Identification of Sex from Foramen Magnum of Egyptian Skulls Using Three Dimensional Computed Tomography

Ragaa T Darwish, Nagla M Salama[1], Mohamed N Elsirafy[2], and Wael S Kholeif[1]

[1] Forensic Medicine and Clinical Toxicology Department
[2] Radiodiagnosis Department

Faculty of Medicine, Alexandria University, Alexandria, Egypt

Abstract   Sex determination from skeletons is an important research subject in forensic medicine. This study aimed to evaluate the sexual dimorphism in the Egyptian skulls based on foramen magnum and some cranial measurements.
Methodology: The present study was performed on 100 adult Egyptian patients of both sexes. Multi- Slice Computerized Tomography (MSCT) scan were obtained and reconstruction of 3D models for the cranium was performed. Various parameters related to the foramen magnum, the right condyle and the left condyle were measured on virtual skulls of adult patients.
Results: The mean length, width and area of foramen magnum were significantly higher in males(35.3 ± 1.9mm, 30.0 ± 1.9mm and 833.50 ± 72.52mm^2 respectively) than in females(32.8 ± 2.5mm, 27.1 ± 2.4 mm and 699.90 ± 92.09mm^2 respectively). The mean lengths of the maximum bicondylar distance, minimum intercondylar distance and maximum medial intercondylar distance were significantly longer in males(48.8 ± 2.3 , 17.2 ± 1.7 and 25.1 ± 2.4mm respectively) than in females (46.1 ± 2.2, 16.2 ± 1.8 and 22.7 ± 1.7mm respectively). A significant difference between males and females was elicited regarding the length (24.8 ± 1.7 and22.7 ± 2.2mm respectively) and the width (14.4 ± 1.3 and 13.5 ± 1.3mm respectively) of the right condyle. The equation which determines sex with high accuracy was the one made from the length of the foramen magnum, length of the right condyle and length of the left condyle, the accuracy reached 87%.
Conclusion: It can be concluded that measurements of the foramen magnum and the condyles obtained using 3D CT and the equations acquired from them are reliable tools in sex determination.

Keywords   Sex Identification, Foramen Magnum, Occipital Condyle

Introduction

One of the crucial aims of a medicolegal investigation is to establish the identity of a deceased, especially in cases where skeletal remains and dismembered or mutilated body parts are recovered and brought for examination. When confronted with one of the previously mentioned cases, often the first question the forensic anthropologist faces is who is the decedent? To determine the answer, it is vital to estimate the "big four": age, sex, stature and race in order to establish the biological profile of the remains (Calcagno JM, 1981).

Sex is the first demographic factor that is determined because it reduces the number of possible matches by 50% (Cardoso and Saunders, 2008).

Various parts of a skeleton are useful in sex determination. Human skull is considered as one of the most reliable bones for sex differentiation (Kanchan et al., 2013).

During severe disruptive injuries, estimation of sex becomes challenging when only a part of skull is brought for examination and hence, a need to derive standards for sex estimation from different regions of the skull. The basal region of the occipital bone is more likely to survive physical insults than the other parts of the skull owing to the abundant soft tissue cover, skull thickness in the region, and its relatively well-protected anatomical position. Thus, there is an increased possibility of recovering this part of skull even in cases

of severe trauma, and studies on the occipital bone may provide useful clues in identification of significantly disrupted remains (Gapert et al., 2009).

Medical imaging modalities, like CT, provide unique data sources for examining modern human variation in a more quantitative manner when extending osteological resources to researchers beyond actual contact (Weber et al., 1998).

Using the newest technology of Multi Slice CT (MSCT) makes it possible to form images that are very similar to the original bone shape that needs to be measured, in any axis and in a rapid manner (Verhoff et al., 2008).

The foramen magnum is an important landmark of the skull base and is of particular interest for anthropology and forensic medicine. The sex discriminant value of the foramen magnum has always attracted the attention of researchers who stressed its value in sex discrimination. The ability to construct a biological profile from metric analysis on virtual skeletons and the ability to develop formulas from these measurements will help to solve many medicolegal problems. The present study aimed at establishing the accuracy and the reliability of the foramen magnum and some cranial measurements in sex determination using three dimensional computed tomography (3D CT).

Subjects and Methods

The present study was performed on 100 adult Egyptian patients of both sexes from Lower Egypt. All patients were chosen randomly when referred to the Radio-Diagnosis Department of Alexandria Main University Hospital for radiological investigations by Multi- Slice Computerized Tomography (MSCT) of the skull. Prior permission was sought from Head of Radiology Department and an informed consent was obtained from all patients before participation in the present study. Patients with skeletal deformities, degenerative alterations, traumatic or pathological lesions of head that could preclude accurate measurements were excluded.

For each case, the MSCT scan was obtained and reconstruction of high quality 3D models for the cranium was performed. Various parameters related to the foramen magnum and both the right and the left condyles were measured on virtual skulls of the adult patients.

The metric parameters (in mm) were as follows:

A-Measurements of the foramen magnum and the inter condylar distance (Figure 1) (Uysal et al., 2005)

- Length of the foramen magnum (LFM): The maximum internal length of the foramen magnum along the mid sagittal plane.

