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Evaluation of Skull Base Parameters in Sex Determination Using Anthropometric Measurements among a Sample of Egyptians

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Abstract Determination of sex is a vital element in forensic and anthropological examination. In certain circumstances, such as in explosions, warfare and other mass disasters, sex prediction may be a difficult task as a result of loss of important body parts. The skull base bones have a high resistance to adverse environmental conditions. Accordingly, this study aimed to investigate the accuracy of different anthropometric measurements of the skull base for sex determination, to establish parameters that can reliably determine the sex of an unidentified skull.

Material and methods: Eighty Egyptian adult skulls were subjected for the following anthropometric measurements; **palatal measurements**; incisive foramen to greater palatine foramen (right and left), right to left greater palatine foramen and incisive foramen to basion, **mastoid notch measurements**; incisive foramen to mastoid notch (right and left) and right to left mastoid notch and **foramen magnum measurements**; sagittal and transverse diameters, area and circumference. All measurements were taken using Vernier caliper and the circumference was measured by a flexible tape. **Results:** The results showed significant sexual difference in all the studied anthropometric measurements. The resulting formula using palatal measurement had the highest accuracy (94.1%), followed by mastoid notch that revealed 90.2% accuracy while the least accuracy was that of foramen magnum (89.2%). All measured parameters of skull base gave an accuracy of 96.1%. It was concluded that the skull base is a good basis for sex determination in adult Egyptians.

Keywords Skull base, anthropometric measurements, sex determination.

Introduction

Determination of sex is a vital element in forensic anthropological examination and is a crucial aspect in developing the biological profile of an unidentified person. It is also important for other estimations such as age and stature that depend mainly on the sex of an individual (Dayal et al., 2008; Vidya et al., 2013).

Sex identification is essential as it may reduce approximately fifty percent of the subjects in human identification processes (Knight and Saukko, 2004*)*. The determination of sex in skeletons is only possible once the male or female has reached adulthood. After puberty, different factors such as hormones, environment and muscle activity influence human skeleton development (Stewart, 1998).

Since sexual dimorphism is not uniformly expressed in the skeleton, various researches have studied the accuracy of sex determination that varies considerably between different bones (such as skull, pelvis, humerus and mandible). (Meindl and Russell, 1998; Mitesh et al., 2013; Rogers, 2009; Spradley and Jantz, 2011).

However, in certain circumstances, such as in explosions, warfare and other mass disasters like aircraft crashes, or in extreme post-mortem changes, sex prediction may be a difficult task as a result of loss of important body parts. (Günay and Altinkök, 2000).

The skull is considered as the second best skeletal part, after the pelvis, in sex determination. The skull bones have a high resistance to adverse environmental conditions over time, resulting in the greater stability of the dimorphic features as compared to other skeletal bones. Therefore, it is considered as a suitable material for different anthropological and forensic investigations. Fortunately, cranial base is preserved in most of cases (Brasileños et al., 2009).

Unfortunately, examination of the parameter of a single bone may lead to different results. Therefore, various parameters must be collected from a single bone to augment the accuracy of the findings (Naikmasur et al., 2010).

The adult skull is composed of a set of bones that are rich in information regarding sexual dimorphism, which can be assessed both by morphological and osteometric methods (Krogman and Iscan, 1986; Lima et al., 2012).

Kemkes - Grottenhaler (2001) stated that the metric analysis is extremely population specific and may be less accurate when applied to individuals of unknown sample origin.

Furthermore, there is a marked variability among different populations which is influenced by genetic, environmental and socio-economic factors, making it crucial to use sex determination parameters specific for each population. Without knowing the national skull measurements, scientific investigators are forced to use international tables, which may lead to uncertain results (Iscan and Kedici, 2003).

Accordingly, this study aimed to investigate the accuracy of different anthropometric measurements of the skull base for sex determination, to establish parameters that may reliably determine the sex of an unidentified Egyptian skull.

Material and methods

To examine the utility of various skull base dimensions in sex determination of adult Egyptians, eighty skulls of known sex (40 males and 40 females) were examined. They were obtained from the Anatomy and Forensic Medicine and Clinical Toxicology departments, Faculty of Medicine, Alexandria University. Skulls showing anomalies and deformities were excluded from the study.

The research was approved by the Ethical Committee of the faculty of medicine, Alexandria University.

