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RESEARCH ARTICLE

Adult sex estimation using Three Dimensional Volume Rendering Multislice Computed Tomography of the foramen magnum and occipital condyles: A study in Egyptian population

Rehab Ibrahim Abdel-Karim [a], **Abdalla Mohamed Housseini** [b], **Rania Kamal Hashish** [a*].

[a] Forensic Medicine & Clinical Toxicology Department, Faculty of Medicine, Suez Canal University, Egypt.

[b] Diagnostic Radiology Department, Faculty of Medicine, Suez Canal University, Egypt.

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***Corresponding Author**

Rania Kamal Hashish

Abstract

Sex identification using fragmented skeletal remains is a very challenging task in forensic medicine. The aim of the present study was to estimate the accuracy of occipital condyles and foramen magnum measurements in sex prediction, also to develop a logit response model for sex identification in Egyptian population. Computed tomography studies of adult individuals (70 individuals: 46 males and 24 females) who carried out temporal Computed tomography examinations in Diagnostic Radiology department were included. Seven dimensions of both occipital condyles and foramen magnum were measured. Males showed larger measurements than females. Left occipital condyle length and foramen magnum width using Binary Logistic Regression could predict sex with an overall accuracy 90% and with accuracy of 91.3% & 87.5% in males and females respectively.

INTRODUCTION

Sex identification of an individual is a very challenging task in forensic medicine especially if skeletal remains are used **(Gapert et al., 2009a)** Sex can be estimated with 100% accuracy using the whole skeleton, 98% accuracy when the skull and pelvis are used. But when the skull alone is used for sex estimation, the accuracy is 80-90% **(Krogman and Iscan, 1986).** Therefore; pelvic bone is the best area for sex identification, followed by the skull (**Bass**, **1971).**

In certain situations, it is difficult to find the whole skeleton; as in mass disasters and in cases criminals mutilate their victims to make their identification difficult. In such cases, fragmented skeletal remains especially those of the skull could be valuable for sex identification (**Asala, 2001).**

Base of the skull is thick and it lies in a protected anatomical position, therefore it is likely to survive damage in fires, explosions and violence **(Raghavendra Babu, 2012).** Various studies focused on using foramen magnum dimensions in sex estimation in different populations (**Günay and Altinkök,** 2000; **Gapert et al., 2009a; Raghavendra Babu et al., 2012; Kanchan et al., 2013; Natsis et al., 2013; Shanthi and Lokanadham, 2013; Ukoha** et al., 2011**; Westcott and Moore-Jansen, 2001; Suazo et al., 2009).**

Radiological studies using foramen magnum and/or occipital condyles measurements have been conducted by many researchers (**Murshed et al., 2003; Uysal et al., 2005; Uthman et al., 2012).** Murshed et al. (2003) reported that foramen magnum dimensions measured using Computed Tomography were larger in males than in females. Another study conducted by Uysal et al. (2005) showed that all measurements in males were larger than those in females, but only the length and width of the right condyle and foramen magnum width were significantly different. Uthman et al. (2012) concluded that sex can be determined using Computed Tomography measurements of foramen magnum.

Sexing of the crania depends on size differences **(Gapert et al., 2009a)**, which are influenced by genetic, social, and environmental factors. Therefore sex identification differs from one population to another **(Rösing et al., 2007).** According to our knowledge; this is the first study to estimate sex using measurements of foramen magnum and occipital condyles in Egyptian population.

The present study was carried out to estimate the accuracy of the foramen magnum and occipital condyles measurements obtained by Three Dimensional Volume Rendering Multislice Computed Tomography in sex prediction and to develop a logit response model for sex identification in Egyptian population.

MATERIALS AND METHODS

This is a descriptive cross-sectional study, it was carried upon CT studies of a sample of Egyptian population (70 individuals: 46 males and 24 females). These individuals were randomly selected from those who carried out temporal CT examination in Diagnostic Radiology department, Suez Canal University Hospital, Ismailia, Egypt for different clinical indications. The included CT studies belongs to adult individuals (aged 18 years and above). Poor quality studies and studies of individuals with any congenital or acquired diseases that may cause cranial deformities or affects cranial dimensions were excluded.

