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Foramen magnum, occipital condyles and hypoglossal canals morphometry: anatomical study with clinical implications

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Background: *Current study examines morphometric alterations of the foramen magnum (FM), occipital condyles (OCs) and hypoglossal canals (HCs) and highlights all the morphometric parameters of the FM area that present side asymmetry, gender dimorphism and are affected by the ageing.*
Materials and methods: *One hundred and forty-one (73 male and 68 female) Greek adult dry skulls were examined.*
Results: *Short and long OCs were detected in 27.7% and 26.2%. A combination of short OCs and long HCs was presented in 27.5%. A complete septum was found in 23.6% of the HCs and osseous spurs in 12.9%. Side asymmetry was detected regarding the HCs length ($p = 0.046$), the maximum extracranial ($p = 0.001$) and minimum intracranial ($p = 0.001$) diameters. Mean FM anteroposterior and transverse diameters, FM perimeter and FM surface area were significantly larger in male than in female skulls ($p = 0.001$ for each parameter). Similarly, the OCs length (right, $p = 0.004$ and left, $p = 0.024$) and width (right, $p = 0.008$ and left, $p = 0.006$) the left distance HC-OC posterior border ($p = 0.048$), the anterior ($p = 0.011$) and posterior ($p = 0.001$) intercondylar distances and the HCs right length ($p = 0.046$) were significantly greater in males. A significant decrease was observed with ageing in FM anteroposterior diameter ($p = 0.038$), FM surface area ($p = 0.05$), anterior intercondylar distance ($p = 0.014$) and HC-OC posterior border ($p = 0.013$).*
Conclusions: *The study confirmed that only specific HC dimensions showed side asymmetry (HCs maximum extracranial and minimum intracranial diameters and HCs length), gender dimorphism (HCs right length and left distance HC-OC posterior border) and age influence (HC-OC posterior border and HC left extracranial minimum diameter) among young, adults and elderly individuals. FM and OCs dimensions presented gender dimorphism and the age influenced only FM anteroposterior diameter and surface area and the anterior intercondylar distance. The safe zone of OCs drilling in Greeks, calculated by the distance HC-OC posterior border represents the maximum HC depth and is among the lowest values reported in the literature. The significant decrease of this distance with ageing confirms the existence of a drilling safe zone for young, adults and elder individuals. Regarding OCs length, the same probability exists dealing with a short or a long OC during condylectomy. Before planning a transcondylar approach, the coexistence of short OCs and long HCs should be taken into account. These outcomes will be useful for a safe surgery in the craniocervical region in Greeks.* (Folia Morphol. 2017; 76, 3: 446–457)

Key words: foramen magnum, occipital condyle, hypoglossal canal, asymmetry, gender, age

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INTRODUCTION

The complex occipital bone area is constituted of the foramen magnum (FM), the anterolateral located occipital condyles (OCs) and the hypoglossal canals (HCs) situated anterior to the OCs and inferomedially to the lower border of the jugular foramen. Morphologic and morphometric variabilities of the occipital bone structures may coexist in the same individual or among different subjects of the same or different populations, as a result of genetic and heritable epigenetic interactions [38]. Skull base variations may also be part of a pathological process (tumours, aneurysms, congenital or acquired malformations and trauma) [4] and their surgical approach is technically demanding and requires the profound knowledge of anatomy [30]. Awareness of FM, OCs and HCs morphometric details enables an improved angle of surgical exposure with a wider access for a safe and successful surgery. The far lateral transcondylar approach and its modifications demand the extensive vertebral artery dissection, the HC exposure and the OCs and jugular tubercle removal. During condylectomy, clumsy manipulations may injure vertebral artery, jugular vein and bulb [40], damage the lower cranial nerves and cause craniocervical instability [4]. The preoperative computed tomography (CT) scan of the area is essential, as captures all details of bone formations and represents probable abnormal areas of lytic lesions or lines of fractures [2]. The detailed understanding of the relations FM-OCs and OCs-HCs is of immense significance during skull base interventions. Although there are published studies highlighting FM, OCs and HCs morphometry [7, 31, 32, 41], side asymmetry or gender influence, little information exists about the detailed morphometry of the basiocciput combined with the correlations FM-OCs, FM-HCs and OCs-HCs. Furthermore, the age impact in FM, OCs and HCs area is underestimated, although it is known that ageing is closely related to bone loss [31]. To our knowledge no study exists, viewing age effects in FM, OCs and HCs dimensions, investigating different age groups (young, adults and elderly) in the total sample and separately in male and female subjects.

The current study examines FM, OCs and HCs morphometric alterations, their correlations, and investigates side asymmetry, gender dimorphism and age influence.

MATERIALS AND METHODS

One hundred and forty-one (73 male and 68 female) intact Greek dry skulls from the osseous collection of our Department were divided into three age-groups: 20–39 years of age (19 skulls — 14 male and 5 female), 40–59 (36 skulls — 19 male and 17 female) and 60 and above (86 skulls — 40 male and 40 female) in order to examine age impact in FM, OCs and HCs morphometry in the total sample and separately in male and female skulls. Skulls damaged in skull base area and with gross evident deformities were excluded. All distances were measured using a digital sliding calliper (Mitutoyo ABSOLUTE 500-196-20), accurate to 0.01 mm. By using ImageJ software, FM perimeter and surface area were calculated. All measurements performed by a single investigator were taken twice and the average of two values was finally recorded. Skulls placed vertically to the horizontal plane on a stand with the external occipital protuberance located to the horizontal plane, were photographed with a Sony 16.1-megapixel Digital Camera (fixation 47.5 cm) positioned at a distance of 20 cm from each skull. The studied parameters were: FM anteroposterior diameter — APD (basion to opisthion distance), FM transverse diameter — TD (distance between the lateral margins of FM at the point of greatest lateral curvature) (Fig. 1A), FM perimeter and FM surface area. Moreover, the OCs length (distance along the long axis from the edges of the articular surfaces), OCs width (distance from the articular edges along a line perpendicular to the long axis) (Fig. 1A), and the maximum OCs thickness (maximum distance between the lower margin of the HC internal opening and the lower OC margin) (Fig. 1D) were also recorded, for both OCs. The anterior and posterior intercondylar distances (AID and PID) between the anterior and posterior OCs tips were also calculated (Fig. 1B). The HC length (distance from the extracranial to intracranial orifice) (Fig. 1D), the HC extracranial and intracranial maximum and minimum diameters and the distance HC-OC posterior border were also detected (Figs. 1C, E). The HCs were also investigated bilaterally for the existence of osseous spurs and septa.