All skulls were subjected for the following anthropometric measurements (Figures 1 & 2)

Palatal measurements	
IF-RGPF	Incisive foramen-right greater palatine foramen
IF-LGPF	Incisive foramen-left greater palatine foramen
RGPF-LGPF	Right greater palatine foramen-left greater palatine foramen.
B-IF	Basion (midpoint located on the anterior margin of foramen magnum)- Incisive foramen.
Foramen magnum (FM) measurements	
FMSD	FM sagittal diameter (the greatest anteroposterior dimension)
FMTD	FM transverse diameter (the greatest width)
FMC	FM circumference
FMA	FM area
Mastoid notch measurements	
IF-RMN	Incisive foramen-right mastoid notch (anterior margin)
IF-LMN	Incisive foramen-left mastoid notch (anterior margin)
RMN-LMN	Right mastoid notch (anterior margin)-left mastoid notch (anterior margin)

All measurements were taken using Vernier caliper (figure 3). FMC was measured by a flexible tape in centimeter and FMA was automatically calculated using a formula given by Routal et al (1984); Area = LFM × WFM × π / 4. L (length) and W (width)

All data were subjected to descriptive and discriminant analyses using the SPSS package (version 20) for Windows software. P-Value was considered significant at values ≤ 0.05.

Descriptive analysis was applied, calculating mean and standard deviation. Then Student's t-test was used to compare between the male and female mean values for each variable. Sexual Dimorphism Index was calculated as; mean male value/ mean female value x100 to find the ability of each variable in sexing the skulls.

Wilk's lambda was calculated for each variable to test which parameter contributed significantly in discriminant function. The closer the Wilks' lambda to 0, the more the variable contributed to the discriminant function.

Subsequently to determine the ability to discriminate between the males and female skulls from these measurements, stepwise discriminant function analysis was performed. It determined the optimal combination of variables for sex determination.

Results

A total of 80 adult skulls of known sex were studied (40 males and 40 females); the results were based on the palate, foramen magnum and mastoid notch measurements of the skull base.

Table (1) shows the metric parameters revealing a significant sex difference. It also shows the index of sexual dimorphism; all values were greater than 100 indicating higher male dimensions.

Table (2) demonstrates the results of stepwise discriminant function analysis for the different studied variables using Wilks' Lambda test revealing, palatal measurements; IF-RGPF, IF-LGPF and RGPF-LGPF having the least Wilks' Lambda as the best sex discriminators followed by mastoid notch measurement (IF-RMN and IF- LMN). The least sex discriminator was FMSD.

Table (3) displays the results of stepwise discriminant analysis of skull base measurements. All parameters were entered for function 1 to be used. In case of intact skull base, it gave the highest accuracy for sex determination (96.1%). Each dimension was multiplied by its unstandardized coefficient. The results of multiplication were then put in linear combination along with a constant. The obtained discriminant score was compared with a demarking point that was indicated as the midpoint between males and females arithmetical average.

The three groups of measurements were applied separately to the regression model.

Table (4) demonstrates discriminant function employed the palatal measurements as the best sex discriminator with accuracy of 94.1% using the four parameters, while lesser accuracy (93.2%) was obtained with the using of only IF-RGPF, IF-LGPF and RGPF-LGPF parameters (tables 4 &5). Table (6) demonstrates discriminant function obtained when applying FM parameters with accuracy of 89.2%, while mastoid notch parameters accuracy was 90.1%, as shown in table (7).

Table (1): Descriptive Statistics for sex difference of palate, foramen magnum and mastoid notch parameters, showing sexual dimorphism index and comparison of the different anthropometric parameters using student t-test among males (n=40) and females (n=40) (in cm).