Method

Seven dimensions were measured in the present study. They were previously used by Uysal et al. (2005) who modified Giles and Elliot's work **(Giles and Elliot, 1963)**. The used measurements were:

1. Length of right and left occipital condyles (LRC, LLC): Maximum length of both occipital condyles along the long axis from the edges of the articular surface. Figure 1
2. Width of right and left occipital condyles (WRC, WLC): Maximum width of both occipital condyles from the articular edges along a line perpendicular to the long axis. Figure 1
3. Minimum inter-condylar distance (MnID): The minimum distance between medial edges of the articular surfaces of both condyles. Figure 2.
4. Maximum medial inter-condylar distance (MID): The maximum distance between the medial articular margins of the two condyles. Figure 2.
5. Maximum bicondylar distance (MBD): The maximum distance between lateral edges of the articular surfaces of the two condyles. Figure 2.
6. Foramen magnum length (LFM):Maximum foramen magnum internal length along the midsagittal plane. Figure 3.
7. Foramen magnum width (WFM): Maximum foramen magnum internal width perpendicular to the midsagittal plane. Figure 3.

All CT examinations were done using 16-channel Multi-detector scanner (Aquilion; Toshiba™ medical systems, Tokyo, Japan) with the following parameters:120 KVp, 50mAs, 0.75 helical pitch, 0.5s scan time, 16 x 0.5 mm collimation, 0 tilt, 512 x 512 Image reconstruction matrix,120 mm field of view (FOV) and mean patient effective dose: 3.54 ± 0.6 milisievert (mSv.)

All images were retrieved on the CT workstation (Vitrea™ workstation 2 version 4.1.14.0) for post-processing and creation of the Three Dimensional Volume Rendering Technique (3D VRT) images. All measurements were done by 3D VRT to overcome the obliquity seen in axial as well as coronal and sagittal reformatted images. All measurements were calculated by the same consultant radiologist to avoid inter-observer bias. Measurements were recorded in centimeters and to one decimal place. They were measured on two separate occasions (10 days apart) and in case of difference the mean value was obtained for increased accuracy.

Statistical analysis

Statistical analysis was done using SPSS for Windows 16 version. Binary Logistic Regression (BLR) analysis upon all measurements was done to identify which measurement or combination of more than one has the greatest ability of sex determination. Statistical significance was considered at P <0.05.

Approval of the institutional Research Ethics Committee was obtained.

