ORIGINAL ARTICLE

Hyperostosis frontalis interna: criteria for sexing and aging a skeleton

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Abstract Estimation of sex and age in skeletons is essential in anthropological and forensic medicine investigations. The aim of the current study was to examine the potential of hyperostosis frontalis interna (HFI) as a criterion for determining sex and age in forensic cases. Macroscopic examination of the inner aspect of the frontal bone of 768 skulls (326 males and 442 females) aged 1 to 103, which had undergone a head computerized tomography scan, was carried out using the volume rendering technique. HFI was divided into two categories: minor and major. HFI is a sex- and age-dependent phenomena, with females manifesting significantly higher prevalence than males ($p<0.01$). In both females and males, prevalence of HFI increases as age increases ($p<0.01$). We present herein the probabilities of designating an unknown skull to a specific sex and age cohort according to the presence of HFI (standardized to age distribution in an Israeli population). Moreover, we present the probability of an individual belonging to a specific sex or age cohort according to age or sex (respectively) and severity of HFI. We suggest a valid, reliable, and easy method for sex and age identification of unknown skulls.

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Introduction

Estimation of sex and age in skeletons is essential in anthropological and forensic medicine investigations. Numerous methods for estimating sex have been published in the literature. One of the accepted techniques for sex determination is based on dimorphism of skull elements: size differences of the mastoid processes, glabella, supraorbital ridges, palate, frontal sinuses, etc. [1–6]. Age estimation in adults is very complicated and imprecise due to many environmental factors. Age estimation is based, among others, on epiphyseal and suture closure, degree of tooth wear, and development of degenerative changes on joint surfaces [1, 2, 5]. In the present study, we examined the possibility of using hyperostosis frontalis interna (HFI) as a method for estimating sex and age of skeletons.

HFI is an overgrowth of bony tissue on the inner plate of the frontal bone of the calvaria. It is expressed as a bilateral nodular bony overgrowth, restricted to the area between the superior sagittal sinus medially and the middle meningeal artery posteriorly [7–9]. HFI was traditionally considered as part of a much larger syndrome known as the "Morgagni–Stewart–Morel–Moore syndrome" which included obesity, virilism, neuropsychiatric symptoms, and headaches [8, 10]. At present, HFI is considered an independent condition, as the majority of patients are asymptomatic [7].

Studies have demonstrated that the etiology of HFI differs from that of other cranial hypertrophies associated with Frohlich's syndrome, Paget's disease, leontiasis ossea,

acromegaly, osteomas, and pregnancy osteophyts, although all these pathologies may share endocranial hyperostosis in the frontal bone [8, 9]. HFI is a sex- and age-dependent phenomena: females manifest significantly higher prevalence of HFI compared to males, and as age increases, HFI prevalence and severity increase [7, 8].

Validity of the established methods for sexing and aging skulls alone decrease considerably with the individual's age. Moreover, sexing the skull of an individual aged ≥50 years based on morphology alone may lead to erroneous results [5]. Therefore, there is a need for a sex-linked trait that can be easily identified in forensic cases by using reliable and validated techniques. Previously, when a complete skull was discovered, radiographs and endoscopy were the only diagnostic options for observing the interior of the skull. Radiographs are unable to diagnose early stages of HFI [7], and endoscopy is quite cumbersome. Today, with the use of computerized tomography (CT), access to the skull's interior is much more feasible. Several recent studies have demonstrated the effectiveness of 3-D reconstruction based on multislice CT used in forensic science for linear measurements [11] and sex and age estimation [12–14].

The aim of the current study was to examine the potential of using HFI for sexing and aging in forensic cases via CT images.

Materials and methods

Macroscopic examination was carried out on 768 living individuals: 326 males aged 1 to 103 (mean=57, SD=28, median=64) and 442 females aged 1 to 99 (mean=60, SD=24, median=67) from the Haifa district in Israel who had undergone a head CT scan (standard protocol) for diagnostic purposes previous to this study, between the years 2005–2008 [Brilliance 64 (Philips Medical Systems, Cleveland, Ohio): slice thickness 3 mm*1.5, 120 kV, 300–400 mAs, rotation time 0.4–0.5 s, pitch 0.39, FOV 220 mm and Matrix 512*512]. HFI was identified via CT images using the volume rendering (VR) technique and multiplanar reconstruction (MPR) for verification (Philips EBW workstation, 90–150 slices were used per volume rendering reconstruction) and was based on Hershkovitz et al's [7] principles. Two types were defined: minor HFI (equivalent to Hershkovitz et al's [7] type B)—an elevated bony ridge without clear margins, usually occupying less than 25% of the frontal bone surface area and major HFI (equivalent to Hershkovitz et al's [7] types C and D)—an extensive nodular bony overgrowth with irregular thickening, occupying more than 25% of the inner plate of the frontal bone (Fig. 1).