		Male *(n = 40)*		Female *(n = 40)*		
	Sexual dimorphism index	**Range**	**Mean+SD**	**Range**	**Mean+SD**	**p**
Palatal measurements						
IF – RGPF	151.5	2.96-4.10	3.53 ± 0.31	2.00-3.80	2.33±0.37	<0.0001*
IF – LGPF	149.2	2.84-4.00	3.48±0.32	2.03-3.70	2.33±0.33	<0.0001*
RGPF – LGPE	130.0	2.07-3.21	2.85±0.15	1.93-2.68	2.19±0.16	<0.0001*
B – IF	115.8	6.91-9.93	8.30±0.48	6.64-7.95	7.17±0.34	<0.0001*
Foramen magnum measurements						
FMSD	120.9	2.23-3.82	3.37±0.37	2.23-3.51	2.78±0.31	<0.0001*
FMTD	119.5	2.15-3.00	2.81±0.18	2.00-3.03	2.35±0.30	<0.0001*
FMC	121.4	5.00-6.80	6.19±0.48	4.60-6.50	5.10±0.50	<0.0001*
FMA	146.9	4.87-9.00	7.45±1.11	4.07-8.36	5.07±1.07	<0.0001*
Mastoid notch measurements						
IF-RMN	113.8	8.23-10.76	9.77±0.55	8.01-9.31	8.58±0.28	<0.0001*
IF-LMN	114.6	8.15-11.65	9.85±0.54	8.13-9.40	8.59±0.26	<0.0001*
RMN – LMN	111.0	8-10.3	9.17±0.56	7.84-9.14	8.26±0.31	<0.0001*

Quantitative data is expressed in (Mean. ± SD) and was compared using t-student test.

Table (2): discriminant function analysis of palate, foramen magnum and mastoid notch parameters using Wilks' lambda test

	Wilk's Lambda	**F**	**P**
IF – RGPF	0.239	184.346*	<0.001*
IF – LGPF	0.240	183.667*	<0.001*
RGPF – LGPF	0.171	281.429*	<0.001*
B – IF	0.361	102.627*	<0.001*
FMSD	0.587	40.870*	<0.001*
FMTD	0.506	56.651*	<0.001*
FMC	0.479	63.093*	<0.001*
FMA	0.494	59.307*	<0.001*
IF-RMN	0.375	96.686*	<0.001*
IF- LMN	0.335	114.994*	<0.001*
RMN – LMN	0.515	54.675*	<0.001*

Table (3): Stepwise analysis showing stanadardized and unstandardized coefficient and equation for sex determination from all the studied measurements.

Model		Unstandardized Coefficients
1	(Constant)	7.898
	IF- RGPF	-.184
	IF- LGPF	0.002
	RGPF LGPF	-0.441
	DBIF	-0.085
	FMSD	-.315
	FMTD	-0.505
	FMC	-0.445
	FMA	0.084
	IF-RMN	-0.029
	IF-LMN	-0.127
	RMN- LMN	-0.113

Equation:
Y=7.989-(0.184*IF RGPF)+(0.002*IF LGPF)-(0.441*RGPF LGPF)-(0.085*B IF)-(0.315*FMSD)-(0.505*FMTD)-(0.445*FMC)+(0.084*FMA)-(0.029*IF RMN)-(0.127*IF LMN)-(0.113*RMN-LMN)
Accuracy = 96.1%
If Y $\leq$ 1.2 individual is male
If Y > 1.2 individual is female

Table (4): Stepwise analysis showing standardized and unstandardized coefficient and equation for sex determination from all palatal measurements.

Model		Unstandardized Coefficients
1	(Constant)	4.650
	IF- RGPF	-0.215
	IF- LGPF	-0.138
	RGPF- LGPF	-0.565
	B-IF	-0.091

***Equation*:**
Y=4.65-(0.215*IF RGPF)-(0.138*LF LGPF)-(0.565*RGPF LGPF)-(0.091*B IF)
Accuracy = 94.1%
If Y $\leq$ 1.7 individual is male
If Y > 1.7 individual is female

Table (5): Stepwise analysis showing standardized and unstandardized coefficient and equation for sex determination from IF-RGPF, IF-LGPF and RGPF- LGPF palatal measurements.

Model		Unstandardized Coefficients
1	(Constant)	4.217
	IF- RGPF	-.253
	IF- LGPF	-.159
	RGPF- LGPF	-.608

Equation:
Y= 4.217-(0.253* IF-RGPF)-(0.159* IF-LGPF)-(0.608* RGPF-LGPF)
Accuracy = 93.2%
If Y$\leq$ 1.31individual is male
If Y > 1.31 individual is female

Table (6): Stepwise analysis showing standardized and unstandardized coefficient and equation for sex determination from foramen magnum measurements.