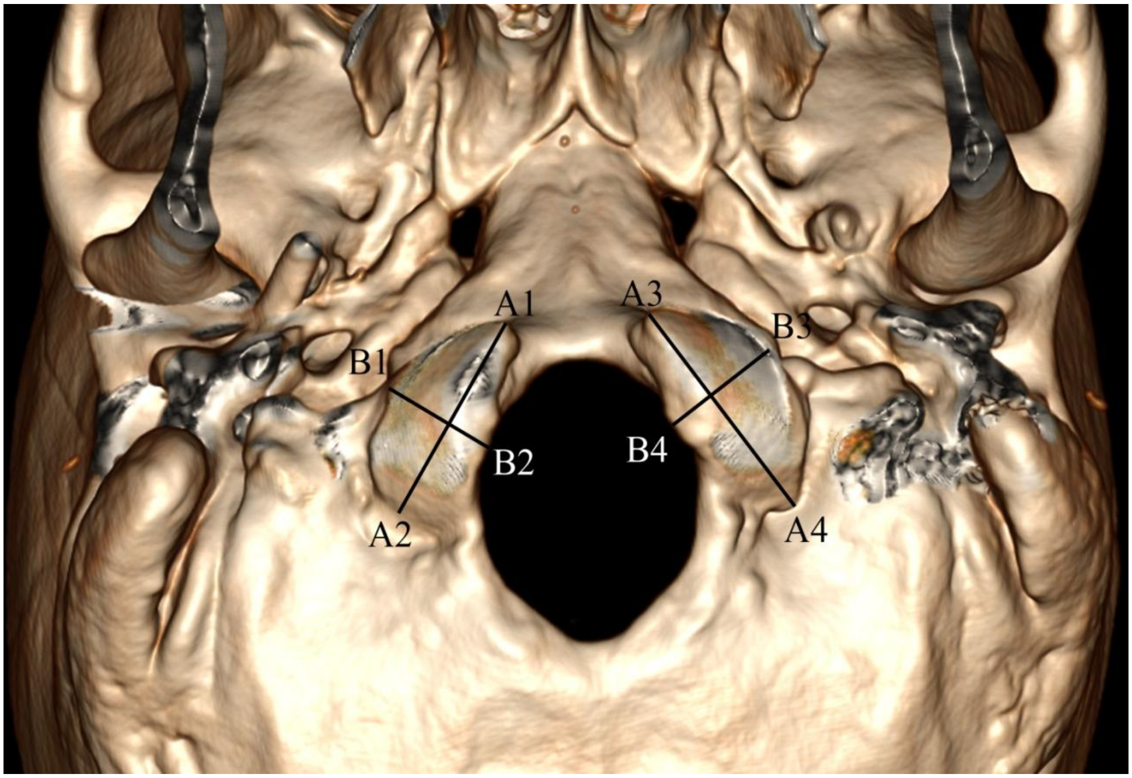

Figure 1: Figure 1: Three Dimensional Volume Rendering image of the skull base shows four measurements: length of right occipital condyle (A1-A2), length of left occipital condyle (A3-A4), width of right occipital condyle (B1-B2) and width of left occipital condyle (B3-B4).

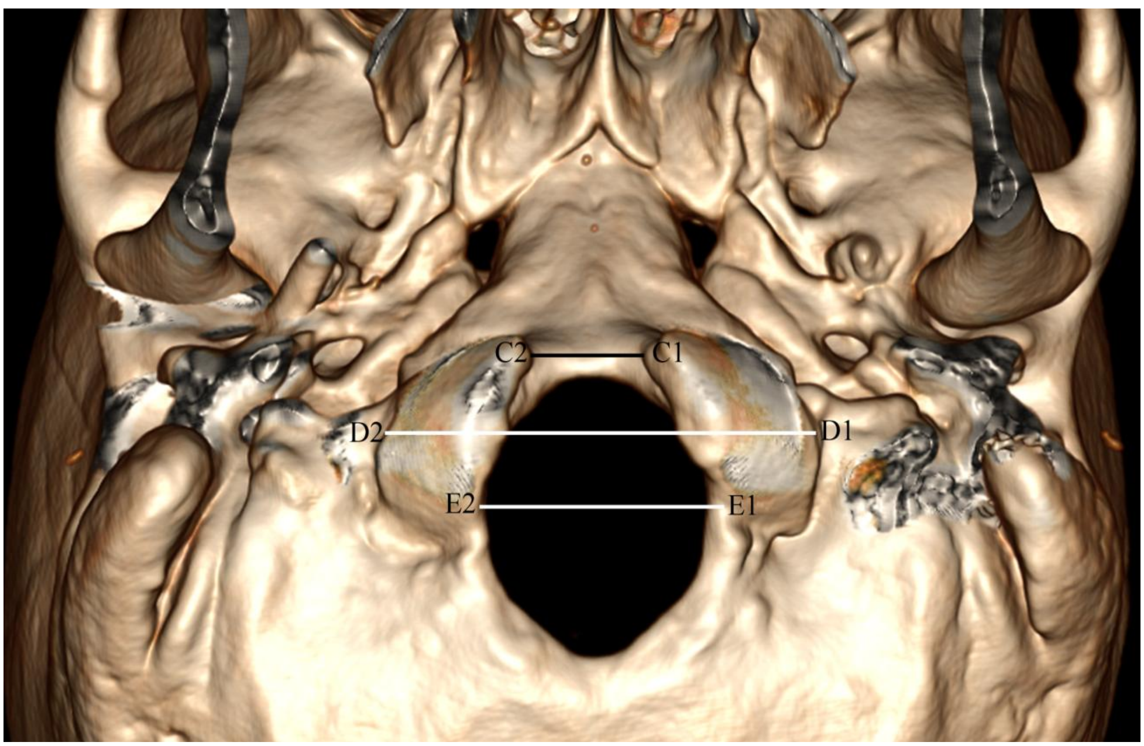

Figure 2: Three Dimensional Volume Rendering image of the skull base shows four measurements: minimum intercondylar distance (C1-C2), maximum bichondylar distance (D1-D2), and maximum medial intercondylar distance (E1-E2).