Statistical analysis

Descriptive statistics (mean ± standards deviation, median, minimum and maximum values) were evaluated for all the measured parameters. Kolmogorov-Smirnov test was performed for the evaluation of the normality of distributions. Non parametric χ^2 test was used to detect differences between percentages. The paired sample t-test and Wilcoxon Signed Rank test were used to investigate side asymmetry,

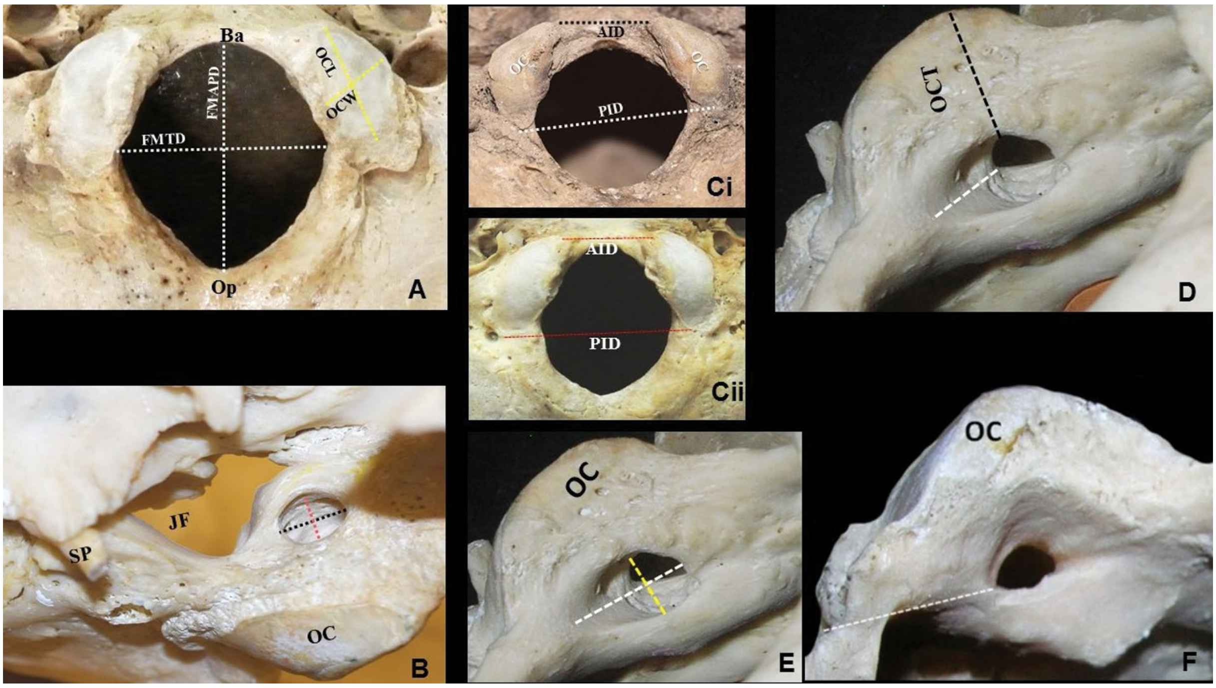

Figure 1. Metric distances of the foramen magnum (FM), occipital condyles (OC) and hypoglossal canal (HC); **A.** FM anteroposterior diameter — FMAPD, FM transverse diameter — FMTD, OCs length and width; **B.** HC maximum extracranial (red dotted line) and minimum extracranial (black dotted line) diameters; SP — styloid process; JF — jugular foramen; **Ci, Cii.** Anterior and posterior intercondylar distances (AID and PID) between the anterior and posterior OCs tips; **D.** Maximum OCs thickness (black dotted line) and the HC length (white dotted line); **E.** HC maximum intracranial (white dotted line) and minimum (yellow dotted line) diameters; **F.** Distance HC-OC posterior border (white dotted line). OCT — OC thickness; OCW — OC width; OCL — OC length; Ba — basion; Op — opisthion.

Mann-Whitney U-test and t-test for gender dimorphism, Kruskal-Wallis and one-way ANOVA tests for the correlation with the age. The Pearson correlation test was used for the correlation between the measured parameters. For all the analyses, values of p less than 0.05 were accepted as significant and statistical analysis was carried out using IBM SPSS Statistics for Windows, version 21.0.

RESULTS

Results obtained from the metric parameters of the OCs and HCs according to the side of occurrence are summarised in Table 1, the FM, OCs and HCs according to the gender in Tables 2 and 3 and all parameters according to the age in Table 4. The OCs were classified according to their lengths (mean value, 23.69 ± 2.71 mm). After the consideration of the upper boundary, we chose the 75th percentile, as the upper limit for the normal range of OCs length. Thus, the 25–75th percentile (21.80–25.35 mm) was accepted as the normal group and percentiles smaller than 25th were classified as short OCs, whereas higher than 75th were considered as long OCs. Thus, 27.7% of the OCs were short and 26.2% long. Similarly, taking into consideration the 25–75th percentile of the right-sided HCs maximum extracranial diameters (6.74–7.37 mm) and left-sided HCs maximum extracranial diameters (6.42–7.59 mm), values greater than 7.37 mm on the right and 7.59 mm on the left side were considered as long HCs and lower than 6.74 mm on the right and 6.42 mm on the left side were classified as short HCs. Thus, in 51 skulls, 34 (24.1%) right HCs and 36 (25.5%) left HCs were long and in 81 skulls, 74 (52.5%) right HCs and 33 (23.4%) left HCs were short. Among them, 14 (27.5%) skulls presented a combination of long HCs and short OCs. The mean AID and PID were 20.63 ± 2.64 mm and 42.32 ± 3.48 mm. After morphological investigation, a complete septum was found in 23.6% of the HCs (14.2% on the right, 8.5% on the left side and 5.7% bilaterally) (Figs. 2C–G), while osseous spurs were detected in 12.9% (11.4% on the right and 14.3% on the left side) (Fig. 2B).