Model		Unstandardized Coefficients
1	(Constant)	14.269
	FMSD	-4.513
	FMTD	-5.124
	FMC	0.736
	FMA	0.401

Equation:

Y=14.269-(0.4.513*FMSD)-(5.124 *FMTD)+(0.736*FMC)+(.401*FMA)

Accuracy =89.2%

If Y $\leq$ 1.6 individual is male

If Y > 1.6 individual is female

Table (7): Stepwise analysis showing standardized and unstandardized coefficient and equation for sex determination from mastoid notch measurements.

Model		Unstandardized Coefficients
1	(Constant)	7.037
	IF-RMN	-0.220
	IF-LMN	-0.383
	RMN - LMN	-0.22

Equation:

Y=7.037-(0.220*IF- RMN)-(0.383*IF-LMN)-(0.22*RMN- LMN)

Accuracy = 90.1%

If Y $\leq$ 1.5 individual is male

If Y > 1.5 individual is female

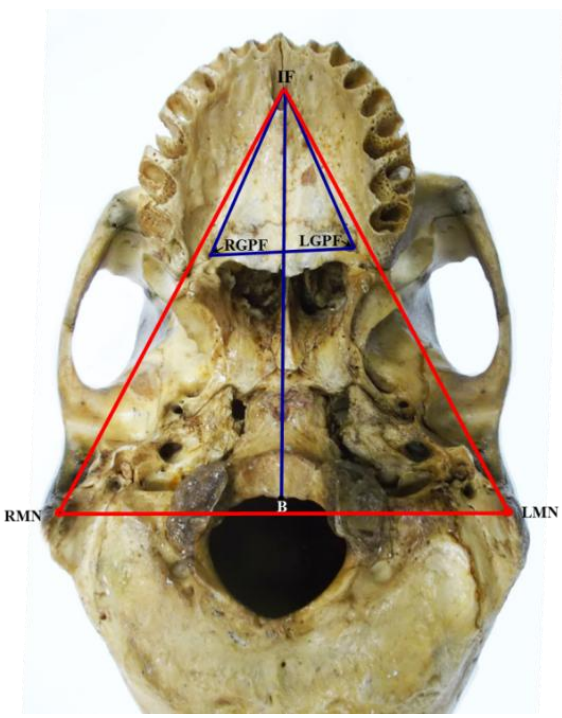

Figure (1): Base of skull showing:
RGPF= right greater palatine foramen.
LGPF= left greater palatine foramen
RMN= right mastoid notch.
LMN= left mastoid notch
IF= incisive foramen.
B=basion

Figure (2): Base of skull showing measurements of foramen magnum:
FMTD= foramen magnum transverse diameter.
FMSD= foramen magnum sagittal diameter.

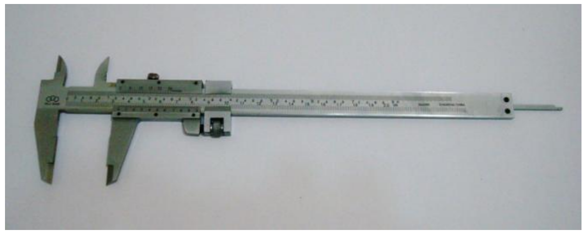

Figure (3): Vernier Caliper

Discussion

Human identification consists of a sequence of steps to ascertain the identity of individuals. In this respect, forensic anthropology plays a significant challenge in reconstructing the biological profile (Prabhu and Acharya, 2009).

It is well known that the reliability of human identification is in direct proportion with the data gathered from the individuals. Thus, evaluation of all dimorphic bones in the human skeleton would be an ideal state for sex determination. However, there are different cases in which a complete skeleton is unavailable, hindering this type of identification. Fortunately, the bone of skull base is covered by a large volume of soft tissue and has a well-protected anatomical position (Gapert et al., 2009). Therefore, it may be useful in sex determination of skeletal remains and in profiling sex dimorphic criteria in these cases.

Nowadays, DNA profiling is used as a mean of determining sex and identification if comparative material is available. It is, however, not always possible to harvest DNA and the cost of such an examination must be taken into account (Francesquini et al., 2007).

Methods based on morphological and anthropometric measurements are practical, simple, of low-cost and reliable, as demonstrated by several studies. Visual observations are often used but statistical methods using metric traits are becoming more popular (Macaluso et al., 2012; Shankar et al., 2013).

Hence, discriminant function analysis is an entirely objective statistical technique for sex determination. It was also stated that the efficacy of sex discriminant equations is not sure in populations other than the ones from which they have been derived (Hsiao et al., 1996).