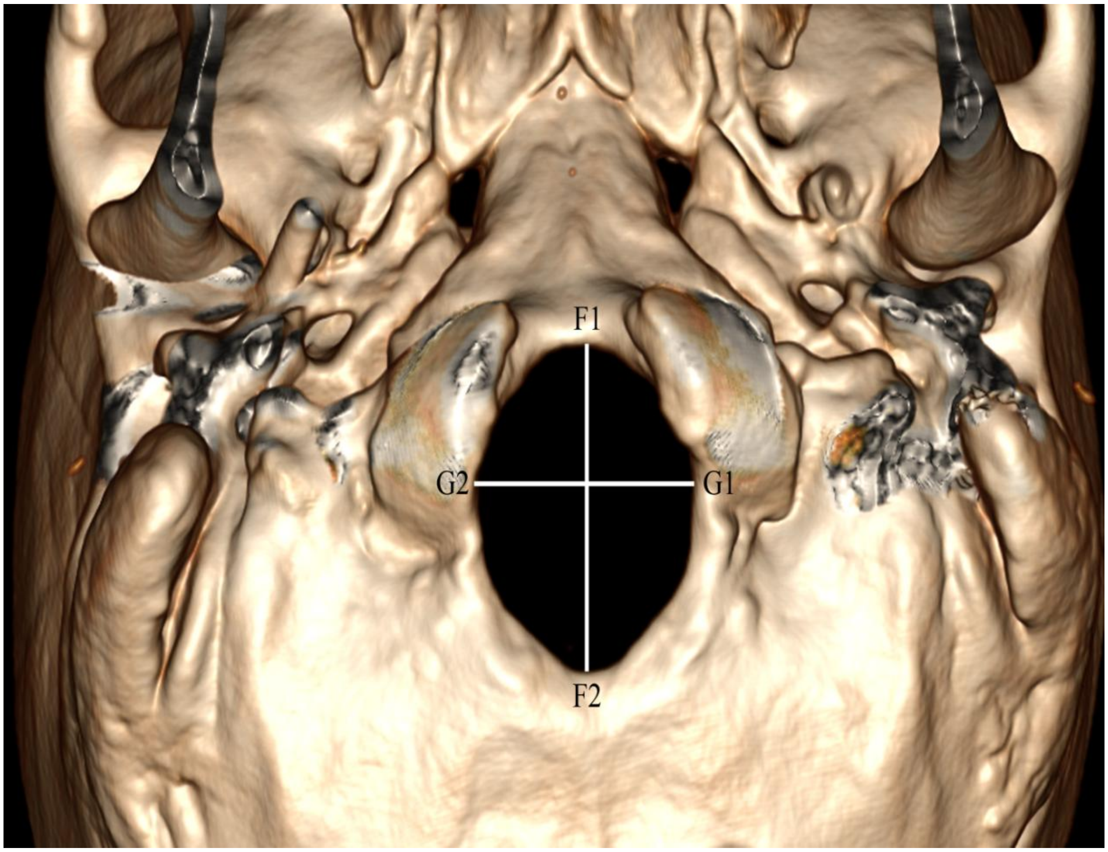

Figure 3: Three Dimensional Volume Rendering image of the skull base shows three measurements: length of the foramen magnum (F1-F2) and width of the foramen magnum (G1-G2).

RESULTS

CT studies of 70 individuals were included (46 males and 24 females), their age ranged from 19–70 years. Seven dimensions were measured; minimum and maximum values as well as mean and standard deviation of each measurement were calculated for both sexes **Table 1**.

