digital radiographs revealed a tendency for MS persistence to be frequently related to FS underdevelopment at least at the vertical portion of the frontal bone [21]. The present study is performed with advanced imaging modality allowing comprehensive survey of the FS shape and size. The results confirm previous findings and show that the *metopism* is frequently accompanied by an underdeveloped FS. Furthermore, the significant strong positive correlations between the FH measurements in both series show that the FS pneumatization is a spatially-coordinated process since its progress is proportionately expressed in the vertical and horizontal plates of the frontal bone.

In the metopic series the bilateral FS aplasia is rarer than the unilateral one, which is entirely right-sided. Besides, when the MS persists the FS is considerably smaller. These findings imply that the MS preservation inhibits the FS development. If this is so, it would be expected that the suppressed pneumatization of the vertical portion would be compensated with a hyperpneumatization of the orbital one. Such a tendency, however, is not observed. It has been suggested that the MS probably does not suppress the FS pneumatization itself [18, 21]. Rather, their co-occurrence is an expression or aftereffect of a certain condition during the early developmentand this hypothesis is supported by the present results as well.

It has been supposed that the midface hypoplasia blocks one of the major stimuli for the FS pneumatization, exactly the need to provide a structural bridge between neurocranium and face [32]. Such disorders like Hajdu-Cheney syndrome, cleidocranialdysostosis and pyknodysostosis exibit diminished FS pneumatization [32], as well as MS preservation [16]. The underlying factors causing the common occurrence of *metopism* and FS underdevelopment in non-syndromic individuals, however, are still unclear and are object of further investigations.

Conclusion

The persistent MS was frequently co-occurred with significantly small and underdeveloped FS. Furthermore, the right FS lobe in the metopic series was smaller with considerably decreased horizontal pneumatization, whereas the control series did not show significant bilateral differences in the FS dimensions. The significant positive correlations between the FS measurements showed that the FS pneumatization in both series is a spatially-coordinated process and its progress is proportionately expressed in the vertical and horizontal frontal bone plates.

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