Side asymmetry. Side asymmetry with left side dominance was detected at the HC length and at the HC maximum extracranial and minimum intracranial diameters. OCs were symmetrical concerning their length, width and thickness. Side symmetry was also

Table 1. Side symmetry and asymmetry in occipital condyles (OCs) and hypoglossal canals (HCs) morphometry. Lengths and widths are expressed in mm

OCs and HCs morphometry	Side of occurrence				P
	Mean ± standard deviation		Min–max (range)		
	Right side	Left side	Right side	Left side	
OCs length	23.66 ± 2.84	23.66 ± 2.67	13.34–29.92 (16.58)	15.15–29.47 (14.32)	0.996
OCs width	11.77 ± 1.52	11.85 ± 1.63	7.77–16.38 (8.61)	8.40–16.59 (8.19)	0.569
OCs thickness	10.09 ± 1.66	10.03 ± 1.45	6.45–19.03 (12.58)	6.12–14.09 (7.97)	0.935
HC-OC posterior border	8.16 ± 1.28	8.18 ± 1.23	4.71–12.79 (8.08)	4.38–12.04 (7.76)	0.802
HCs length	8.89 ± 1.50	9.03 ± 1.53	4.98–12.10 (7.12)	4.76–12.09 (7.33)	0.046*
HC maximum extracranial length	6.85 ± 1.04	7.06 ± 0.95	4.87–9.76 (4.89)	3.89–9.66 (5.77)	0.001*
HC maximum intracranial length	5.40 ± 0.87	5.38 ± 0.75	3.48–7.84 (4.36)	3.20–7.31 (4.11)	0.755
HC maximum intracranial length	6.54 ± 1.04	6.55 ± 0.95	4.60–9.57 (4.97)	4.19–8.79 (4.60)	0.432
HC minimum intracranial length	5.17 ± 0.87	4.89 ± 0.82	2.74–7.93 (5.19)	2.67–7.34 (4.67)	0.001*

*Side asymmetry

Table 2. Morphometric details of the foramen magnum (FM) anteroposterior diameter (FMAPD), transverse diameter (FMTD), FM perimeter and FM surface area in male and female skulls. Diameters are expressed in mm

FM	Male skulls		Female skulls		P	Total	
	Mean ± standard deviation	Min–max (range)	Mean ± standard deviation	Min–max (range)		Mean ± standard deviation	Min–max (range)
FMAPD	36.16 ± 2.29	30.74–42.98 (12.24)	33.86 ± 2.31	26.70–38.69 (11.99)	0.001	35.05 ± 2.57	26.70–42.98 (16.28)
FMTD	31.32 ± 2.51	22.12–36.67 (14.55)	28.97 ± 2.32	22.67–34.72 (12.05)	0.001	30.19 ± 2.69	22.12–36.67 (14.55)
FM perimeter	118.40 ± 8.39	97.20–142.09 (44.89)	110.87 ± 8.89	86.71–133.64 (46.93)	0.001	114.77 ± 9.40	86.71–142.0 (55.38)
FM area	826.44 ± 118.53	511.10–1101.00 (589.90)	726.26 ± 111.07	443.30–1.037.0 (593.70)	0.001	778.15 ± 125.11	443.30–1101.0 (657.70)

Table 3. Morphometric details of the occipital condyles (OCs) length, width, thickness and distance from HC to posterior border of the OC on the right and left side in males and females. The anterior and posterior intercondylar distances (AID and PID) and hypoglossal canals (HCs) lengths from the intracranial to extracranial orifice. Distances are expressed in mm

OCs and HCs morphometry	Males			Females			P
	Mean ± SD	Min–max	Range	Mean ± SD	Min–max	Range	
OCs right length	24.33 ± 2.57	18.45–29.59	11.14	22.95 ± 2.96	13.34–29.92	16.58	0.004*
OCs left length	24.07 ± 2.59	15.15–29.47	14.32	23.23 ± 2.71	16.79–28.54	11.75	0.024*
OCs right width	12.10 ± 1.50	9.45–16.38	6.93	11.43 ± 1.47	7.77–15.05	7.28	0.008*
OCs left width	12.21 ± 1.66	9.01–16.59	7.58	11.46 ± 1.51	8.40–15.01	6.61	0.006*
Right HC-OC posterior border	8.30 ± 1.30	5.98–12.79	6.81	8.02 ± 1.24	4.71–11.41	6.7	0.196
Left HC-OC posterior border	8.38 ± 1.12	5.48–12.04	6.92	7.97 ± 1.30	4.38–11.12	6.74	0.048*
AID	21.17 ± 2.71	15.71–29.19	13.48	20.05 ± 2.45	13.89–25.87	11.98	0.011*
PID	43.36 ± 3.35	36.52–52.13	15.61	41.23 ± 3.30	34.44–51.64	17.20	0.001*
HC right length	9.14 ± 1.49	5.17–12.10	6.93	8.63 ± 1.48	4.98–11.82	6.84	0.046*
HC left length	9.13 ± 1.37	5.27–11.93	6.66	9.93 ± 1.70	4.76–7.33	7.33	0.446

*Statistical significance difference; SD — standard deviation

Table 4. Morphometric details of foramen magnum anteroposterior and transverse diameters (FMAPD and FMTD), FM perimeter and FM surface area in three age-groups. The distance hypoglossal canal (HC)-OC posterior border on the right and left side in three age groups, the anterior and posterior intercondylar distances (AID and PID). All distances are expressed in mm

