Egyptian Journal of Forensic Sciences (2012) 2, 81–88

Contents lists available at SciVerse ScienceDirect

Egyptian Journal of Forensic Sciences

journal homepage: www.ejfs.org

ORIGINAL ARTICLE

Adult sex identification using digital radiographs of the proximal epiphysis of the femur at Suez Canal University Hospital in Ismailia, Egypt

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Received 2 January 2012; revised 10 March 2012; accepted 17 March 2012
Available online 8 September 2012

KEYWORDS

Digital radiography;
Sex identification;
Femur epiphysis;
Forensic anthropology

Abstract Sex identification is an important step toward establishing identity from unknown human remains. The study was performed to test accuracy of sex identification using digital radiography of proximal epiphysis of femur among known cross-sectional population at Suez Canal region. Seventy-two radiographs of femur of living non-pathologic individuals were included. Original sample was divided into two equal groups of females and males (24 each). Test sample (group 3) included 24 radiographs. Six landmarks (A–F) were selected and 15 distances were generated representing all possible combinations of these landmarks. A is a point on the shaft under lower end of lesser trochanter, B is a point on the shaft. A–B is perpendicular to the axis of the shaft. C and D are points on femoral neck. E and F are points on femoral head. In original sample, mean and standard deviation were calculated, then accuracy, sensitivity and specificity. In test sample, the 15 distances were used to identify sex of that radiograph according to the cut-off value made from original sample.

In original sample, CE and EF were most distinctive measurements for sexual dimorphism. AB and CF showed least accuracy (66.7% and 70.8%). BF, CE and EF were most sensitive for identification.

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Peer review under responsibility of Forensic Medicine Authority.

ELSEVIER Production and hosting by Elsevier

http://dx.doi.org/10.1016/j.ejfs.2012.03.001

In test sample, CE and EF showed 100% accuracy. AB and CF showed least accuracy (54.2% and 62.5%). AC, AE, BC, BE, BF, CE and EF were most sensitive for identification.

Digital radiography of femur can be an alternative measurement used in sex identification in Egyptian population.

1. Introduction

The identity of the dead is an essential part of post-mortem examination.[1] The need for identification may arise in cases of homicide, suicide, bomb blasts, terrorist's attacks, wars, air plane crashes, road and train accidents, as well as natural mass disasters like tsunami, floods, and earth quakes.[2] One of the principal biological traits to be established from skeletal remains is the sex of the individual.[3]

The accuracy of sex identification from unknown skeleton remains depends on the degree of sexual dimorphism exhibited by the skeleton.[4] In humans most differences between the sexes do not become apparent until after puberty,[5] usually in the 15–18 year period.[1]

Sex identification is more reliable if the complete skeleton is available, but in forensic cases human skeletal remains are often incomplete or damaged. [4]

The ability to determine sex from isolated and fragmented bones is of particular relevance and importance especially in cases where criminals mutilate their victims in attempt to make their identification difficult [6] and also in mass disasters as bones are usually commingled, charred and fragmented.[7]

The pelvis and skull exhibiting prominent sexually dimorphic characters can predict sex with fairly high accuracy. But in their absence the task of the medico-legal expert becomes quite difficult especially in cases where isolated or fragmentary bones are recovered. Recently, there is a greater trust toward morphological and metrical analysis of other postcranial bones especially the long bones for the purpose of determining sex.[8]

The femur is the longest and heaviest bone in the human skeleton. Because of its strength and density it is frequently recovered in forensic and archeological settings.[7]

If the existing skeletal elements are partially exposed as in semi- decomposed and charred remains, special techniques, like maceration, are needed in order to carry out the standard osteometric techniques. In these cases image-processing techniques like radiography or computed tomography could be of great assistance.[7] The use of radiography and other medical imaging specialties to aid in investigating civil and criminal matters has increased as investigators realize how radiologic technology can yield information that otherwise is unavailable.[9] Recently digital radiographs have been employed in sex assessment of the femur with satisfying results.[10]

The advantage of a digital image is that it can be manipulated and can be computer processed.[11]

Population differences have been demonstrated in both the metric and morphological manifestations of sexual dimorphism .[12] Therefore, anthropometric standards have to be constantly renewed and to be population-specific.[13]

The purpose of this cross-sectional descriptive study is to study the accuracy of sex identification on the basis of digital radiography of the proximal epiphysis of the femur among a known cross-sectional population at Suez Canal region in Egypt. Since the validity of discriminant function equation in sex determination is population specific, the aim of the present study is to derive similar equations for the femur of Egyptians.

2. Materials and methods

This is a cross-sectional descriptive study involving 72 radiographs of the proximal epiphysis of the femur of living un-fractured and non-pathologic volunteers from patients attending the Suez Canal University Hospital in Ismailia, Egypt. The volunteers were patients who had to receive pelvic-abdominal X-ray examination for other health problems. The study was reviewed by the Research Ethics Committee of the University and a written informed consent for participation was taken from each research subject.