All measurements were larger in males than in females. T-test was performed between the mean values of each measurement among males and females, to estimate if the difference in measurements was enough to use them in sex estimation.

Although all measurement were larger in males, Binary Logistic Regression revealed that only two of them were shown to be significantly statistically different ($p < 0.05$); the two significant measurements were LLC (mean 2.71±0 .26cm for males, mean: 2.36 ±0.14cm for females) and WFM (mean: 3.40± 0.34cm for males and 3.14±0.21cm for females) **Table 2**.

The following equation has (or better provides) the highest possibility of sex prediction from foramen magnum and occipital condyles dimensions according to BLR analysis:

Logit response model (L) = 15.793(LLC) +5.441(WFM) - 46.676.

According to logit response (L), the probability of being a male (P) is calculated through P =1 / (1+e) L. (e = 1.917) and that of being a female is (1-P).

According to BLR, LLC and WFM can be used to calculate the probability of the case to be a male or a female with an overall accuracy of 90.0% and with the accuracy of 91.3% and 87.5% in males and females respectively.

Table (1). Minimum and maximum diameters, Mean, Standard deviation and comparison t-test of the foremen magnum and occipital condyles measurements.

	Gender	Minimum	Maximum	Mean	Std. Deviation	t	P value (t-test)
LRC	Male Female	2.1 2	3.2 3	2.691 2.40	.2411 .133	5.406 6.411	.000[a]
WRC	Male Female	0.9 1.0	1.5 1.3	1.222 1.113	.1332 .1116	3.435 3.633	.001[a]
LLC	Male Female	2.1 2.1	3.2 2.7	2.709 2.367	.2555 .1435	6.066 7.169	.000[a]
WLC	Male Female	0.9 0.9	1.5 1.3	1.191 1.075	.1208 .1189	3.844 3.864	.000[a]
MnID	Male Female	0.4 0.5	1.0 0.8	.722 .683	.1332 .0868	1.276 1.452	.206
MID	Male Female	2.6 2.6	4.0 3.5	3.157 3.042	.3270 .2104	1.558 1.779	.124
MBD	Male Female	4.4 4.4	5.7 5.5	5.109 4.954	.3352 .3036	1.889 1.950	.063
LFM	Male Female	3.4 3.3	5.1 4.5	4.217 3.875	.3779 .3517	3.683 3.768	.000 [a]
WFM	Male Female	2.5 2.8	4.4 3.5	3.398 3.138	.3429 .2081	3.400 3.942	.001[a]

[a] statistically significant. Measurements are in centimeters

Table (2) Binary Logistic Regression models for sex estimation from Foramen Magnum and Occipital condyles measurements.

	B	**S.E**	**Wald**	**df**	**Sig.**	Exp(B)	95.0%C.I. for EXP(B)	
							Lower	Upper
LRC	-.769-	4.689	.027	1	.870	.463	.000	4.542E3
WRC	-5.699-	7.126	.640	1	.424	.003	.000	3.896E3
LLC	15.793	6.218	6.450	1	.011	7.227	36.800[a]	1.419E12
WLC	10.587	8.039	1.734	1	.188	3.961	.006	2.759E11
MnID	9.816	5.399	3.306	1	.069	1.833	.465	7.223E8
MID	-2.432-	3.352	.526	1	.468	.088	.000	62.719

MBD	-4.088-	2.445	2.796	1	.095	.017	.000	2.021
LFM	1.925	1.720	1.252	1	.263	6.853	.235	199.575
WFM	5.441	2.455	4.911	1	.027	230.720	1.875[a]	2.839E4
Constant	-46.676-	15.150	9.492	1	.002	.000		

SD, standard deviation; SE, standard error;
[a] Correlation is significant at the 0.05 level.