- Width of the foramen magnum (WFM): The maximum internal width of the foramen magnum perpendicular to the mid-sagittal plane.
- Foramen magnum index (FMI) (Sangvichien et al., 2007): It was calculated by dividing the length of the foramen magnum by the width of the foramen magnum.
- Foramen magnum area (FMA) (Gunay et al., 1997): It was calculated using the Radinsky`s formula: FMA (in mm2) = 0.25×L×W×22/7L= length of the foramen magnum. W=width of the foramen magnum.
- Maximum bicondylar distance (MBD): The maximum distance between the lateral edges of the articular surfaces of the condyles. It is also known as the bicondylar breadth.
- Maximum medial intercondylar distance (MID): The maximum distance between the medial articular margins of the condyles. It is also known as the intercondyler breadth.
- Minimum intercondylar distance (MnID): The minimum distance between the medial edges of the articular surfaces of the condyles.

B- Measurements of the occipital condyles (Figure 2) (Uysal et al., 2005)

- Length of right condyle (LRC): The maximum length of right condyle along the long axis from the edges of the articular surface.
- Width of right condyle (WRC): The maximum width of right condyle from the articular edges along a line perpendicular to the long axis.
- Length of left condyle (LLC): The maximum length of left condyle along the long axis from the edges of the articular surface.
- Width of left condyle (WLC): The maximum width of left condyle from the articular edges along a line perpendicular to the long axis.
- Condylar index (CI). It was calculated by dividing the length of the occipital condyle by the width of the occipital condyle .It was calculated for the right and the left occipital condyles (RCI and LCI respectively).

The data collected were fed to the computer and analyzed using IBM SPSS software package version 20.0. Quantitative data were described using mean and standard deviation, median, minimum and maximum. The distribution of quantitative variables was tested for normality using Kolmogorov-Smirnov test, Shapiro-Wilk test and D'Agstino test. Histogram and QQ plot were also used for vision test (Leslie and Geoffrey, 1991; Kirkpatrick and Feeney, 2013).
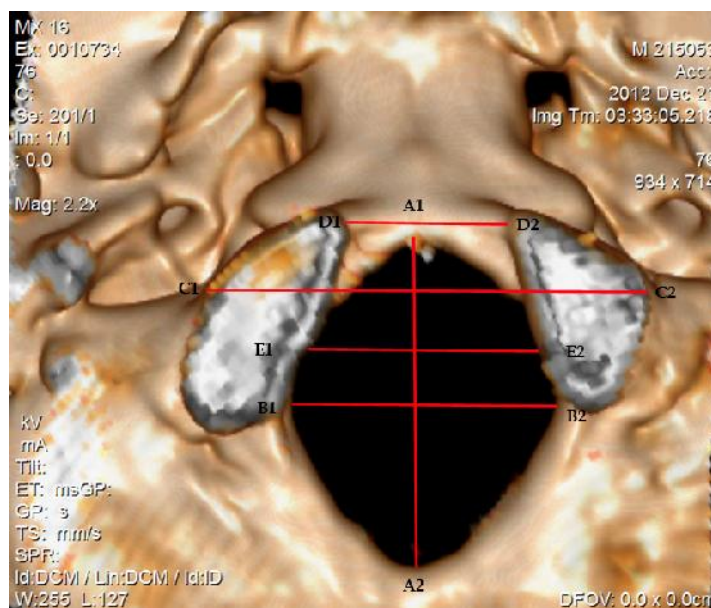
Figure 1: 3DMSCT of the base of the skull showing the different measurements (in mm) for the foramen magnum and the inter condylar distance.

A_1–A_2 (LFM) = the maximum internal length of the foramen magnum along the mid sagittal plane.

B_1–B_2 (WFM) = the maximum internal width of the foramen magnum perpendicular to the midsagittal plane.

C_1–C_2 (MBD) = the maximum distance between the lateral edges of the articular surfaces of the condyles.

D_1–D_2 (MnID) = the minimum distance between the medial edges of the articular surfaces of the condyles

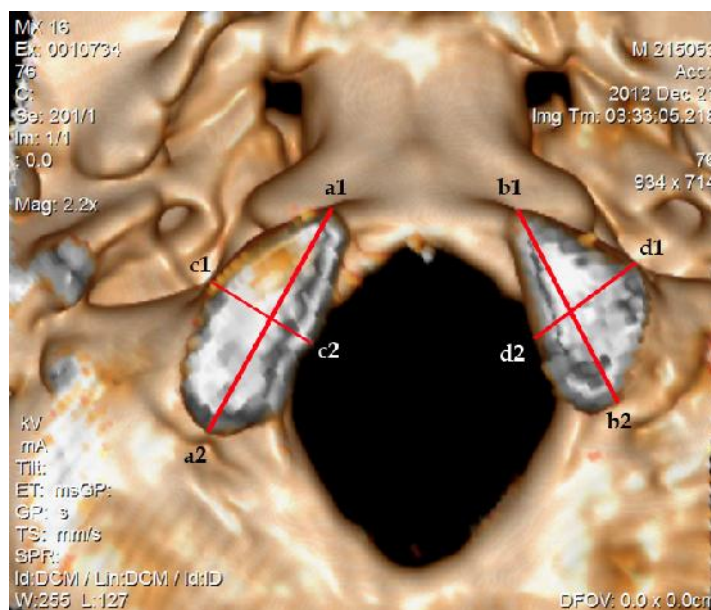E_1–E_2 (MID) = the maximum distance between the medial articular margins of the condyles

Figure 2: 3DMSCT of the base of the skull showing the different measurements (in mm) for the right and left occipital condyles.

a_1–a_2 (LRC) = the maximum length of right condyle along the long axis from the edges of the articular surface.

b_1–b_2 (LLC) = the maximum length of left condyle along the long axis from the edges of the articular surface.

c_1–c_2 (WRC) = the maximum width of right condyle from the articular edges along a line perpendicular to the long axis.

d_1–d_2 (WLC) =the maximum width of left condyle from the articular edges along a line perpendicular to the long axis

Results

Table (1) shows the age distribution of male& female patients. In males, it ranged from 19-56 years with a mean age of 31.58 ± 9.03 years while in female sit ranged from 18– 60 years with a mean age of $40.93 \pm$

13.40 years. There was significant difference as regard age between both sexes, where p ≤ 0.001. Forty percent of the patients were in age group ranging from 18-30 years.