Statistical parameters were obtained via descriptive statistics for each measurement (SPSS 15.0). The association between HFI, age, and sex were examined using the t test and chi-square test.

Inter- and intra-reliability tests were carried out on 27 individuals who had undergone a head CT at the Carmel Medical Center, Haifa, Israel [Brilliance 64 (Philips Medical Systems, Cleveland, Ohio). The inter-observer test was performed by three independent researchers (I.H., G.D., and H.M.); the intra-observer test was performed three times by H. M. with a 2-week interval between each sample ranking. Both tests produced good results, Kappa=0.75 and Kappa=0.793, respectively.

To validate the VR method in diagnosing HFI, 46 cadaver skullcaps (Sackler Faculty of Medicine, Tel-Aviv University) were scanned and rated twice (at 1-month intervals): once using the VR technique and once with direct observation. The Kappa test generated "almost perfect" results (K=0.82) [15].

Results

HFI is a sex- and age-dependent phenomena. Females significantly manifested higher prevalence of HFI compared to males ($\chi^2 = 43.704$, df=1, $p<0.01$), e.g., 24% of the females manifested major HFI compared to 5% of the
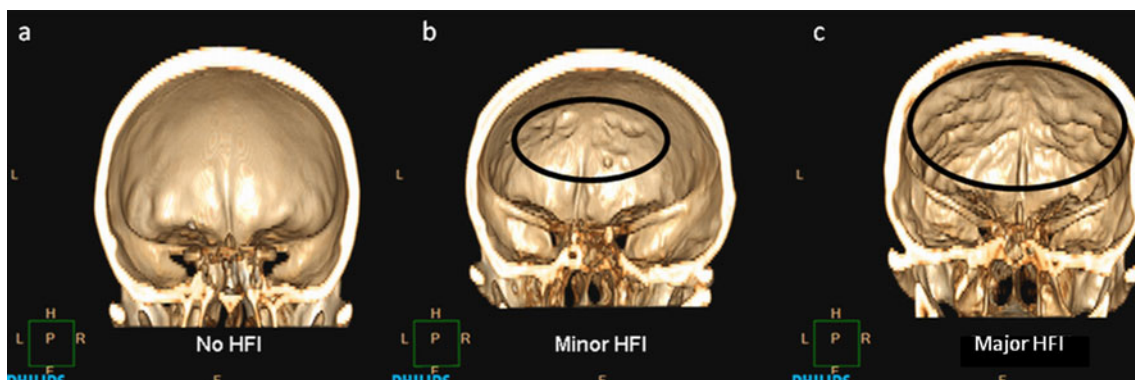

Fig. 1 Hyperostosis frontalis interna types classified via the CT volume rendering method: **a** no HFI, **b** minor HFI, and **c** major HFI

Table 1 The probability of an unknown individual belonging to a specific sex and age cohort according to the presence of HFI, standardized to age distribution in the Israeli population [16]

Sex	Age cohort	No HFI (%)	Minor HFI (%)	Major HFI (%)
Females	0–19	23.4	0.0	0.0
	20–39	13.7	20.8	4.2
	40–54	6.1	14.4	17.2
	55–69	3.4	11.4	22.5
	70+	1.7	6.1	32.1
Males	0–19	24.1	2.0	0.0
	20–39	13.0	23.8	8.5
	40–54	8.1	6.4	7.6
	55–69	3.8	11.7	3.1
	70+	2.7	3.5	4.8
Total		100.0	100.0	100.0

Table 3 The probability of a female skull belonging to a specific age cohort according to the presence of HFI, standardized to age distribution in the Israeli population [16]

Age cohort	No HFI (%)	Minor HFI (%)	Major HFI (%)
0–19	48.4	0.0	0.0
20–39	28.4	39.5	5.5
40–54	12.6	27.3	22.6
55–69	7.0	21.6	29.7
70+	3.5	11.6	42.2

female with no HFI is ≥70 years old (Table 3). Furthermore, the probability that a male skull with major HFI is between 0–19 years old is nil (Table 4).

males. As age increased, prevalence of major HFI increased in both females and males ($p<0.01$), e.g., 20% of females aged 55–69 years manifested major HFI, while less than 5% of the younger age cohort of 20–39 years manifested major HFI. The same tendency was shown in males.