FM morphometry	Age groups						P
	20–39		40–59		60–79		
	Mean ± SD	Min–max (range)	Mean ± SD	Min–max (range)	Mean ± SD	Min–max (range)	
FMAPD	36.41 ± 2.31	32.77–40.76 (7.99)	35.04 ± 2.49	30.31–39.45 (9.14)	34.75 ± 2.58	26.70–42.98 (16.28)	0.038*
FMTD	31.06 ± 2.32	27.18–35.14 (7.96)	30.05 ± 2.99	25.08–36.67 (11.59)	30.05 ± 2.62	22.12–36.19 (14.07)	0.317
FM perimeter	118.07 ± 8.72	107.65–137.77 (30.12)	110.87 ± 8.89	86.71–133.64 (46.93)	114.56 ± 9.77	86.71–142.09 (55.38)	0.280
FM area	839.80 ± 123.74	687.32–1068.9 (381.62)	770.79 ± 116.32	564.80–1037.4 (472.65)	767.16 ± 125.26	443.34–1101.90 (658.56)	0.05*
AID	21.99 ± 2.06	18.95–26.40 (7.45)	21.00 ± 2.93	15.62–29.19 (13.57)	20.16 ± 2.52	13.89–25.87 (11.98)	0.014*
PID	43.70 ± 4.04	35.67–50.69 (15.02)	42.73 ± 3.36	36.92–52.13 (15.21)	41.84 ± 3.33	34.44–51.14 (16.70)	0.135
Right HC-OC posterior border	8.51 ± 1.42	5.98–11.41 (5.43)	8.58 ± 1.23	6.18–12.79 (6.61)	7.91 ± 1.21	4.71–10.85 (6.14)	0.014*
Left HC-OC posterior border	8.70 ± 1.43	6.18–12.04 (5.86)	8.52 ± 1.19	5.48–11.17 (5.69)	7.93 ± 1.13	4.38–10.73 (6.35)	0.008*

*Statistical significance difference; SD — standard deviation

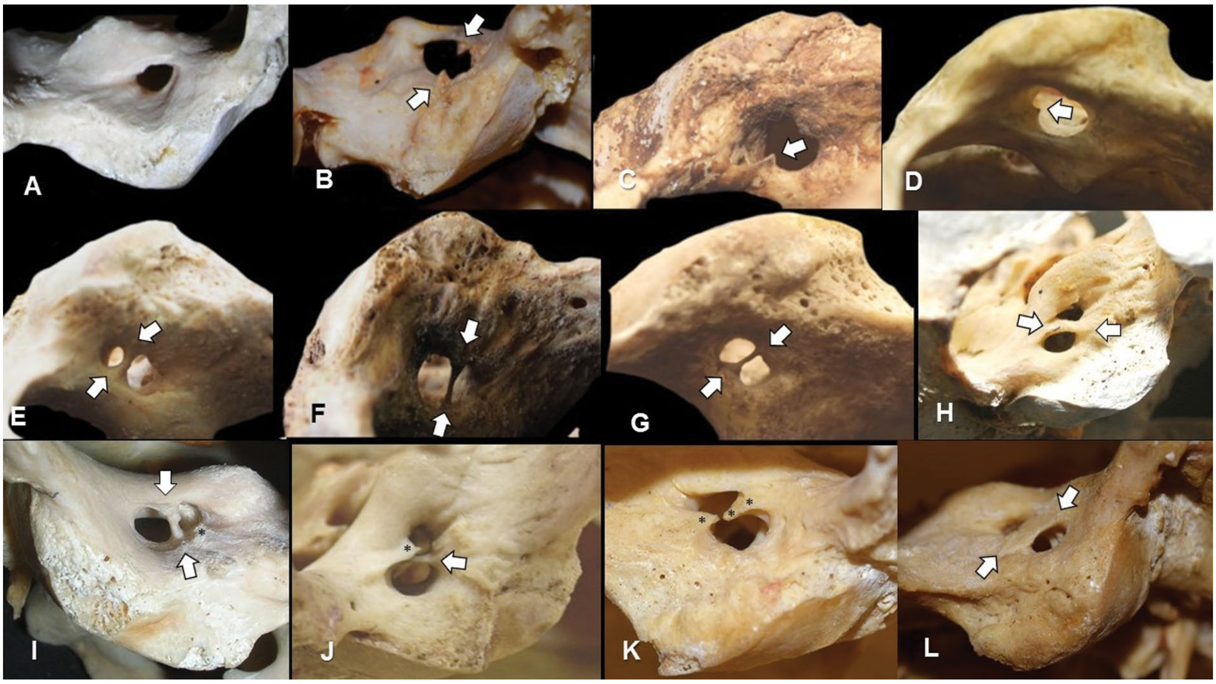

Figure 2. Hypoglossal canal (HC) septation and spurs; **A**. Single HC; **B, C, D.** Osseous spur at the upper, lower and lateral border of the intracranial HC opening (white arrows); **E, F, G.** Complete septation in the whole HC (intracranial to extracranial) — double HCs (white arrows); **H, L.** Septum at the HC intracranial opening; **F, G, I, J.** Septa at the middle compartment of HC; **I, J, K.** Combination of spurs (*) to intracranial HC septation (white arrows).

detected regarding the distance HC-OC posterior border and the HC minimum extracranial and maximum intracranial diameters (Table 1).