Table (3) Foramen magnum measurements in different studied populations

Variables	Gapert et al, (2008)	Babu et al (2012)	Suazo et al (2009)	Gruber et.al. (2009)	Catalina (1987)	Ukoha et al (2011)	Natsis et al(2013)	Uysal et al(2005)[a]	Present study [a]
LFM male (mean±SD)	35.91±2.41	35.68±1.77	36.5±2.6	37.1±2.7	36.2±2.60	36.26±2.3	36.20±3.39	37.08±1.9	42.17±3.7
LFM female (mean±SD)	34.71±1.91	32.57±2.08	35.6±2.50	35.8±3.5	34.30±2.04	34.39±3.88	34.79±2.39	34.87±2.6	38.75±3.5
WFM male (mean±SD)	30.51±2.60	28.91±1.62	30.6±2.5	32.4±2.4	31.1±2.60	30.09±2.5	30.92±3.15	30.83±2.0	33.98±3.4
WFM female (mean±SD)	29.6±1.53	28.19±1.76	29.5±1.9	31.0±2.8	29.6±1.53	28.16±1.9	29.61±2.08	28.93±2.4	31.38±2.0
Origin	Britain	India	Brazil	Central Europe	Spain	Nigeria	Greece	Turkey	Egypt

measurements of the present study are multiplied by 10 to convert to mm, SD, standard deviation

Measurements are in millimeter
[a] measurements taken from CT

Table (4) Measurements of Occipital condyles in different studied populations

Variables	Westcott and Moore-Jansen (2001)	Westcott and Moore-Jansen (2001)	Singh and Talwar (2013)	Natsis et al (2013)	Gapret et al (2009)	Uysal et al(2005)[a]	Present study[a]
LRC Male mean ± SD				26.30±2.92	24.95±2.53	22.84±1.97	26.91±2.411

LRCfemale, mean ± SD				24.70±2.66	23.30±2.28	20.86±1.38	24.0±1.33
LLC male mean±SD	23.2 ±2.9	24.7 ±2.7		26.48±2.80	25.16±2.51	22.73±2.26	27.09±2.555
LLC female (mean±SD)	22.0±12.0	22.8± 2.2		24.57±2.13	23.74±2.44	20.58±2.24	23.67±1.435
WRC male, mean ± SD				13.13±2.01	12.01±1.41	12.56±1.35	12.22±1.332
WRC female, mean ± SD				13.04±1.99	11.42±1.21	11.80±1.49	11.13±1.116
WLC male, mean ± SD	12.8± 1.2	12.3± 1.2		13.24±2.20	12.05±1.69	12.50±1.57	11.91±1.208
WLC female, mean ± SD	12.0± 1.5	11.7± 1.3		12.74±1.63	11.57±1.16	11.78±1.06	10.75±1.189
MBD male mean ± SD	49.6±3.8	51.9±3.2	46.73±2.79		51.29±2.97	46.82±3.20	51.09±3.352
MBD female mean ± SD	47.3±4.1	49.8±2.9	44.29±2.43		48.67±3.17	43.98±2.84	49.54.3.036
MnID,male mean ± SD	20.1±3.0	20.9±2.4	14.88±2.26		21.12±3.18	5.60± 0.97	7.22±1.332
MnID,female mean ± SD	18.6±2.5	19.2±2.0	14.33±2.56		19.00±2.40	4.91± 0.83	6.83±0.868
MID,male mean ± SD		43.3±3.3	26.15±3.31		36.82±3.10	26.69±2.49	31.57±3.270
MID,female mean ± SD		41.6±3.0	24.71±4.57		35.12±3.09	24.69±2.82	30.42±2.104
Sample origin	African American	European American	Indian	Greek	Britain	Turkish	Egyptian
Accuracy of prediction	76%[b]		66-70%[b]		76.7%	81%[b]	90%[b]

All measurements are in millimeter; SD, standard deviation

[a] measurements taken from CT

[b]Function used includes foramen magnum variable

measurements of the present study are multiplied by 10 to convert to mm

DISCUSSION

The present study reveals that foramen magnum length and width are significantly larger in males than females. These results agree with the majority of previous studies in different populations **(Gapert** et al., 2009a;

Raghavendra Babu et al., 2012; **Suazo et al., 2009; Catalina-Herrera, 1987; Radhakrishna et al., 2012; Ukoha et al., 2001; Shanthi and Lokanadham**, 2013; **Natsis** et al., 2013; **Murshed** et al., 2003). On the contrary, other studies did not detect any sexual dimorphism (**Kanchan et al., 2013; Singh and Talwar**, 2013; **Gruber et al., 2009),** while Manoel et al. (2009) found the width of foramen magnum to be significantly larger in males.