Comparative statistics with the maximum and minimum values, means and standard deviations for the length and the width of the foramen magnum in both males and females are presented in Table (2). The table reveals that the mean length of the foramen magnum was significantly longer in males (35.3 ± 1.9 mm) than in females (32.8 ± 2.5mm) where p=<0.001. The mean width of the foramen magnum was also significantly larger in males (30.0 ± 1.9 mm) than in females (27.1 ± 2.4 mm) where p≤0.001.

Although the length and the width of the foramen magnum in males were significantly longer than females, yet there was no significant difference between males and females concerning this length-breadth index or FMI where P=0.080. (Table 3)

Table (4) demonstrates that FMA was significantly lower in females (699.90±92.09mm^2) compared to males (833.50±72.52mm^2) where P≤0.001.

Table (5) depicts that the mean length of the maximum bicondylar distance in males was 48.8 ± 2.3mm while in females it was 46.1 ± 2.2mm.There was a significant difference between both sexes regarding MBD where p≤0.001.

It also elucidates that the mean length of the minimum intercondylar distance was significantly longer in males (17.2 ± 1.7mm) than in females (16.2 ± 1.8mm) where p≤0.004.

Table (5)compares between males and females as regards the maximum medial intercondylar distance in which the mean lengths of the maximum medial intercondylar distance was significantly longer in males (25.1 ± 2.4mm) than in females (22.7 ± 1.7mm) where p≤0.001.

Table (6) revealed that in males, the length of the right condyle ranged from 20-28mm with a mean of 24.8± 1.7mm, while in females it ranged from 15-29mm with a mean of 22.7±2.2mm. Also, the width of the right condyle in males ranged from 11-17 mm with a mean of 14.4±1.3mm whereas in females it ranged from 11-16mm with a mean of 13.5±1.3mm. The present work showed a significant difference between both sexes regarding the length and width of the right condyle where p≤0.001 and p≤0.001 respectively.

Table (7) demonstrates that the mean length of the left condyle was significantly longer in males (24.7 ± 1.7 mm) than in females (23.4 ± 1.8 mm) where p≥0.013, but no significant difference was noticed between the width of the right and left condyles between males and females (p≥0.059).Moreover there was no significant difference between the width of the right and left condyles within the same sex where t=0.614 and p=0.542 in males and t=1.355 and p=0.182 in females (Table 8).

Table (9) illustrates that although the mean right and left condylar indices were slightly higher in males than in females yet no significant difference was elicited (P=0.337 and 0.864 respectively).

Table (10) demonstrates that among all the measured dimensions of the foramen magnum and occipital condyles in the studied Egyptian population sample, the width of the foramen magnum had the highest discriminating index with 85.6% accuracy, followed by the length of the foramen magnum (82.1%). The width of the left condyle was the parameter that had the least discriminating index (58.2%).

Table (11) represents six significant regression equations that were obtained for predicting sex using of the studied measurements of the foramen magnum and both condyles as independent variables and sex as dependent one.

Linear regression analysis was applied for predicting sex using the length of right condyle (LRC), length left condyle (LLC) and length of foramen magnum (LFM). The equation was significant (p≤0.001) with accuracy 87.0%. Males were predicted if value of the equation is ≥0.45(Equation 1).

Also linear regression analysis was applied for predicting sex using width of the right condyle (WRC), width of the left condyle(WLC) and width of the foramen magnum (WFM). The equation was significant (R^2=0.417 and p≤0.001) with accuracy 86.0%. Males were predicted if value of the equation is ≥0.58(Equation 2).

Multiple regression analysis was applied for predicting sex using all the measured parameters of the foramen magnum and occipital condyles [length of foramen magnum (LFM), width of foramen magnum (WFM), maximum bicondylar distance (MBD) , maximum medial intercondylar distance (MID),length of right condyle (LRC), width of right condyle (WRC), Length of left condyle (LLC), Width of left condyle (WLC) and minimum intercondylar distance (MnID)]. The equation was significant (R^2=0.469 and p<0.001) with accuracy 86%. Males were predicted if value of the equation is ≥0.41 (Equation 3).

Linear regression analysis was also used to predict sex from [length of foramen magnum (LFM), width of foramen magnum (WFM), maximum bicondylar distance (MBD), maximum medial intercondylar distance (MID) and minimum intercondylar distance (MnID). The equation was significant (R^2=0.453and p<0.001) with accuracy 85%. Males were predicted if value of the equation is ≥0.48 (Equation 4).

Equation 5 was imitative from the length and width of the foramen magnum (LFM and WFM) . The equation was significant (R^2=0.378 and p<0.001) with accuracy 84%. Males were predicted if value of the equation is ≥0.59.