Gender dimorphism. In males, mean FMAPD (36.16 ± 2.29 mm), FMTD (31.32 ± 2.51 mm), FM perimeter (118.40 ± 8.39 mm[2]), FM surface area

(824.49 ± 117.85 mm^2), OCs right (24.33 ± 2.57 mm) and left length (24.07 ± 2.59 mm), OCs right (12.10 ± 1.50 mm) and left width (12.21 ± 1.66 mm) were significantly higher than in females (FMAPD 33.86 ± 2.31 mm, FMTD 28.97 ± 2.32 mm, FM perimeter 110.87 ± 8.89, FM surface area, 726.08 ± ± 110.27 mm^2, OCs right length, 22.95 ± 2.96 mm, OCs left length 23.23 ± 2.71 mm, OCs right width, 11.43 ± 1.47 mm and OCs left width, 11.46 ± 1.51 mm) (Tables 2 and 3). In male skulls, the mean AID (21.17 ± 2.71 mm) and PID (43.36 ± 3.35 mm) were significantly lower than in female (AID, 20.05 ± 2.45 mm and PID, 41.23 ± 3.30 mm). Although, in males mean HCs right length (9.14 ± 1.49 mm) and left distance HC-OC posterior border (8.38 ± 1.12 mm) presented significantly higher values versus females (HCs right length, 8.63 ± 1.48 mm and left distance HC-OC posterior border, 7.97 ± 1.30 mm); no gender dimorphism was observed regarding the HCs left length, HCs maximum and minimum extracranial and intracranial diameters and the right distance HC-OC posterior border (Table 3). Double HCs (Figs. 2C–F) were observed in 21.9% in males (15.1% right and 6.8% left) and 19.5% in females (13.2% right and 10.2% left) and osseous spurs in 12.1% in males and in 15.2% in females.

Age impact. In the total sample, FMAPD in the first (36.41 ± 2.31 mm), second (35.04 ± 2.49 mm) and third (34.7 5 ± 2.58 mm) age groups showed a significant decrease ($p = 0.038$), particularly evident between the first and third age groups ($p = 0.029$). Similarly, FM area ($p = 0.05$), AID ($p = 0.014$) and distance HC-OC posterior border on both sides decreased significantly from the first to the second and third age groups (Table 4). No significant age impact was found on FMTD, FM perimeter, OCs length, width and thickness on both sides, PID, HCs length, HCs maximum and minimum extracranial and intracranial diameters. Concerning the age influence separately in males and females, the mean AID decreased significantly in male skulls ($p = 0.009$), particularly between first and third ($p = 0.038$) and second and third age groups ($p = = 0.033$). In male ($p = 0.021$) and female ($p = 0.05$) skulls, a significant decrease of the right distance HC-OC posterior border was found. Also, a significant decrease was detected in male skulls, as regards the HCs maximum left extracranial diameter ($p = 0.020$).

In Pearson correlation analysis, FM, OCs, and HCs metric distances were examined between them and also correlations on both sides (length to length — width to width) and correlations of FM perimeter and FM surface area and the distance HC-OP posterior border were detected. Strong correlations ($p = 0.0001$) appeared between FMAPD and FM perimeter ($r = 0.767$), FMAPD and FM area ($r = 0.769$), FMTD and FM perimeter ($r = 0.617$), FMTD and FM area ($r = 0.652$), FMTD and PID ($r = 0.510$), FM perimeter and FM area ($r = 0.918$), OCs right and left length ($r = 0.689$), OCs right length and PID ($r = 0.502$), OCs right and left width ($r = 0.716$), OCs right and left thickness ($r = 0.765$), right and left distances HC-OC posterior border ($r = 0.625$), HCs right and left lengths ($r = 0.845$), HCs right and left maximum extracranial diameters ($r = 0.507$) and right and left minimum intracranial diameters ($r = 0.667$).

DISCUSSION

In the present study, mean FMAPD was higher than FMTD and referred values were close to the findings of Catalina-Herrera [6], Reina et al. [32] and Natsis et al. [22, 23]. Both diameters were significantly larger in males than in females, as in the majority of investigations [6, 19, 22, 32]. Manoel et al. [18] found significantly higher values in males than in females only for FMTD (30.3 ± 0.20 mm and 29.4 ± 0.23 mm, respectively) and this differentiation was attributed to racial miscegenation (study of black and white skulls). To our knowledge, Abdel-Karim et al. [1] reported the highest values of FMAPD and FMTD in males (42.17 ± ± 3.77 mm and 33.98 ± 3.42 mm) and females (38.75 ± ± 3.51 mm and 31.38 ± 2.08 mm). In the current study, male skulls presented significant higher values of FM perimeter and surface area than female. The existed FM morphometric differences between males and females cannot be explained with the embryological development of the occipital bone, as Scheuer and Black [33] stated. During growing process, central nervous system is developed and matured prior to the skeletal system and a complete fusion of different parts of the occipital bone appears between 5 and 7 years of age. Therefore, complete fusion of the occipital bone should not lead to gender dimorphism and secondary mechanisms may play a fundamental role in alterations of FM diameters [33]. Head weight may influence FM size on both genders. Male brain is heavier than female and higher load causes an increase in mechanical forces transmitted through the atlanto-occipital region. The FM and adjacent structures are preserved by the muscles attachment to the area. This attachment explains why male skulls with larger

