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Hyperostosis frontalis interna as an age-related phenomenon – Differences between males and females and possible use in identification

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ABSTRACT

Hyperostosis frontalis interna (HFI) is a condition manifested by thickening of the inner surface of the frontal bone and it could be useful when dealing with the identification of human remains in various anthropological and forensic investigations. We compared the macroscopic appearance and morphologic (metric) features of the skulls in cases with and without HFI, in both sexes, and wanted to establish whether age determined occurrence of HFI. To achieve this aim, we performed prospective autopsy study, covering ten-year period (2007–2016). Study group consisted of southeast Europe Caucasian subjects, with determined age and sex. The severity of HFI was classified by two forensic pathologists independently, according to the four types (A–D) proposed by Hershkovitz et al. Thicknesses of the frontal and temporal bones, as well as the longitudinal and frontal diameters of the skulls were measured. The sample consisted of 35 males and 112 females with HFI, and 55 males and 202 females without HFI (404 individuals in total). Type B was the most common type of HFI among males (45%) and type C among females (41%). HFI type D was almost four times more common in females than in males (OR = 3.73). Frontal and temporal bones were thicker in all subjects who have HFI. Thickness of the skull was not age-dependent, in the entire sample, or in subjects with HFI, or in the control group (in all the cases Spearman's Rho was < 0.3). Age seemed to be a predicting factor for HFI occurrence only in females. Females younger than 55 years have similar risk for HFI occurrence as males. An unidentified skull with the general markers of old age and severe form HFI is most probably from a female decedent.

1. Introduction

When dealing with the identification of human remains in various anthropological and forensic investigations, estimation of sex and age is essential. The postcranial skeleton (e.g. long bones and pelvis in particular) is considered a better indicator for sex assessment than the skull, which many authors regard as the second best [1–3]. In practice, however, incomplete skeletons or even only skulls in isolation are found. Physical anthropologists record morphological (nonmetric) traits, some of them being binary in nature (present/absent) or represented as ordinal grades of expression [4]. There are many skull landmarks being used for this purpose, such as size differences of the mastoid processes, glabella, supraorbital ridges, palate, frontal sinuses [1,5–7], or some specific pathological features of the skull, such as hyperostosis frontalis interna (HFI) [8].

Hyperostosis frontalis interna is an idiopathic condition manifested by bone formation involving the endocranial surface of the frontal bone [9]. In a studious and large sample size study (including 3797 skulls from three different time periods, varied geographic locations and ethnic groups), Hershkovitz et al. [10] separated the hyperostosis frontalis interna (HFI) from the hyperostosis cranialis diffusa (HCD), defining the HFI as “a disorder of the endocranial plate that remodels into a more cancellous phenotype” and further classifying it into four types (A–D), based on the location in the frontal bone, the extent of involvement, appearance, shape, border type, and involvement of other bones. This classification has been widely accepted and frequently cited in medical literature.

HFI is much more common in females than in males. Most of the studies regarding HFI in males are case reports [11–16]. The common denominator in all of these studies is that the aetiology of HFI is ambiguous, but most likely related to a hormonal imbalance; in males, HFI most probably emerges as a result of inadequate androgen stimulation, or rather as a result of the changes in the estrogen/androgen ratio [17].

The aim of our study was to analyse and compare the macroscopic

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appearance (according to four types, A–D) and morphologic (metric) features (thickness of frontal and temporal bones, longitudinal and frontal diameters) of the skulls in cases with and without HFI, in both sexes. Furthermore, we wanted to establish whether age determines the occurrence of HFI in males, compared to females and could this be useful in the identification of human remains.