Another equation was derived from length of right condyle (LRC), width of right condyle (WRC) and width of foramen magnum (WFM)] .The equation was significant (R^2=0.449 and p<0.001) with accuracy 84%. Males were predicted if value of the equation is ≥0.48.

Table (1): Distribution of male and female patients according to their age and sex (n=100)

Age	Sex					
	Male (n = 55)		Female (n = 45)		Total (n = 100)	
	No.	%	No.	%	No.	%
18–	28	50.9	12	26.7	40	40.0
30 –	16	29.1	8	17.8	24	24.0
40 –	8	14.5	9	20.0	17	17.0
50 – 60	3	5.5	16	35.6	19	19.0
Min. – Max.	19.0 – 56.0		18.0 – 60.0		18.0 – 60.0	
Mean ± SD	31.58 ± 9.03		40.93 ± 13.40		35.79 ± 12.09	
t	3.997					
p	0.001*					

*Min: Minimum; Max: Maximum; SD: standard deviation; t: Student t-test; *significance at p ≤ 0.05*

Table (2): Student t-test of the length and the width of the foramen magnum (in mm) measured on 3DMSCT in both sexes (n=100)

	Males (n=55)	Females (n=45)	Total (n=100)
LFM (mm)			
Min. – Max.	31.0 – 40.0	22.0 – 37.0	22.0 – 40.0
Mean ± SD.	35.3 ± 1.90	30.28 ± 0.25	34.2 ± 2.5
t	5.801		
p	<0.001*		
WFM(mm)			
Min. – Max.	25.0 – 34.0	16.0 – 32.0	16.0 – 34.0
Mean ± SD.	30.0 ± 1.9	27.1 ± 2.4	28.7 ± 2.6
t	6.877		
p	<0.001*		

*LFM= length of the foramen magnum; WFM= width of the foramen magnum; Min: Minimum; Max: Maximum; SD: standard deviation; t: Student t-test; *significance at p ≤ 0.05*

Table (3): Comparison between males and females according to the foramen magnum index using student's t-test (n=100)

Foramen magnum index	Males (n=55)	Females (n=45)	Total (n=100)
Min. – Max.	0.97 – 1.40	1.08 – 1.44	0.97 – 1.44
Mean ± SD.	1.18 ± 0.10	1.21 ± 0.09	1.20 ± 0.10
t	1.770		
p	0.080		

*Min: Minimum; Max: Maximum; SD: standard deviation; t: Student t-test; *significance at p ≤ 0.05*

Table (4): Comparison between males and females according to foramen magnum area (in mm2)using student's t-test (n=100)

Foramen magnum area	Males (n=55)	Females (n=45)
Min. – Max.	682.0-1015.14	276.57-880.0
Mean ± SD.	833.50±72.52	699.90±92.09
t	8.117	
P	<0.001*	

*Min: Minimum; Max: Maximum; SD: standard deviation; t: Student t-test; *significance at p ≤ 0.05*

Table (5): Statistical analysis of the maximum bicondylar distance, minimum intercondylar distance and maximum medial intercondylar distance (in mm) measured on 3DMSCT in both sexes using student t- test (n=100)

	Males (n=55)	Females (n=45)	Total (n=100)
MBD			
Min. – Max.	45.0 – 53.0	41.0 – 50.0	41.0 – 53.0
Mean ± SD.	48.8 ± 2.3	46.1 ± 2.2	47.6 ± 2.6
t	5.965		
P	<0.001*		
MnID			
Min. – Max.	13.0 – 21.0	12.0 – 20.0	12.0 – 21.0
Mean ± SD.	17.2 ± 1.7	16.2 ± 1.8	16.7 ± 1.8
t	2.988		
P	0.004*		
MID			
Min. – Max.	19.0 – 30.0	20.0 – 26.0	19.0 – 30.0
Mean ± SD.	25.1 ± 2.4	22.7 ± 1.7	24.0 ± 2.4
t	5.752		
P	<0.001*		

*MBD= Maximum bicondylar distance; MnID= Minimum intercondylar distance; MID = Maximum medial intercondylar distance; Min: Minimum; Max: Maximum; SD: standard deviation, t: Student t-test; *Significance at p ≤ 0.05*

Table (6): Statistical analysis of the length and the width of the right condyle (in mm) measured on 3DMSCT in both sexes using Student's t-test (n=100)

	Males (n=55)	Females (n=45)	Total (n=100)
LRC			
Min. – Max.	20.0 – 28.0	15.0 – 29.0	15.0 – 29.0
Mean ± SD.	24.8 ± 1.7	22.7 ± 2.2	23.9 ± 2.2
t	5.480		
P	<0.001*		
WRC			
Min. – Max.	11.0 – 17.0	11.0 – 16.0	11.0 – 17.0
Mean ± SD.	14.4 ± 1.3	13.5 ± 1.3	14.0 ± 14.0
t	3.563		
P	0.001*		

*LRC= Length of the right condyle; WRC= Width of the right condyle; Min: Minimum; Max: Maximum; SD: standard deviation; t: Student t-test; *significance at p ≤ 0.05*

Table (7): Statistical analysis of the length and the width of the left condyle (in mm) measured on 3DMSCT in both sexes student's t-test (n=100)