Therefore, the current study aimed to evaluate different anthropometric measurements of the skull base for sex determination using (palatal, foramen magnum and mastoid notch) measurements among a sample of Egyptians.

Palatal measurements:

Bony and dental structures of the palate are often preserved even in the face of serious bodily damage at or following death (Sumati et al., 2012).

In the present study, all measurements of the palate revealed significantly higher male measurements. It demonstrates the usefulness of these variables in evaluating sexual dimorphism as demonstrated by various studies (Moreira et al., 2008; Sumati et al., 2012; Lima et al., 2012).

Lima et al (2012) study demonstrated a significant sexual difference for IF- RGPF (4.3±0.3 in males versus 4.2±0.3 in females) and IF- LGPF measurements (4.4 ±0.3 in males versus 4.2±0.4 in females). Yet, these measurements, in Brazilian population, were higher than the present study which could be explained by the racial differences.

In the current work, the formula that was calculated using the four palatal measurements presented an accuracy of 94.1%, while using the three measurements; IF-RGPF, IF-LGPF and LGPF-RGPF in another formula had an accuracy of 93.1%. This reveals the usefulness of the palate as a fragmented bone in sex determination even if it is completely separated from the rest of the skull base.

In contrast to the present data, Lima et al., 2012 did not demonstrate significant sexual dimorphism of RGPF-LGPF distance. Moreover, the distance B-IF revealed the highest sexual dimorphism (p=0.004) and the least was IF- RGPF (p=0.02). They also revealed an accuracy of 65% in sex determination using palatal measurement. Nevertheless, they did not use LGPF-RGPF in their formula as it showed insignificant sexual difference. This may be attributed to the difference in population samples.

The present study verified the sexual dimorphism of the palatal measurements. So, sexing of skulls of Egyptians could be predicted from a fragment of the skull bone with intact hard palate. This is in accordance with various studies from the Egyptians (Gad El-hak and El Tahry, 2000) and other populations, in spite of different parameters used in these researches (Bigoni et al., 2010, Lima et al. 2012).

Foramen magnum (FM) measurements:

The FM constitutes an important landmark of the skull base and is of particular concern in anthropology, anatomy, forensic medicine and other medical fields (Uthman et al., 2012).

The basal region of the occipital bone is prone to be preserved owing to the abundant soft tissue cover and the well-protected anatomical position (Gapert et al., 2009).

The present study demonstrated that, the mean values of FMSD and FMTD were significantly higher in males than in females. This coincides with various studies; Murshed et al (2003) and Uthman et al (2012) who used CT scanning and Suazo et al (2009) and Jain et al (2015) studies on dry skull. These four studies from different populations: Turkish, Iraqi, Indian and Brazilian populations, respectively showed FMSD and FMTD measurements significantly larger in males than in females. However, their measurements were higher than those demonstrated in the present study. This could be attributed to different factors such as racial, genetic and environmental factors.

In agreement with the current study, Uthman et al (2012) stated that FMC and FMA mean values were significantly higher in males than in females. They also reported that FMC was the best discriminator of sex using FM parameters (Wilks' Lambda = 0.781), followed by FMA (Wilks' Lambda = 0.799), versus FMC (Wilks' Lambda= 0.479) and FMA (Wilks' Lambda= 0.494) in the current study.

Discriminant function analysis was developed using all measured parameters of the foramen magnum and its accuracy was the least (89.2%) compared to the other used parameters in the present study. It could be explained by the fact that, the foramen magnum reaches its adult size early in childhood and is therefore unlikely to respond significantly to secondary sexual changes.

Several authors have emphasized the value of foramen magnum and worked on various parameters for evaluation of its accuracy in sex determination. Uysal et al (2005) revealed sex determination with an accuracy rate of 81%. In Uthman et al study (2012), the accuracy was lesser (69.3%). On the other hand, Suazo et al (2009) showed that all linear dimensions of foramen magnum tested had a low discriminating power, and the variables analyzed (FMSD and FMTD) were able to correctly classify only 66.5% of the examined cases.