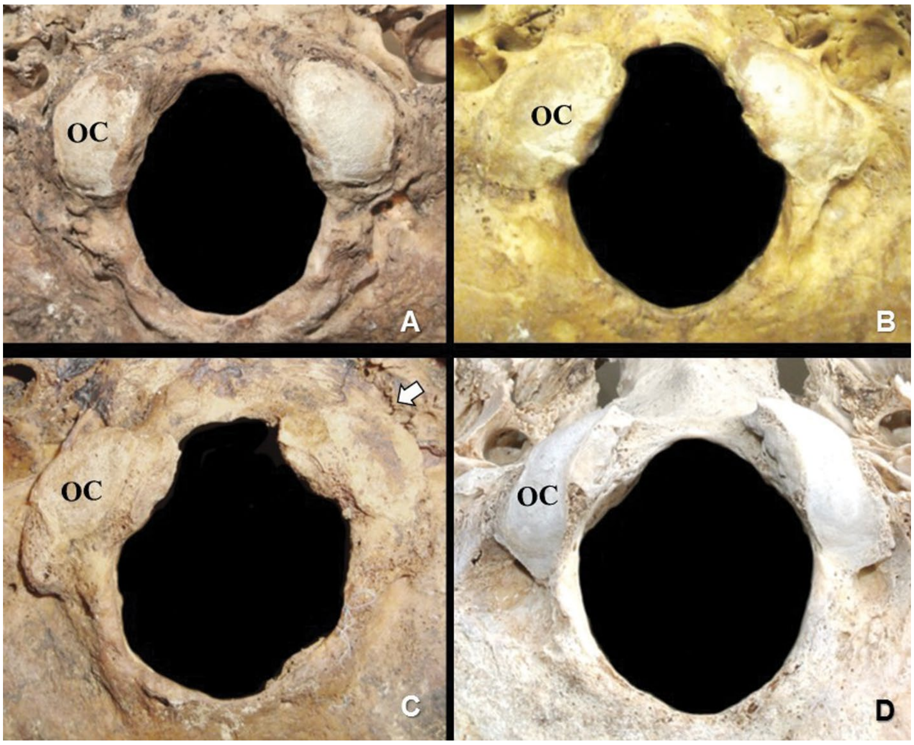

Figure 3. A. Shorts and symmetric occipital condyles (OCs); **B.** Short OCs ventrally oriented (protrusion into the foramen magnum [FM]); **C.** Short and asymmetric OCs (arrow indicate the smaller left OC). The OCs asymmetry in dimensions and position makes irregular the FM; **D**. Long and symmetric OCs.

skeletal muscles have a wider FM surface area than female [18]. Moreover, the existed wide variability among genders in different studies, except of the racial miscegenation, may be due to the different methods of investigation and the different examined samples (dry skulls or CT scans). In craniocervical pathology, FM size is a critical feature for clinical manifestations. A plethora of developmental and acquired craniocervical junction disorders [37] are associated with FM, OCs and HCs morphometric variations and demand a profound understanding of the regional anatomy for the selection of the adequate approach and safe exposure of the involved vital anatomical structures. Cases of atlas occipitalisation lead to a wide decrease (13.1–50.9%) of FM area [17] and cases of achondroplasia, craniometaphyseal dysplasia, Jeune's asphyxiating thoracic dystrophy and Marchesani's syndrome are associated with a stenotic FM, while a wide FM has been reported in patients with Chiari I and II malformations and diastrophic dysplasia [37].

In our sample, 27.7% of the OCs were short and 26.2% long (Fig. 3), whereas Naderi et al. [21] and Avci et al. [2] reported lower incidences (short OCs in 8.6% and 5% and long OCs in 14.1% and 33%). The present study reveals almost equal proportions of long and short OCs, so the surgeon has the same probability to deal with a short or a long OC in Greeks. This finding is of high importance, as the same amount of bone resection in partial condylectomy may cause greater craniocervical instability in short OCs, regardless of the gender. The present morphometric investigation, as other studies [16, 21], revealed a lack of significant size asymmetry in OCs, although Uysal et al. [38] supported that dimensions of the right OCs are statistically of higher discriminant value than dimensions of the left OCs, assuming that this difference may be due to the individual handedness. In our series, the OCs length and width of both sides were statistically larger in males. The OCs gender dimorphism may be justified only a part with biomechanical functions. The atlanto-occipital joint is primarily under static strain and resistance of compression is feasible by the primary cartilages of skull base, so mechanical stress partly explains the dimorphic expression in OCs. It seems that both genetic and epigenetic factors are causing the asymmetry in OCs among genders [12].

The knowledge of the deepest point, at which the OCs can be vertically drilled is referring to the maximum

OCs thickness and is of ultimate importance during condylectomy. Concerning this thickness, side symmetry was detected in our sample, which is in agreement to the results of Naderi et al. [21] and Fetouh and Awadalla [11]. Conversely, Parvindokht et al. [28] found a strong side asymmetry (p = 0.001) with quite lower values (right OCs thickness, 7.21 ± 1.90 and left side, 7.33 ± ± 2.74 mm) than ours. To our view, the sample size is the major factor that influences Parvindokht et al. [28] findings. Side symmetry of the OCs thickness and higher values were detected in our sample in males (right, 10.13 ± 1.53 mm and left side, 10.17 ± 1.38 mm) and females (right, 10.09 ± 1.66 mm and left side, 9.88 ± ± 1.51 mm) in contrast to findings of Kalthur et al. [14] who found side asymmetry among genders calculating OCs thickness in males (right, 10.4 ± 2.0 mm and left side, 9.9 ± 1.4 mm) and females (right, 9.5 ± 2.0 mm and left side, 8.6 ± 1.4 mm).

The OCs converge ventrally, as mean values of AID and PID in our study (20.63 ± 2.64 mm and 42.32 ± ± 3.48 mm) were in close proximity to the findings of Fetouh and Awadalla [11] (20.64 ± 2.86 and 41.4 ± ± 3.48 mm), Ozer et al. [27] (20.9 ± 3.6 and 43.1 ± ± 4.0 mm), Solan [37] (2.0 ± 0.28 and 4.13 ± 0.30 cm) and Naderi et al. [21] (21.0 ± 2.8 and 41.6 ± 2.9 mm). Kizilkanat et al. [16] found the highest values of AID (22.6 ± ± 3.9 mm) and Natsis et al. [22] the highest values of PID (51.61 ± 5.01 mm), whereas Parvindokht et al. [28] reported the lowest values of AID and PID (15.39 ± ± 7.99 mm and 35.60 ± 8.4 mm). Regarding gender influence, Ciceksibasi et al. [8] found gender dimorphism and the lowest values of AID in males (16.09 ± 1.93 mm) and females (14.68 ± 1.80 mm), while Kalthur et al. [14] reported the lowest values of PID (3.8 ± 0.3 and 3.9 ± 0.3 cm). In Greeks, Natsis et al. [22] mentioned the highest significant values of PID (52.80 ± 4.93 mm) in males than in females (50.13 ± 4.71 mm). Dowd et al. [10] proposed that AID and PID could be used in gender determination of unknown skulls due to the higher significant values in males than females, in their sample. The wide difference between AID and PID leaded to an alteration in the anterior and posterior angles of the OCs in our study. This result is of surgical interest as extensive bony removal during condylectomy may be necessary considering the anteroposterior orientation and a narrow intercondylar space. The distance HC-OC posterior border represents the HCs depth and is of great significance during transcondylar approach, as it indicates the maximum amount of OC resection without entering the HC [2]. In our study, the mean right distance HC-OC posterior border (8.16 ± 1.28 mm) and the left distance (8.18 ± 1.23 mm) were slightly different from those detected by Wen et al. [40] (mean total, 8.4 mm) and lower than Barut et al. [3] (right distance 12.5 mm and left 12.6 mm), Avci et al. [2] (9.8 ± 1.1 mm and 9.9 ± 1.4 mm), Kizilkanat et al. [16] (12.2 ± 2.2 mm and 12.4 ± 2.3 mm) and Parvindokht et al. [29] (11.17 ± ± 2.34 mm and 11.69 ± 2.68 mm). Muthukumar et al. [20] and Barut et al. [3] suggested the distance HC-OC posterior border 12 mm and 12.55 mm, as a safe zone of OCs drilling, while our study in Greeks concluded in a safe zone of 8.17 mm (8.34 mm in males and 7.99 mm in females, p = 0.06). This difference is probably explained not only by the racial differences, but by the lack of determination of the exact point of measurement from the internal HC orifice among the studies. Barut et al. [3] also stated that the mean distance HC-OC posterior border is appropriate to 1/2 of the OCs length, while in our study, this value is approximately 1/3 of the OCs length (23.69 ± 2.71 mm), which is the usual amount of bony removal of the OCs. During transcondylar approach, resection of 50% or more of the OC leads to an unstable atlanto-occipital joint and the occipitocervical stabilisation is strongly considered [17]. The HC in Greeks was situated more profound in males than in females and only the left distance HC-OC posterior border was statistically significant. The age influenced both right and left distances in the total sample (Table 4), while age affected only the right distance in males (p = 0.021) and females (p = 0.052). The significant decrease of the distance HC-OC posterior border between the three age groups confirms the existence of a drilling safe zone for each group (first group: 8.61 ± 1.41 mm, second group: 8.54 ± 1.19 mm, third group: 7.92 ± 1.17 mm).