	Males (n=55)	Females (n=45)	Total (n=100)
LLC			
Min. – Max.	21.0 – 27.0	20.0 – 27.0	20.0 – 27.0
Mean ± SD.	24.7 ± 1.7	23.4 ± 1.79	24.11 ± 1.88
t	2.590		
P	0.013[*]		
WLC			
Min. – Max.	12.0 – 17.0	12.0 – 16.0	12.0 – 17.0
Mean ± SD.	14.55 ± 1.29	13.82 ± 1.15	14.22 ± 1.28
t	1.933		
P	0.059[*]		

*LLC= Length of the left condyle; WLC= Width of the left condyle; Min: Minimum; Max: Maximum; SD: standard deviation; t: Student t-test *significance at p ≤ 0.05*

Table (8): Comparison between the length and the width of the right and left condyles (in mm) in the same sex using student's t-test (n=100)

	LRC	LLC	WRC	WLC
Male				
Min. – Max.	20.0 – 28.0	21.0 – 27.0	11.0 – 17.0	12.0 – 17.0
Mean ± SD.	24.8 ± 1.7	24.69 ± 1.76	14.4 ± 1.3	14.55 ± 1.29
t	0.443		0.614	
P	0.660		0.542	
Female				
Min. – Max.	15.0 – 29.0	20.0 – 27.0	11.0 – 16.0	12.0 – 16.0
Mean ± SD.	22.7 ± 2.2	23.40 ± 1.79	13.5 ± 1.3	13.82 ± 1.15
t	1.472		1.355	
P	0.148		0.182	

*LRC= Length of the right condyle; LLC= Length of the left condyle; WRC=Width of the right condyle; WLC= Width of the left condyle; Min: Minimum; Max: Maximum; SD: standard deviation; t: Student t-test; *Significance at p ≤ 0.05*

Table (9): Comparison between males and females right and left condylar indices using student's t-test (n=100)

	Males (n=55)	Females (n=45)	Total (n=100)
Right condylar index			
Min. – Max.	1.47 – 2.27	1.31 – 2.36	1.31 – 2.36
Mean ± SD.	1.74 ± 0.18	1.69 ± 0.21	1.72 ± 0.19
t	0.965		
P	0.337		
Left condylar index			
Min. – Max.	1.40 – 2.0	1.38 – 2.08	1.38 – 2.08
Mean ± SD.	1.71 ± 0.17	1.70 ± 0.17	1.71 ± 0.17
t	0.172		
P	0.864		

*Min: Minimum; Max: Maximum; SD: standard deviation; t: Student t-test; *significance at p ≤ 0.05*

Table (10): Discriminating indices of the measured parameters: LFM, WFM, LRC, WRC, MnID, MBD, MID, LLC and WLC using Student's t-test

	Accuracy %	t	p
WFM	85.6	6.877	<0.001[*]
LFM	82.1	5.801	<0.001[*]
LRC	81.0	5.480	<0.001[*]
MID	80.1	5.752	<0.001[*]
MBD	79.9	5.965	<0.001[*]
WRC	70.2	3.563	0.001[*]
MnID	69.1	2.988	0.004[*]
LLC	66.2	2.590	0.013[*]
WLC	58.2	1.933	0.059[*]

*t: Student t-test; *significance at $p \leq 0.05$; LRC=Length of right condyle; WRC =Width of right condyle; WFM= Width of foramen magnum; LFM= Length of foramen magnum; MBD= Maximum bicondylar distance; MID= Maximum medial intercondylar distance; MnID= Minimum intercondylar distance; LLC= Length of left condyle; WLC= Width of left condyle*

Table (11): Multivariate linear regression equation predicting sex from the studied cranial measurements (in mm) in adult Egyptian

No.	Equation	R^2	Accuracy	p	Cut off Value	Adjusted R^2
I	X = 0.063*LRC + 0.094*LLC + 0.080*LFM -5.974	0.461	87.0%	<0.001[*]	0.45	0.444
II	X = 0.051* LFM+0.032* WFM+0.019* LRC+ 0.061*LLC+0.029* WRC+0.046* WLC+0.216*MnID+ 0.152*MBD +0.302* MID-6.927	0.469	86.0%	<0.001[*]	0.48	0.429
III	X = 0.066*WRC + 0.089*WLC + 0.099*WFM -4.479	0.417	86.0%	<0.001[*]	0.58	0.399
IV	X = 0.039*WFM + 0.046*LFM + 0.42*MBD + 0.176*MnID + 0.37*MID -0.5.315	0.453	85.0%	<0.001[*]	0.48	0.424
V	X= 0.543*LFM + 0.811*WFM-3.633	0.378	84.0%	<0.001[*]	0.59	0.365
VI	X=0.472*LRC+0.397*WRC + 0.379*WFM -5.224	0.449	84.0%	<0.001[*]	0.48	0.426

significance at $p \leq 0.05$; If X> (cut off value) sex is male; LRC=Length of right condyle; WRC =Width of right condyle; WFM= Width of foramen magnum; LFM= Length of foramen magnum; MBD= Maximum bicondylar distance; MID= Maximum medial intercondylar distance; MnID= Minimum intercondylar distance; LLC= Length of left condyle; WLC= Width of left condyle

Discussion

Human identification is one of the major and most important tasks of forensic medicine (Fortes et al., 2012). Identity cannot be established by the simple measurement of a set of parameters of an individual or a body. It can only be established by matching the parameters that can be measured or seen on the individual. The finding of a specific feature or a combination of specific features that is known to be possessed by that individual alone will add considerable weight to the conclusion (Shepherd, 2003). Assessment of sex is one of the most vital determinations to make when it is necessary to establish identity from skeletal remains. Moreover, identification techniques such as

facial reconstruction would be impossible if sex could not be correctly established (Iscan and Loth, 2000).