2. Material and methods

A prospective autopsy study was performed covering a ten-year period (2007–2016). Our study sample comprised all subjects having HFI (males and females), while as a control group we randomly selected subjects without HFI from the autopsy material. Skulls from the entire sample, both with and without HFI, belonged to adult population (18 years or older), Caucasians born in Southeast Europe in the 20th century. Excluding criteria for the entire sample was bone-related pathology of cranium, and severe skull fractures (due to inability to conduct proper skull measuring). Subjects with HFI died of natural (63%) or violent causes (37%). The sample consisted of 35 males and 112 females with HFI, and 55 males and 202 females without HFI. The average age of males with HFI was 62.7 ± 15.4 years (range 27–85), and the average age of males without HFI was 60.8 ± 17.4 years (range 24–93). Females with HFI were 71.3 ± 14.0 years old (range 19–93), and females without HFI were 58.4 ± 19.9 years old (range 19–101) (Fig. 1).

Crania had been opened with an electric saw, using the standard technique described in autopsy technique textbooks: the sawing begins at the mid-temporal zone of one side with the line of the cut running anteriorly toward the forehead (ending 2 cm above the glabellar region) and then continued backwards, ending just above and behind the contralateral ear. Further cuts begin at these end points angled backward, ending 1 cm below external occipital protuberance [18]. Upon opening, we measured the longitudinal and frontal diameters of the skulls using ruler (accurate to 1 mm). Using a Vernier calliper (accurate to 0.5 mm), we measured frontal and temporal bones in the places where the largest thickness was observed, avoiding the middle sagital line.

The severity of HFI was classified according to the four types (A–D) proposed by Hershkovitz et al. [3]: “type A – isolated elevated bony islands, single or multiple, generally under 10 mm in size, found in the anteromedial part of the frontal bone (Fig. 2a); type B – nodular bony overgrowths with slight elevation, identified on < 25% of the frontal bone (Fig. 2b); type C – extensive nodular bony overgrowth with irregular thickening of up to 50% of the frontal endocranial surface (Fig. 2c); and type D – continuous bony overgrowth, involving > 50% of the frontal endocranial surface (Fig. 2d)”. In each case, during the autopsy two forensic pathologists confirmed the severity of HFI or its absence independently.

To estimate the differences, the obtained data were statistically analysed using the Fisher's exact-test, Student's *t*-test, and Mann–Whitney sum ranks for variables with nonparametric distribution. All numerical variables were tested with the Kolmogorov-Smirnov test for normal distribution. Logistic regression was used to find a possible relationship between variables. The ROC curve was used for estimating cut-off values. A *p*-value of < .05 was considered significant. SPSS version 17.0 (license number 106454) is the software that has been used for the statistical analysis.

3. Results

There was no significant age difference between the males with and without HFI ($t = -0.549$; df = 88; $p > .05$), but the females with HFI were older than the males with HFI and females without HFI (Mann Whitney U = 1278.000, $p < .05$; Mann Whitney U = 6727.500, $p < .05$, respectively). Using logistic regression, we showed that in our sample age seemed to be a predicting factor for HFI occurrence in females, but not in males; on the other hand, in females who are younger than 55 years, age did not determine HFI occurrence (Table 1). The ROC curve was used for the estimation of the cut-off value for HFI occurrence – in females, it was 68.5 years, with a sensitivity of 64% and specificity of 74% (AUC = 0.702; $p < .05$); in males, sensitivity and specificity ratios were not satisfactory enough for the estimation of the cut-off value (AUC < 0.5; $p > .05$).

As we previously mentioned, in each case with HFI two experienced forensic pathologists confirmed the severity of the process independently. Type B was the most common type of HFI among males and type C among females (Fisher exact test = 12,173; $p < .05$). Tables 2 and 3 show the distribution of HFI subtypes according to age intervals, in both sexes. HFI type D is almost four times more common in females than in males (OR = 3.73, $p < .05$). Table 4 represents comparison of distribution of HFI subtypes between our and similar study [10].