Double HCs were found in 21.9% in males and 19.5% in females and osseous spurs in 12.1% in males and in 15.2% in females in our sample, a higher incidence than Kaur et al. [15] who found double HCs in 10.5% of the male (3.5% right, 7% left and 5.3% bilaterally) and in 9.1% of the female (6.1% right and left and 3% bilaterally) skulls. Osunwoke et al. [26] detected double HCs unilaterally (12.5% in males and 25% in females) and bilaterally (7.2% in males and 12.5% in females). A wide range of septate HCs exists among populations. The highest incidences of double HCs occur in South Americans (27.4%), Greeks (25.5%), Nigerians (25%) and Americans (24%), while the smallest in Palestinians (7%) and North Indians (12.5%) [39]. A possible explanation for the variable expression of this hyperostotic trait is the influence of different environmental factors (nutrition, climate and biomechanical stress) among populations. Kaur et al. [15] reported that double HCs is a genetically determined feature and no gender dimorphism and side asymmetry occurred, while Corruccini [9] found significant age and gender differences and Skrzat et al. [36] detected side asymmetry among genders. Septate HCs is of clinical importance, as the hypoglossal nerve roots may get trapped in occipital bone, during ossification process, resulting in slight changes of tongue movement and speech.

Hypoglossal canal diameters are of clinical importance considering pathology that affects occipital bone (fractures, intracranial and extracranial neoplasms and congenital defects) [5]. In our study, side asymmetry with left dominance was detected concerning HCs length and gender dimorphism existed only for the right HCs length. Muthukumar et al. [20] reported a mean HCs length much higher (12.6 mm) than ours (8.95 ± 1.50 mm) and Nikumbh et al. [25] much lower significant values in males (0.63 ± 0.09 cm) and females (0.59 ± 0.09 cm). Concerning HC extracranial and intracranial maximum and minimum diameters, symmetry was observed in both genders in our study (Table 3), while Nikumbh et al. [25] reported side symmetry among genders concerning the HC extracranial minimum diameter, after investigating only the extracranial HCs diameters. Contrariwise, Osunwoke et al. [26] found side asymmetry among genders, regarding all intracranial and extracranial HC diameters.