In the present study the mean age of the patients was 35.79 ± 12.09 years. Forty percent of the cases were 18 to less than 30 years, where70% of them were males. In a study done in north India by Jain et al. (2013), the age of the cases ranged from 22 to 60 years, the upper limit of this age (60 years) agree with the upper limit of the age in our study.

In the present work the mean age for female patients was about nine years higher than for males (40.93 ± 13.40 years and 31.58 ± 9.03 years respectively). There was a significant difference as

regards age between both sexes; this could be attributed to the fact that most victims of road traffic accident (RTA) that were referred to the radio diagnosis department for routine radiological investigation were young males who were more involved in outdoor activity.

The present study revealed that the mean length and width of the foramen magnum were significantly higher in males than in females (p=<0.001).This coincides with Selma et al. (2005) and Uysal et al. (2005) who showed that all measurements of the foramen magnum that were performed on virtual skulls of the Turkish population were larger in males than in females.

Similarly, Uthman et al. (2012)trying to evaluate the accuracy of FM dimensions in gender determination among a sample of Iraqi adults, noted that the mean length and width of the FM using helical CT images were significantly higher in men's skulls. In an another study conducted on 100 CT scans of adult Indians, (Gopalrao et al., 2013) confirmed that significant craniometric differences exist in the FM between both sexes where the 2 dimensions were significantly greater in males than in females. This significant higher variable among males than females may be due to the fact that males tend to have significantly larger cranial bases than females (Murshed et al., 2003). Data of the current research are in accordance with those of Jain et al, (2013) in their study on North Indian population. They postulated that the mean length and width of the foramen magnum showed significant difference between males and females and they considered them as important parameters for sex determination and constitution of biological profile. Similarly, Santhosh et al. (2013) in their study in South India, clearly indicate that males display larger mean values than females for both LFM and WFM and that statistically significant sex differences were observed for both dimensions. They clarified that in case of highly fragmentary remains, where no other skeletal remains are preserved, metric analysis of the basal region of the occipital bone may provide a statistically useful indication as to the sex of an unknown skull. Günay and Altinkök (2000) revealed that the morphological differences between skulls of different genders are mainly determined by genetic factors rather than nutrition, hormones, or muscles. Thus, the determination of gender in human skulls is based on morphological differences, mainly on the size and strength of certain structures (Rösing et al., 2007), which may be characteristics of each population that are influenced by genetic, environmental, and socioeconomic factors (Saunders and Yang, 1999).

According to Enlow and Hans (2002), the large size of the FM of the male skulls compared to that of females is explained by the fact that the main neurovascular bundle such as the cervical spinal cord, vertebral arteries, nerves and meninges passing through the skull base are larger in male than females.

On the other hand, Loyal et al. (2013) evaluated the foramen magnum for sex difference among Kenyan skulls. They clarified that the dimensions of the foramen magnum showed only ethnic variation and did not show any sexual dimorphism among Kenyan Africans. Raghavendra et al. (2012) postulated that size differences and the robust nature of the human cranium are unique to each population and thought to be influenced by genetic, environmental and socio-economic factors. Singh and Talwar (2013) in an Indian sample reported that the foramen magnum width and length were larger in females than males in contrast to the present study.

Philipp et al. (2009) and Gruber et al. (2009) found that sexual dimorphism among Central European population was also not found in either the sagittal or transverse diameter of the foramen magnum.

Several authors have emphasized on the value of FM and worked on various parameters for the purpose of sex identification. The present study revealed that the mean length of the foramen magnum in *males* (35.3 ± 1.9) was nearly similar to that of a sample of Indian population (35.5 ± 2.8) (Routal et al., 1984) Brazilian male skulls (36.5±2.6)(Suazo et al., 2009) and to the English population (35.91±2.41) (Gapert et al., 2009). Meanwhile, it was lower than the Turkish (37.2 ±3.43) (Murshed et al., 2003) and Spanish (36.2±2.60) (Herrera 1987) population but it was higher than that of South Indian male skulls (34.37 ± 2.38) (Santhosh et al., 2013).

Similarly the mean LFM of the *female* skulls, in the present work, was found to be 30.28 ± 0.25 which was lower than Brazilian population (35.6±2.5) (Suazo et al., 2009), Turkish (34.6 ± 3.16) (Murshed et al., 2003), Spanish (34.30±2.04) (Herrera 1987), English populations (34.71 ± 1.91) (Gapert et al., 2009), South Indian population (33.80 ± 2.56) (Santhosh et al., 2013), and other Indian samples (32.0 ± 2.8) (Routal. et al.,1984).

Regarding the width of the foramen magnum, the mean male value of the current research (30.0± 1.9), was nearly similar to many other studies as that of Brazilian skulls (30.6±2.5) (Suazo et al., 2009), Indians (29.6±1.9) (Routal et al.,1984), the Turkish (31.6±2.99) (Murshed et al., 2003), Spanish (31.1±2.60) (Herrera 1987), and English population (30.51±2.60) (Gapert et al., 2009), but it was higher than that of the South Indian male skulls (28.98 ± 2.22) (Santhosh et al., 2013).