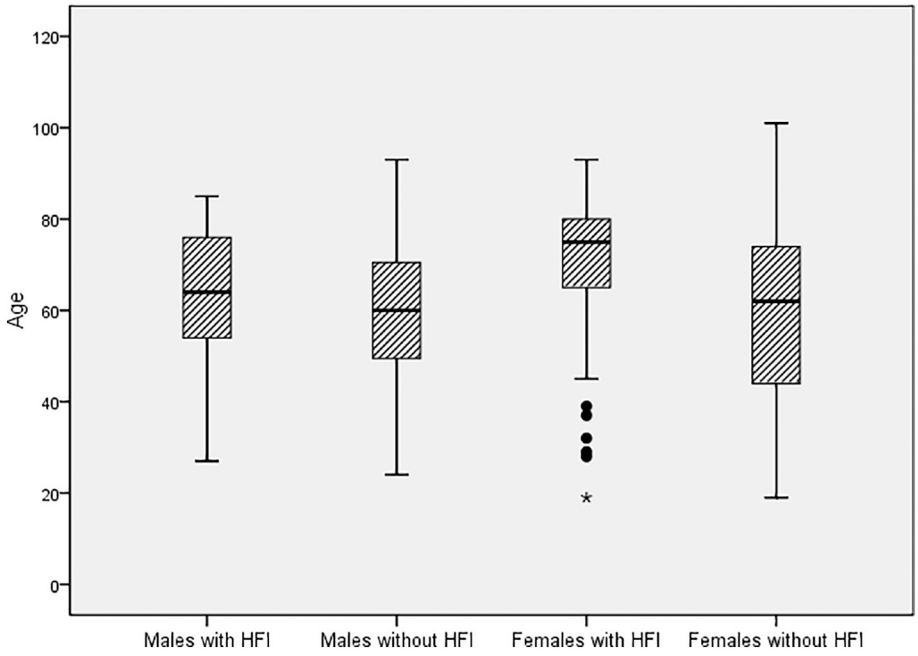

Fig. 1. The box and whisker plots represent age in the study sample. The lower boundary of the box indicates the 25th percentile, the line within the box marks the median, and the upper boundary of the box indicates the 75th percentile. Error bars above and below the box indicate the 90th and the 10th percentiles, respectively. The points and the star are outliners (extreme values outside the 90th and 10th percentiles).

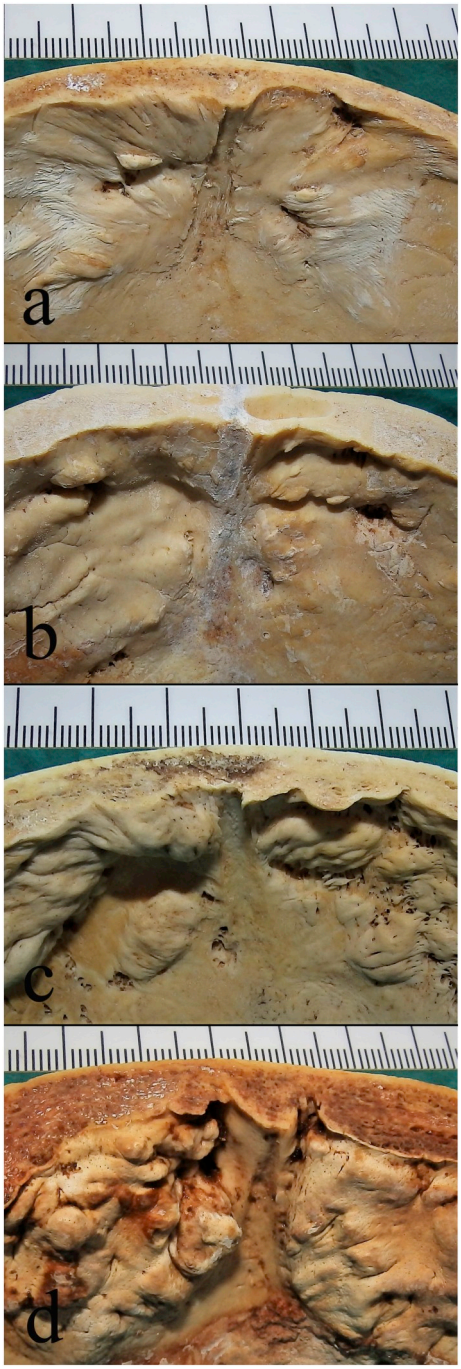

Fig. 2. Macroscopic features of HFI: a – type A, male, 84 years old; b – type B, male, 57 years old; c – type C, male, 75 years old; d – type D, male, 44 years old.