In the present study, these two dimensions are found to be larger than those in Greek (**Natsis et al., 2013)**, Indian (**Raghavendra Babu et al., 2012; Radhakrishna et al., 2012; Routal et al., 1984; Kanchan et al., 2013; Shanthi and Lokanadham, 2013)**, Brazilian **(Suazo** et al., 2009), Turkish **(Murshed** et al., 2003; **Uysal** et al., 2005), British (**Gapert et al., 2009a)**, central European (**Gruber et al., 2009),** Spanish (**Catalina-Herrera, 1987)** and Nigerian **(Ukoha** et al., 2011) populations. Values of foramen magnum dimensions in different studies are demonstrated in **Table3.**

From the previous studies, it is obvious that the values are specific for each population; moreover they might differ in the same population **(Raghavendra Babu et al., 2012; Radhakrishna et al., 2012; Routal et al., 1984; Kanchan et al., 2013; Shanthi and Lokanadham, 2013).** Murshed et al. **(2003)** stated that normal values of foramen magnum dimensions varies widely as the mean values for length range from 28.5mm **(Sendemir et al., 1994) to 48.0mm (Adam, 1987)** and those for width range from 21.4 mm **(Lang et al., 1983) to 40.0mm (Adam, 1987).**

The difference between values in different studies might be referred to sample size and/or methodological differences, as some authors used osteometric techniques on dry skulls, while others used radiological techniques. Munoz found the anatomic values about 0.5 mm lesser than the radiographic values (**Munuz, 1983)**. Murshed et al. (2003) stated that there are differences between the radiographic and the anatomic values; moreover, there is also a wide variation in radiologic values, which might be explained by different radiologic techniques. Different population groups and different methods of statistical analysis might also influence the results of different studies **(Raghavendra Babu et al., 2012)**.

In the present study, the length and width of both occipital condyles are significantly larger in males which agrees with the results of a study in the British population **(Gapert et al., 2009b).** Uysal et al. (2005) found that in Turkish population, right condyle length and width as well as foramen magnum width were significantly larger in males. On the contrary, Westcott and Moore-Jansen (2001) found that left condyles length and width were larger in American males than females. However, Natsis et al. (2013) found that only the length of both condyles was significantly larger in Greek males than females. Once again the difference appears clearly among different populations. **Table 4** shows the mean values for the measurements of condylar region and discriminating power for gender in different populations**.**

Foramen magnum width (WFM) and left occipital condyle length (LLC) were significantly larger in males and were used to calculate sex predictability with an overall accuracy of 90.0%. Holland used regression equations and found that sex can be determined with an accuracy of 71–90% **(Holland, 1986)**. Both Foramen magnum length and area were significantly larger in Indian males, however when length and width were used, they increased the accuracy of sex predictability up to 88% using BLR analysis (**Raghavendra Babu et al., 2012).** When discriminant functional analysis was used in Turkish population, WFM, LRC and WRC were statistically significant in sex determination with an accuracy rate of 81% as reported by Uysal et al. **(2005).** Interestingly, Uthman et al. (2012) found in their study in Iraqi population that both foramen magnum circumference (FMC) and area had low discriminating powers of 67% and 69% respectively, however when LFM, WFM, FMC and area were combined together, they increased the overall accuracy level up to 81.8%.