In females, the mean width of the FM in this study (27.1± 2.4) nearly coincides with an Indian sample (27.1±1.6) (Routal et al.,1984) and South Indian population (27.60±2.67)) (Santhosh et al., 2013), but it was lower than the Brazilian (29.5±1.9) (Suazo et al., 2009), Turkish (29.3±2.99) (Murshed et al., 2003), Spanish (29.6±1.53) (Herrera 1987), and English populations (29.6±1.53) (Gapert et al., 2009). These aspects can be attributed to racial differences.

The present work showed no significant difference between males and females concerning FMI where the mean FMI in males was 1.18 ± 0.10mm while that of females was 1.21 ± 0.09mm (P=0.080). This finding is consistent with the study conducted by Erdil et al. (2010) on Turkish population. In this study, the FMI ranged from 0.97 – 1.44 with a total mean of 1.2±0.10. This nearly agrees with Radhika (2012) who conducted her study on150 adult human dry skulls and found that the FMI ranged from 1.0 –1.7 with a total mean of 1.2.

The present study reported a statistically significant sex difference in the area of the FM as derived by the formula given by Radinsky (1967).It was found that FMA was higher in males than in females as P≤0.001. This could be attributed to the high significant correlation of the FMA with both sagittal and transverse diameters (Murshed et al., 2003) or to the larger structure of skeletal muscle in men.

The data of the present work coincide with those of Ukoha et al. (2011) in his study in Nigeria, Gapert et al. (2008) in Britain, Murshed et al. (2003) in Turkey and Herrera (1987) in Spain. FM measurements on dry skulls done by Wanebo and Chicoine (2001) were very close to the results of the present study.

Günay and Altinkök (2000) measured the FMA directly on Turkish skulls, estimating it by considering the FM as a ''circle'' whose ''radius'' was obtained as the mean value between the half measurements of the length and the breadth. Although these values were higher than those reported in the present study; such variation may be owing to differences between the anatomic and radiographic methods.

In contrast to the present study, Singh and Talwar (2013) reported that in India, the foramen magnum area was larger in females than males. This difference may be due to their small sample size (26 males and 24 females)

In the current study, the mean lengths of the intercondylar distance: MBD, MnID, and MID were significantly longer in males than in females .This difference in the intercondylar distances reflects the asymmetry in the orientation of the occipital condyles which form the lateral limits of craniovertebral junction.

Similar results were obtained by Holland (1986) who measured the intercondylar distances on human skulls manually. Also in Turkey, Selma et al. (2005) reported that all the intercondylar distances were longer in males than females; however these differences were not statistically significant.

On the other hand, Singh and Talwar (2013) in his study done on dry skulls of an Indian population revealed that only MBD was longer in males and MnID and MID were longer in females. This may be explained by the fact that sexual dimorphism is substantially population based, due to a combination of genetic, environmental and socio-cultural factors.

In the current study the mean length and width of the right condyle and the mean length of the left condyle were significantly higher in males than in females, while the mean width of left condyle was slightly higher in males than in females but no significant difference was noticed.

This nearly agrees with Fortes et al. (2013) who studied Brazilian skulls for sex determination from occipital condylar measurements. They declared that the length and the width of both condyles were significantly higher in males than females

Holland (1986), in his study tried to estimate the sex of skeletonized individuals from the cranial bases of burnt cadavers. He reported that the measurements of the region of occipital condyles are useful for determining the sex, with an accuracy of 70–90%.

Similarly, Selma et al. (2005) in Turkey stated that the length and width of the right condyle were statistically significant between both sexes. The length and width of the left condyle were not measured by Selma because of non-visualization by 3D CT.

On the other hand, the present study showed that there was no significant difference concerning the length and the width of the right and left condyles within the same sex. The presence of a minimal asymmetry may be due to genetic factors in some cases, or can be attributed to other different factors such as food or climatic factors (Manoel et al., 2009).

The present work showed that although the mean right and left condylar indices were slightly higher in males than in females yet no significant difference was elicited between them. Similar findings were reported by Fortes et al. (2013) who declared that there was no significant difference between both sexes regarding the condylar index. Radhika (2012) postulated that indices are also affected by the physiological and mechanical conditions that control the relations of the part concerned. Among all the measured dimensions of the foramen magnum and occipital condyles in the studied

Egyptian population sample, the width of the foramen magnum showed the highest accuracy as a discriminating index (85.6%). This is in accordance with Selma et al. (2005) who stated that the WFM was the most significant parameter that distinguish sex. Another study, in Brazil by Manoel et al. (2009) showed that the morphometric linear method of only the WFM was able to determine the morphological differences between sexes and can be used in conjunction with other anthropological techniques for gender determination of unknown individuals.

Discriminant function that applies to cases other than the population used to develop these functions, has known incorrect classification percentage, as sexual dimorphism is population specific.

With significant equations for sex prediction obtained by using multivariate linear regression analysis of the studied measurements of the foramen magnum and of both condyles as independent variables and sex as dependent one an accuracy ranging from 84% to 87% was obtained. To the best of our knowledge, this study was the first to investigate the relation between sex and the lengths of the foramen magnum and the inter condylar distance measured on the reconstructed 3D image of MSCT.