In contrast to the present study, Kanchan et al (2013) and Gruber et al (2009) did not find any sexual dimorphism in the diameters of FM in dry skulls from Central Europe. Yet, Kanchan et al (2013) observed that the area of the FM was significantly different between males and females. They also concluded that there is a limited statistically significant expression of sexual dimorphism in the foramen magnum region. Likewise, several studies declared that the measurements of FM are not reliable in sexing of skulls (Sayee et al. 1987; Deshmukh and Devershi, 2006 ; Raghavendra et al., 2012)

Mastoid notch measurements

In agreement with the present results, Francesquini et al (2007), in Brazil, concluded that, the studied anthropometric measurements; IF-RMN, IF-LMN and LMN-RMN showed significant sexual dimorphism. However, all measurements in that study were higher than our results. They constructed a regression analysis model, yet, it included only two measured variables from the stepwise method; RMN-LMN and B-IF. The other variables of skull base were excluded due to their low significance. The discriminant function was determined with an accuracy of 79.9%.

In contrast, results of the present study revealed RMN-LMN as the least sexual discriminator of these measurements. Regarding the parameters that related to the mastoid notch, the regression equation accuracy was 90.2%.

The differences in accuracy in various researches could be attributed to the variations in the population of the studied samples, methodology, environmental factors and statistical analysis employed.

To the best of our knowledge, there has been no previous study concerning all these parameters together as used in the present study among Egyptians .

To develop specific formulae for sex determination, all parameters were involved in stepwise discriminant function analysis to determine the optimal combination of variables for sex determination in Egyptians.

The discriminant function analysis of all the variables used in the present study provided the highest accuracy of sex determination. Regression equation for sex determination using all measured parameters of skull base gave an accuracy of 96.1%, signifying the utility of the complete skull base measurements in sex determination.

Conclusion

Applying stepwise regression analysis for the measured parameters revealed that the skull base is a good basis for sex determination in adult Egyptians, with outstanding accuracy in case of complete and well preserved bone. Moreover, in cases of destruction of the skull base with only fragments remaining, reasonable degrees of accuracy were achieved. Studies on larger sample and more measurable variables are required to further confirm and support the results of the current work.

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الملخص العربي

تقييم دور معلمات قاعده الجمجمة في التعرف علي الجنس باستخدام القياسات الانثروبولوجيه بين عينه من المصريين

عبير شتا و هايدي جاهد[1] و ايهاب الزواوي[2]

يعد تحديد الجنس عنصرا اساسيا في الفحص الانثروبولوجي والقضائي. كما يعد قاع الجمجمة ذو مقاومه عالية لمختلف الظروف البيئية . لذلك استهدفت الدراسة الحالية فحص مدي دقه استخدام بعض القياسات الانثروبولوجيه ودراسة امكانيه الاعتداد بها للاستعراف عن الجنس بفحص عظام الجمجمة مجهولة الهوية.

وقد تم فحص ثمانين من الجماجم لمصريين بالغين باستخدام بعض القياسات الانثروبولوجيه التأليه:

قياسات الفك :المسافة بين الثقب القاطع و الثقب الحنكى الاكبر (يمين و يسار) والمسافة بين الثقب الحنكى الاكبر الأيمن والايسر و كذلك المسافة بين الثقب القاطع و نقطة القاعدة. وقياسات الحز الخشائي : المسافة بين الثقب القاطع و الحز الخشائي (يمين و يسار) و المسافة بين الحز الخشائي الأيمن والايسر .وقياسات الثقب الكبير: القطر السهمي للثقب الكبير و القطر المستعرض للثقب الكبير و مساحة الثقب الكبير و محيطه الدائري .

النتائج: وقد اظهرت الدراسة اختلاف ذو دلاله إحصائية لجميع القياسات الانثروبيولوجيه المستخدمة بين الاناث والذكور . وقد اسفرت الدراسة ايضا ان اعلي دقه للمعادلات الناتجة كانت الخاصة بالقياسات الحنكية (٩٤,١ %) يليها المعادلة المشتملة علي قياسات الحز الخشائي ٩٠,٢ % بينما كانت المعادلة الخاصة بقياسات الثقب الكبير هي الاقل في الدقة ٨٩,٢ %بينما كانت المعادلة المشتملة علي جميع قياسات قاع الجمجمة المستخدمة كانت هي الأعلى علي الاطلاق٩٦,١ %. ويستنتج من ذلك ان قاع الجمجمه يعد اساسا جيدا لتحديد الجنس بين المصريين البالغين.

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