Table 1 presents the probabilities of an unknown skull, i.e., sex and age unknown, belonging to a specific sex and age cohort according to its HFI category after standardization to age distribution in Israel [16]. For example, there is more than a 32% chance that an unknown skull with major HFI is a female over 70 years old. Table 2 presents the probability of a skull, of which age is known, to be either male or female according to the HFI degree (standardized to age distribution in Israel [16]): there is an 86.9% probability that a skull aged 70+ years with major HFI is a female. Tables 3 and 4 present the probability of a skull of which sex is known to belong to a specific age cohort (standardized to age distribution in Israel [16]). For example, there is a 3.5% chance that a

Discussion

HFI is a sex- and age-dependent phenomena [7, 8]. In females, it is simple to correlate age with hormonal regulation (sexual maturity, premenopausal, menopausal, and post-menopausal periods), while in males, the hormonal changes from sexual maturity to death are much slower and more subtle [17]. A significant difference in HFI development has been observed in males and females. The prevalence of major HFI is much higher in females than in males; however, the development of HFI in a healthy male is probably more influenced by genetics and congenital factors than age.

In this study, we suggest a valid, reliable, and easy method for sex and age identification of unknown skulls, in conjunction with other established methods. Although the possibility that HFI may be used for forensic purposes has been studied [18], this is the first paper to present a statistical analysis of age, sex, HFI prevalence, and HFI severity in the general population, producing a forensic tool for identifying sex and age of a specimen based on the specific HFI classification. Moreover, previous studies have reported HFI to be independent of geographical origin: European Americans and African Americans exhibit similar rates of HFI [7], which strengthens the relevancy of the method for different populations.

Table 2 The probability of an individual with a known age belonging to a specific sex according to the presence of HFI, standardized to age distribution in the Israeli population [16]

Sex	Age cohort	No HFI (%)	Minor HFI (%)	Major HFI (%)
Females	0–19	49.2	0.0	–
	20–39	51.4	46.6	32.7
	40–54	42.8	69.3	69.3
	55–69	46.9	49.4	87.9
	70+	38.9	63.7	86.9
Males	0–19	50.8	–	–
	20–39	48.6	53.4	67.3
	40–54	57.2	30.7	30.7
	55–69	53.1	50.6	12.1
	70+	61.1	36.3	13.1

Table 4 The probability of a male skull belonging to a specific age cohort according to the presence of HFI, standardized to age distribution in the Israeli population [16]

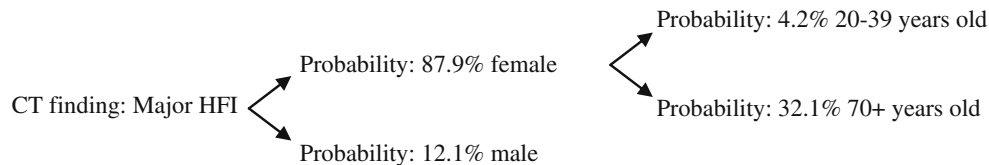| Age cohort	No HFI (%)	Minor HFI (%)	Major HFI (%)
0–19	46.6	4.2	0.0
20–39	25.1	50.3	35.5
40–54	15.7	13.4	31.6
55–69	7.4	24.7	12.9
70+	5.2	7.4	20.1

Conclusion for practice

Forensic examiners are advised to pursue the following steps:

1. CT scan of the skull (standard skull protocol is sufficient).
2. Identify presence/absence of HFI using the VR method and verify via MPR methods.
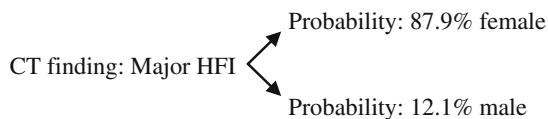3. If present, rate the degree of HFI (present scale: minor and major) based on the standards described above.
4. Use the tables: if age and gender are unknown, employ Table 1. If age is known but sex is unknown, employ Table 2, and if sex is known but age is unknown, use Table 3 for females and Table 4 for males.
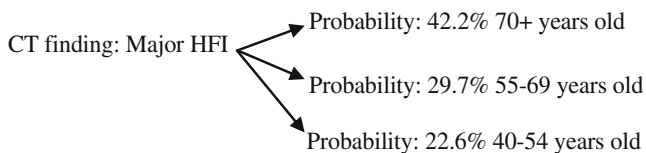
For example:

1. Age and sex are unknown:

CT finding: Major HFI → Probability: 87.9% female → Probability: 4.2% 20-39 years old / Probability: 32.1% 70+ years old
CT finding: Major HFI → Probability: 12.1% male

2. Age is known, for example 55–69 years old, and sex is unknown:

CT finding: Major HFI → Probability: 87.9% female
CT finding: Major HFI → Probability: 12.1% male

3. Sex is known, for example, female, and age is unknown:

CT finding: Major HFI → Probability: 42.2% 70+ years old
CT finding: Major HFI → Probability: 29.7% 55-69 years old
CT finding: Major HFI → Probability: 22.6% 40-54 years old

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