Recommendation

1. Modern imaging techniques are advised to gain access to forensic medicine.
2. New generations of MSCT devices should be established in the main university hospital.
3. The study of the symmetry of both condyles and its relation to age and sex is recommended.
4. Other foramina of the skull advised to be considered.
5. Further studies are needed to detect the relation between age and stature and the size of the foramen magnum.
6. Studies on the shape and size of the foramen magnum among different races is recommended.
7. Studies on a larger sample with more age groups are needed to further confirm the findings of our study. Similar studies are also proposed in other population groups.
8. Research with a larger study design and a greater number of measurable variables is advised to discriminate between male and female skulls in Egyptian population.

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الملخص العربي

الاستعراف على الجنس من الثقبة العظمى في جماجم المصريين باستخدام الأشعة المقطعية ثلاثية الأبعاد

رجاء درويش[1] و نجلاء سلامة[1] و محمد الصيرفي[2] و وائل خليف[1]

يعتبر تحديد النوع واحد من أهم و أول السمات التي يجب تقيمها في كل حالة عند الاستعراف على الإنسان لأغراض الطب الشرعي ويمكن تحديد الجنس من خلال الشكل أو طرق القياس المختلفة.

تعتبر الثقبة العظمى مَعلما مُهما في قاع الجمجمة وذات أهمية خاصة لعلم الإنسان والطب الشرعي وقد اجتذب تحديد الجنس من الثقبة العظمى اهتمام الباحثين مما أكد قيمتها في تحديد النوع.

وكان الهدف من هذه الدراسة هو تحديد مدى دقة و موثوقية الثقبة العظمى وبعض قياسات الجمجمة في تحديد الجنس باستخدام الأشعة المقطعية ثلاثية الأبعاد.

وقد أجريت هذه الدراسة على عدد مائة من المصريين البالغين من الجنسين وتم اختيار كل المرضى بشكل عشوائي عند تحويلهم إلى قسم الأشعة التشخيصية بالمستشفى الرئيسي الجامعي بالإسكندرية لإجراء الفحوصات الإشعاعية.وقد تم الحصول على الموافقة المسبقة من جميع المرضى قبل المشاركة في الدراسة.ولقد تم الحصول على الأشعة المقطعية متعددة المقاطع لكل حالة وإنشاء نماذج ثلاثية الأبعاد عالية الجودة للجمجمة. ثم تم قياس العديد من الأبعاد المتعلقة بالثقبة العظمى واللقمة اليمنى و اليسرى للجماجم الافتراضية في المرضى البالغين.

البيانات التي تم جمعها تم تحليلها إحصائيا وتم استخدامها لصياغة المعدلات من القياسات المختلفة.

وقد أظهرت الدراسة النتائج الآتية:

- كان متوسط طول وعرض و مساحة الثقبة العظمى الثقبة العظمى أعلى في الذكور (٣٥.٣±١.٩مم و ٣٠.٠±١.٩مو٨٣٣.٥٠±٧٢.٥٢مم٢ تباعا) عنه في الإناث (٣٢.٨±٢.٥ مم و ٣٠.٠±١.٩مم و ٦٩٩.٩±٩٢.٠٩ مم٢ تباعا).

- كان متوسط أطوال المسافة القصوى والأدنى والقصوى الوسطى بين اللقمتين أطول كثيرا في الذكور عن الإناث وكان هذا الاختلاف ذو دلالة إحصائية حيث بلغت متوسط قيمتها في الذكور (٤٨.٨±٢.٣ و١٧.٢±١.٧ و٢٥.١±٢.٤ مم تباعا) وفي الإناث (٤٦.١±٢.٢ و١٦.٢±١.٨ و٢٢.٧±١.٧ مم تباعاً).

- وقد اظهر العمل الحالي فرق كبير بين الجنسين فيما يتعلق بطول اللقمة اليمنى (٢٤.٨±١.٧ و٢٢.٧±٢.٢ مم تباعاً) وعرضها (١٤.٤±١.٣ و١٣.٥±١.٣ مم تباعاً)وكان هذا الفرق ذو دلالة إحصائية.

- كما أن متوسط طول اللقمة اليسرى أطول كثيرا في الذكور (٢٤.٧±١.٧مم) عن الإناث (٢٢.٧±٢.٢مم) ولم يكن هناك فرق ذو دلالة إحصائية بين الجنسين فيما يتعلق بعرض اللقمة اليسرى.

- كان متوسط مؤشر اللقمة اليسرى واليمنى أطول قليلا في الذكور عن الإناث بدون دلالة إحصائية.

- من بين كل قياسات الثقبة العظمى واللقمة الخلفية في هذه الدراسةكان عرض الثقبة العظمى أعلى مؤشر للتمييز بين الجنسين يليها طول الثقبة العظمى وكان عرض اللقمة اليسرى أقلهم تميزا.

باستخدام تحليل الانحدار المتعدد تم التوصل للعديد من المعادلات حيث كان أدق هذه المعادلات المعادلة لتحديد الجنس باستخدام طول الثقبة العظمى و طول اللقمة اليمنى و اليسرى وكانت دقة المعادلة ٨٧%.

وقد أسفرت هذه الدراسة عن العديد من التوصيات من أبرزها:

١. استخدام تقنيات التصوير الحديثة ا   في مجال في أبحاثات ما بعد الوفاة، حيث أن القدرة على   افتراضية حل الكثير من المشاكل .   .

. هناك حاجة لإجراء دراسات على عينات أكبر .

١ قسم الطب الشرعي والسموم الإكلينيكية – كلية الطب – جامعة الإسكندرية

٢ قسم الأشعة التشخيصية – كلية الطب – جامعة الإسكندرية