Table 1
Univariate logistic regression model for correlation between age and HFI occurrence, regarding sex.

Age	B	p value	OR	CI 95%
Females	0.044	< .05	1.045	1.028–1.061
Males	0.007	.580	1.007	0.982–1.034
Females < 55 yrs	0.024	.369	1.024	0.973–1.078

OR – odds ratio, CI – confidence interval

Table 5 shows the morphologic features of skulls in both sexes. Frontal and temporal bones are thicker in subjects that have HFI, regardless of sex (in males, for the frontal bone the Mann Whitney is U = 164.500, $p < .05$, and for the temporal bone U = 518.000, $p < .05$; in females, for the frontal bone the Mann Whitney is U = 2439.500, $p < .05$, and for the temporal bone U = 6177.500, $p < .05$). The thickness of the skull was not age dependent, in the entire sample (for frontal bone Spearman's Rho was 0.189; for temporal bone Spearman's Rho is 0.258), or in subjects with HFI (for frontal bone Spearman's Rho was 0.025; for temporal bone Spearman's Rho was 0.025), or in the control group (for frontal bone Spearman's Rho was 0.006; for temporal bone Spearman's Rho was 0.251).

In females, the longitudinal diameter was slightly smaller in subjects with HFI (the Mann Whitney U = 9706.500, $p < .05$), while in other groups there were no differences regarding longitudinal and frontal diameters (Table 5).

4. Discussion

The reported rates of HFI in published studies are around 20% for females and 3% for males [9,10,17,19], indicating that HFI is rather uncommon among males. For most physical anthropologists, sex remains an unshakable biological given and a binary [20]. In the 1960s and 1970s, new theoretical concepts emerged when sex was identified as biologically given, and gender as the social and symbolic product of biological differences [21]. We consider discussing those considerations beyond the scope of this paper, but would like to stress that some features and conditions encountered mostly on the female skull (such as HFI) can also be found in males, and most of those, due to many (patho) physiological reasons, are being consider as “less manly” or “more feminine”. In that sense, we might very broadly conclude that HFI is not specific for the female sex, but could rather be “linked” to female gender.

Compared to females, HFI in males is usually moderate in extent (types A and B), while type D is rarely reported. In their large sample study, which included both modern and historic skeletal populations, as well as cadaver population, Hershkovitz et al. reported that in male skeletal sample they observed only one case of HFI type C and none of type D [10]. Compared to the skeletal population, they had a relatively small sample of cadaver population, where most males with HFI had type A, and only one had type D [10] (Table 4). Similarly, in our sample, males most commonly had milder forms of HFI and 3 out of 35 subjects (aged 44, 64, and 79) had type D HFI. This could mean that type D HFI in males is not uncommon, but still a rare finding.

Moore [22] considered HFI and HCD to be different manifestations of the same process, with HFI occurring first, as a precursor to HCD. Hershkovitz et al. [10] gave priority to the term HFI over HCI, since HFI is the common term in medical literature and the involvement of other areas of the endocranium may imply a different aetiology. In our sample, all the subjects with HFI (male and female) had thicker frontal and temporal bones, and this is in accordance with the results of the previous studies conducted in females [19,23,24]. It is still debatable whether HFI and HCD are different manifestations of the same process, since thickening of the inner table is rarely seen only on the frontal bone. Microarchitecture analyses of the frontal, temporal and occipital bones, using micro-computed tomography (microCT), might provide an answer to this question. Bracanovic et al. used microCT to assess the microarchitecture of the frontal bone in females with various types of HFI, and they detected differences between females with moderate (type A, B and C) and severe (type D) HFI in the regions of diploe and the inner table [24]. Further studies are needed to evaluate not only the frontal, but also the temporal and occipital bones; male subjects should be included too. Such a research might clarify whether HFI and HCD are, in fact, the same phenomenon, with similar (or maybe the same) changes in bone microarchitecture in both sexes.