On the other hand, lower sex discriminating powers were detected using discriminant function analysis as reported in a study in French population where the length of the left occipital condyle and minimum intercondylar distance (MnID) determined sex with an accuracy rate of only 67.7% (**P.J. Macaluso, 2011).** This discriminating power is close to that detected by Singh and Talwar who found that maximum bicondylar breadth (BCB) produced the only significant difference and that the accuracy of sex prediction ranged from 66% to 70% in their study in Indian population. This might be attributed to their small sample size (50 skulls), additionally, they didn't measure occipital condyles length or width (**Singh and Talwar, 2013)**. In Brazilian population, variables analyzed were able to correctly classify only 66.5% of examined cases, this low percentage was attributed to the large genetic mix in Brazilian population, moreover, occipital condyles dimensions were not measured (**Suazo et al., 2009)**. Westcott and Moore-Jansen (2001) reported that variables used in their study correctly classified only 76% of the examined cases and this low percentage was also attributed to lack of homogeneity of their sample.

Gapert et al, (2009b) using discriminant function analysis found bicondylar breadth (BCB) to be the most successful single variable for sex prediction, followed by minimal intercondylar distance (MnID) and left condyle maximum length while sex was predicted with an overall accuracy of 76.7%. However, when they analyzed foramen magnum sexual dimorphism in a previous study, they found WFM to be the most reliable variable for sex determination (65.8% overall accuracy) while the best combined variables proved to be WFM + FMC (70.3%) (**Gapert et al., 2009a)**. On the contrary, Manoel et al., (2009) in their study on Brazilian population found no significant relation between foramen magnum diameters and gender using multiple logistic regression.

From the previously mentioned studies, it is obvious that the discriminating power differs according to the variables included, also according to the statistical method used for analysis. The difference between the results of the present study and those of other studies might be attributed to different variables used, different sample size or different techniques used for measurements; as the present study depended on radiologic measurements while various studies used osteometric measurements.

Authors explained the limited expression of sexual differences in the foramen magnum by its development as it reaches adult size in early childhood before secondary sexual characteristics influence its growth. However, they suggested that after growth cessation in skull base region, the dimensions of foramen magnum might increase due to bone resorption (**Gapert et al., 2009a; Manoel et al., 2009).** In addition, the passage of main neurovascular bundle through the skull base with larger structure in males than females might be responsible for larger foramen magnum area in males (**Manoel et al., 2009).** According to Gapert et al., (2009b) sexual dimorphism expression is increased in occipital condyles compared to foramen magnum and is influenced by head weight which is transmitted through the atlanto-occipital joint. Consequently, greater head weight and larger neck musculature in males could influence the size of the articular surface. However they suggested that these factors play only a minor role and sexual dimorphism of occipital condyles is influenced more by other factors such as population, health, nutrition, development, physical stresses, and genetic factors**.**

From the results of the previous studies, various researchers concluded that foramen magnum had a low sex discriminating power especially in Populations with large genetic mix **(Suazo et al., 2009)**. However, this power increased when equations included variables of both occipital condylar region and foramen magnum dimensions. The majority of authors also agree that sexual dimorphism is population specific and variables discriminating sex in one population differ from those in other populations **(Raghavendra Babu et al., 2012; Gapert et al., 2009a; Manoel et al., 2009; Suazo et al., 2009).** Therefore, the need for more studies on different populations with large sample size is mandatory.

Logistic regression analysis and discriminant function analysis have been widely applied in various studies which showed negligible differences in results between both methods when sample size was greater than fifty **(Harris and Troy Case, 2012)**, as in the present study. Therefore results of the present study can be comparable with other studies that use discriminant function analysis.

CONCLUSION

In conclusion, the present study demonstrated that foramen magnum and occipital condyles dimensions are significantly larger in males. Moreover, left occipital condyle length and foramen magnum width can be used successfully for sex estimation with an overall accuracy of 90% and with an accuracy of 91.3% & 87.5% in males and females respectively**.**

LIMITATION OF THE STUDY

Limitations for this study included low sample size which is collected from one region (Suez Canal area), furthermore, measurements being recorded in centimeters. It is recommended that further studies using skull base dimensions be done with larger sample size, being collected from different areas in Egypt.

ETHICAL APPROVAL

Approval of the Research Ethics Committee, Faculty of Medicine, Suez Canal University was obtained for this study.

CONFLICT OF INTEREST

There are no conflicts of interest.

FUNDING

There are no sponsors or funding agents for the research

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