Age-related bone loss affects men and women, alike. Skrzat et al. [36] examining bone mineral density in skulls of young and old individuals concluded that structural changes are the result of a decrease in calcium concentration in old skulls. Age-related bone loss starts at an early age long before any hormonal change and is characterised by a slower, more gradual decline in bone mass than in case of postmenopausal bone loss [24]. More particularly, at an older age, periosteal apposition leads to an increase in bone perimeter. This process maintains bone strength in ageing bones by depositing new bone on the outside (periosteal) of the cortex in order to compensate for the intrinsic bone loss on the inside (endosteal). There are also age-related osseous changes, such as the disrupted architecture, the altered composition of bone mineral and matrix, the delayed repair of fatigue microdamage, the excessive turnover, and the inadequate bone size [24]. This mechanism could explain all the above alterations observed in FM, OCs and HC canal area. In our study, a decrease in FMAPD and FMTD with ageing was observed; however, only the first dimension showed statistically significant difference. FMAPD presented the higher decrease between the three age groups. As regards FM perimeter and surface area, the current study underlines a non-significant increase of FM perimeter between second and third age groups and a significant decrease in FM area between first, second and third age group in the total sample, whereas male and female skulls did not be influenced by the age. Decrease of muscle mass will predominantly affect the areas of muscles attachment [38]. Therefore, the skull base osseous structures are affected and a decrease in FM dimensions, particularly evident in FMAPD and FM area takes place. The ageing process causes degenerative changes in FM area with bone resorption and external bone apposition via the secondary ossification process [31], the so-called bone remodelling [35]. The FMAPD showed no significant age impact in male and female skulls. Gapert et al. [12] investigating two age groups < 50 years and $>$ 50 years old mentioned no significant age effect on the total sample, on males and females. Shaikh and Kulkarni et al. [34] examining adolescents (13–25 years) and adults (above 25 years) reported that adult females showed significant increase in FMAPD over the adolescent females, while adolescent males presented significant increase in FMAPD and FMTD over the adolescent females. On the other hand, adult males did not show any significant increase in any parameter of the FM dimensions over adult females. The OCs length, width and thickness and the HCs length, maximum and minimum intracranial and extracranial diameters did not influenced by the age, in the total sample, in male and female skulls with only exception, the HC extracranial minimum diameter in males on the left side, that was influenced significantly ($p = 0.020$) by the age. Thus, it seems that the age did not participate significantly in morphometric alterations of the OCs and HCs dimensions. On the contrary, AID and distance HC-OC posterior border are affected by the aging, as the AID decreased significantly between three age groups in the total sample and in male skulls particularly between first and third ($p = 0.038$) and second and third age groups ($p = 0.033$) and the distance HC-OC posterior border showed a significant decrease in the total sample and on the right side of both genders (males, p = 0.021 and females, p = 0.05). The significant decrease between the three age groups confirms that a different drilling safe zone exists for each age group. After the calculation of the mean distance HC-OC posterior border in each age group, the safe zone of OCs drilling is 8.61 ± 1.41 mm in the first age group, 8.54 ± 1.19 mm in the second age group and 7.92 ± 1.17 mm in the third age group. Another important feature of the present study is the positive and particularly strong correlations between FMAPD-FM perimeter, FMAPD-FM area, FMTD-FM perimeter, FMTD-FM area, FMTD-PID, FM perimeter-FM area, OCs right length-OCs left length, OCs right width-OCs left width, OCs right thickness-OCs left thickness, OCs right length-PID, right distance HC-OC posterior border-left distance HC-OC posterior border, HCs right length-HCs left length, HC right maximum extracranial diameter-HC left maximum extracranial diameter and HC right minimum intracranial diameter-HC left minimum intracranial diameter. The strong correlation between FM area-FMAPD (p = 0.0001, r = 0.769) and FM area-FMTD (p = 0.0001, r = 0.658) comes in agreement with Murshed et al. [19] who reported that FM area showed highly significant correlations for the FMAPD ($p < 0.01$, r = 0.847) and FMTD ($p < 0.001$, r = 0.834). Similarly, Gökce et al. [13] found a strong correlation (p = 0.001) between FMAPD-FMTD in males (r = 0.340) and females (r = 0.770) and FMAPD-FM area in males (r = 0.720) and females (r = 0.870). Parvindokht et al. [29] found positive correlation between OCs length-OCs width (r = 0.387), while in our study no such correlation existed. Parvindokht et al. [28] also detected a positive correlation between OCs width-FM perimeter (r = 0.433), while in the current study, a weak correlation between OCs width and FM perimeter only on the right side existed (p = 0.010, r = 0.218). Cicekzibasi et al. [8] found a significant association between OCs right length and OCs left length ($p < 0.01$, r = 0.870). The current study also confirms strong correlation between OCs right length and OCs left length (p = 0.0001, r = 0.689) and moreover a strong correlation also existed between OCs right width and OCs left width (p = 0.0001, r = 0.716). Naderi et al. [21] detected a weak correlation between OCs right length and FMAPD (p = 0.001, r = 0.399) and OCs left length and FMAPD (p = 0.001, r = 0.367), result that agrees with the findings of current investigation, (OCs right length and FMAPD, r = 0.277 and OCs left length and FMAPD, r = 0.375). In fact, correlations observed in the study present a strong dependency between right and left side in all OCs and HCs diameters, while weak correlations were detected between all OCs and HCs diameters. A weak correlation between OCs length and HC maximum extracranial diameter was observed in the total sample (p = 0.010, r = 0.218). To further understand this finding, if in preoperative CT scan a patient with short or long OCs is detected, the related HCs is not necessary to follow the OCs dimensions (a long OC does not always correspond to a long HC and vice-versa). When a long HC is located under a short OC, the surgeon may have to change the amount of bone drilling and should be alert during condylectomy in order to avoid hypoglossal nerve injury. The coexistence of short OCs and long HCs in our sample was 27.5%. Hence, 3–10 cases will need an alteration in the surgery plan. This number may not correspond to the major part of the cases, nevertheless it could be associated with neural complication followed the transcondylar approach. In the present study, side asymmetry existed only regarding the distances: HC maximum extracranial and minimum intracranial diameters and HC length. The gender influenced FM and OCs dimensions and from the HC diameters only the HC right length and the left distance HC-OC posterior border. Considering the age impact in the total sample, only the FMAPD, FM area, AID, right and left distances HC-OC posterior border were significantly affected by the ageing. When the age impact was considered separately in males and females, only the AID and the right distance HC-OC posterior border were significantly influenced on both genders and the HC left minimum extracranial diameter, only in males. It seems that FM and OCs dimensions present significant differences among genders, but only FM size is influenced by the age anteroposterior, while OC dimensions showed no statistical difference among young, adults and elderly subjects. Finally, the distance HC-OC posterior border which is of the utmost importance during surgery, presented differences between the genders and the three age groups.

CONCLUSIONS

In conclusion, the detailed morphometric examination of the basiocciput and the correlation analysis between its osseous structures, add important information for the anatomists and clinicians, as the study confirmed that only specific HC dimensions showed side asymmetry (HC maximum extracranial and minimum intracranial diameters and HC length), gender dimorphism (HC right length, left distance HC-OC posterior border) and age influence (right and left distances HC-OC posterior border and HC left minimum extracranial diameter) among young subjects, adults and elderly individuals. All FM and OCs dimensions presented gender dimorphism, while side symmetry existed in OCs dimensions and the age influenced only FMAPD, FM area and the AID. The study also provides useful knowledge for surgeons interfering in FM, OCs and HCs region in Greeks. The safe zone of OCs drilling, calculated by the distance HC-OC posterior border represents the maximum HC depth and is among the lowest values reported in the literature. The significant decrease of this distance between the three age groups confirms the existence of a drilling safe zone for each age group. Regarding OCs length, there is the same probability of dealing with a short or a long OC during condylectomy. Before planning a transcondylar approach, the coexistence of a short OC and a long HC should be taken into account. Our outcomes will be useful for a safe surgery in the craniocervical region in Greeks.

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