We wanted to test the hypothesis that the process of HFI development influences the cranial vault volume; therefore, we measured frontal and temporal bone thickness, as well as longitudinal and frontal diameters of the skulls. As our results have shown, females with HFI do

Table 2
Distribution of HFI subtypes according to age intervals, in males.

Females		Age interval (years)								Total
		< 20	21–30	31–40	41–50	51–60	61–70	71–80	> 80	
HFI type	A	1	1	1	0	3	1	3	2	12 (11%)
	B	0	0	1	2	4	4	10	4	25 (22%)
	C	0	1	0	0	4	9	23	9	46 (41%)
	D	0	0	1	0	3	5	9	11	29 (26%)
Total		1	2	3	2	14	19	45	26	112 (100%)

have slightly smaller longitudinal diameter compared to females without HFI, which could be due to the thicker frontal bone. In males, there are no differences in skull diameters whatsoever. There have been extensive data in the literature associating HFI with headaches [14,25], epilepsy and dementia [26] and some authors point out that the presence of HFI suggests a decrease in brain volume which may indicate the beginning of degenerative processes of the brain [23]. Our results imply that HFI does not affect cranial vault size, and in our opinion, neuropsychological implications of HFI remain vague.

In our sample, the thickness of the frontal and temporal bones were not age dependent, regardless of the presence of HFI (in all cases, Spearman's Rho coefficient is < 0.3). Therefore, measuring the skull thickness would probably not be useful for predicting the age of a decedent.

In our study, logistic regression has shown that age is a predictor for HFI occurrence in females, but not in males. In fact, the older the woman was, the more severe the HFI type was. Females younger than 55 years had the same risk of HFI occurrence as did males, but after this age HFI manifestation starts to be age-related. One of the differences between females older and younger than 55 years is menopause. Menopause refers to a point in time that follows 1 year after the complete cessation of menstruation, and the postmenopause describes the years following that point. The average age of its onset is 47, and menopausal transition typically spans from 4 to 7 years [27]. It seems that menopause (and the relatively sudden decrease in estrogen production) could be the trigger for HFI occurrence or its transition into a more severe form. The process is still rather slow, and only after approximately 13.5 years can we predict (with acceptable sensitivity and specificity ratio) that a woman might have HFI. This theory could explain why HFI is more common in females (compared to males) and why older females have more severe forms of HFI. However, the results of our study suggest that in males, as well as in females younger than 55 years, some other factors could influence the occurrence of HFI, and this factor may or may not be similar or the same.

Our results show that males with HFI are younger than females with HFI and that younger males tend to have milder forms of HFI. Earlier studies suggest that HFI probably emerges as a result of inadequate androgen stimulation [11–17]. In this sense, it could be an inherent condition, or a condition acquired in early adulthood that leads to relative or absolute hypogonadism (Klinefelter's syndrome, testicular atrophy, and obesity), or some other factor that most probably does not have the potency to cause severe forms of HFI. There is only one study with experimental design in which the authors examined whether sex hormones in males may generate the development of HFI [17]. Males who have been hormonally treated for prostate cancer (androgen suppression) are at a higher risk of developing HFI compared to healthy males. In fact, the longer the duration of hormonal treatment, the higher the risk of developing HFI. In our study, there were no male subjects with undisputed autopsy findings consistent with hypogonadism (except for a few cases of gynecomastia), nor were there any reliable heteroanamnestic data on the possible conditions that could have led to hormonal disturbances. It is possible that androgen itself does not produce the HFI phenomenon, but rather the change in the estrogen/androgen ratio (namely a surplus of estrogen) [17]. However, only prospective, primarily clinical, controlled studies, where hormone levels are measured and consecutive head CT scans are used, could confirm this theory.

When dealing with the skeletalized human remains, the determination of sex is statistically the most important criterion, as it immediately excludes approximately half the population whereas age, stature, and ancestry each provide points within a wide range of variables [28]. In general, robusticity tends to characterize male and gracility female skeletons [20]. Spradley et al. have shown that, for sex estimation, in both American Blacks and Whites, the cranium provides an overall cross-validated classification rate of 90–91%, while multiple postcranial elements provide between 92% and 94% [29]. That means that postcranial metrics continue to provide better estimates of sex than nonmetric or metric traits of the skull, but there is" a catch "– what if an anthropologist doesn't have multiple postcranial elements at their disposal? It comes handy that HFI could be observed even when only the frontal bone is preserved.

Our results suggest that HFI type D is roughly four times more common in females than in males, and it is almost exclusively present in females older than 50 years. May et al. stated that there is > 32% chance that an unknown skull with major HFI is a female over 70 years old, while there is an 86.9% probability that a skull aged 70+ years with major HFI is a female [2]. Our findings support these results – when finding an unidentified skull with the general markers of old age (osteoporosis, articular surface degeneration, osteophytes) and severe HFI, there is a great chance that it belongs to a female decedent.

In conclusion, there are no differences in the morphology of HFI in males compared to females, meaning that this phenomenon is probably the same in both sexes. Males tend to have milder forms of HFI (type B). Males with HFI are younger than females with HFI, but HFI occurrence

Table 3
Distribution of HFI subtypes according to age intervals, in females.

Males		Age interval (years)							Total
		21–30	31–40	41–50	51–60	61–70	71–80	> 80	
HFI type	A	1	2	0	0	2	2	0	7 (20%)
	B	0	1	1	1	6	3	3	16 (45%)
	C	0	0	1	5	1	1	1	9 (26%)
	D	0	0	1	0	1	1	0	3 (9%)
Total		1	3	3	6	10	7	4	35 (100%)

Table 4
Comparison of distribution of HFI subtypes in our study and study done by Hershkovitz et al. [10].

HFI subtypes	Males[a]	Males[b]	Females[a]	Females[b]	Total[a]	Total[b]
A	7 (20%)	4 (60%)	12 (11%)	7 (39%)	19 (13%)	11 (42%)
B	16 (45%)	1 (13%)	25 (22%)	3 (15%)	41 (28%)	4 (15%)
C	9 (26%)	1 (13%)	46 (41%)	6 (31%)	55 (37%)	7 (28%)
D	3 (9%)	1 (13%)	29 (26%)	3 (15%)	32 (22%)	4 (15%)
Total	35 (100%)	7 (100%)	112 (100%)	19 (100%)	147 (100%)	26 (100%)

[a] Subjects from our study sample.
[b] Subject from the study done by Hershkovitz et al [10], regarding only cadaver population.

Table 5
Thickness of the frontal and temporal bones, longitudinal and frontal diameters of skulls in the study sample.

	Frontal bone (mm)	Temporal bone (mm)	Longitudinal diameter (mm)	Frontal diameter (mm)
Males with HFI	10.1 ± 2.0	6.9 ± 1.8	153.6 ± 8.4	138.4 ± 7.2
Males without HFI	6.3 ± 1.7	5.3 ± 1.8	154.2 ± 6.9	139.2 ± 7.5
p-value	< .05	< .05	> .05	> .05
Females with HFI	9.7 ± 2.9	6.3 ± 2.1	150.2 ± 6.8	133.7 ± 6.2
Females without HFI	5.5 ± 1.9	4.8 ± 1.4	151.8 ± 6.8	133.6 ± 6.4

in males is not age-related. Females younger than 55 years have the same risk for HFI occurrence as males; however, after this age HFI manifestation starts to be age-related. Menopause could be one of the key events in the HFI pathogenesis and aetiology, and the progression of HFI is probably related to a sudden shift in sex hormones concentration. Other factors (which may or may not be similar, or the same) could influence the occurrence of HFI in males and females younger than 55 years. An unidentified skull with the general markers of old age and severe form (type D) HFI is most probably from a female decedent. Measuring the thickness of the frontal and temporal bones was not found to be useful for the prediction of the age of decedent.

Declarations of interest

None

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