The 72 radiographs were divided into original sample (48 radiographs) and test sample (24 radiographs).

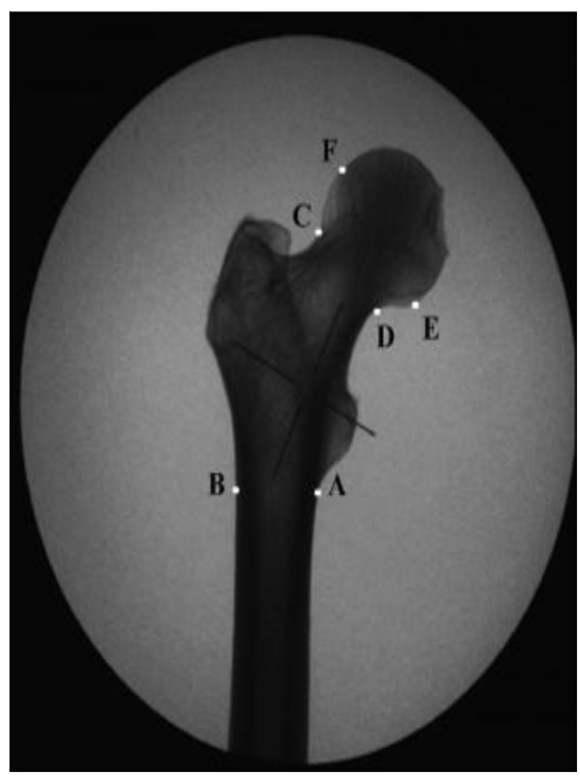

Figure 1 Landmarks selected on the radiograph of the proximal femoral epiphysis[7]: Quoted from: Kranioti E, Vorniotakis N, Galiatsou C, İşcan M, Michalodimitrakis M. Sex identification and software development using digital femoral head radiographs. Forensic Sci Int 2009;189(1):113.e1–113.e7[7].

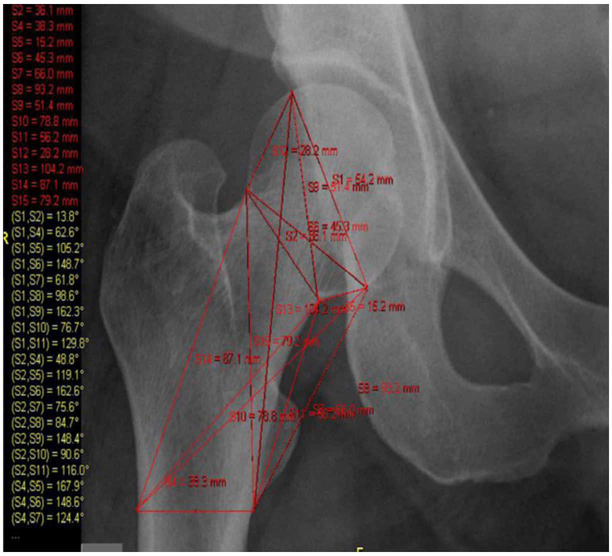

Figure 2 Landmarks selected on the radiograph of the proximal femoral epiphysis: Quoted from the digital radiography workstation used in the study.

The original sample was divided into two groups. Group (1) included 24 radiographs of male individuals (mean age = 39.83 ± 10.06 years and range was 22–62 years) and group (2) included 24 radiographs of female individuals (mean age = 41.38 ± 11.61 years and range was 23–60 years).

The test sample included (group 3) 24 radiographs of the proximal epiphysis of the femur that were randomly selected and were not a part of the original reference series; in which the sex was known only to the radiologist but not to the researcher.

Group (3) included 10 male individuals (mean age = 40.50 ± 13.88 years and range was 23–64 years) and 14 female individuals (mean age = 41.57 ± 10.91 years and range was 27–58 years).

Antero-posterior view of the proximal epiphysis of the femur using a digital X-ray machine was obtained and computed.

The radiographs were obtained while patient was supine with focus film distance equals 100 cm. Six landmarks (A–F) were selected in the radiograph and 15 distances were generated representing all possible combinations of these landmarks.[7] Then the 15 generated distances were calculated (computer-based). The selected landmarks are shown in (Fig. 1) and described as follows:

Where (in Figs. 1 and 2):

- Point (A): on the shaft under the lower end of the lesser trochanter.
- Point (B): on the shaft so that the distance A–B (representing the sub-trochanteric diameter in the radiograph) is perpendicular to the axis of the shaft.
- Points (C and D): selected on the femoral neck where the curvature changes forming the head so that the distance from C to D is the minimum neck diameter.
- Points (E and F): on the femoral head, so that the distance E–F is the maximum femoral diameter parallel to C–D.

In the original sample, statistical analysis of each of the fifteen variables including mean and standard deviation were calculated. As a result, standard parameters (including mean and standard deviation) for sex identification using digital radiography of the femoral head among a known cross-sectional population were obtained for each of the fifteen variables for both males & females.

Unpaired student *t*-test was used to compare between the two groups of the original sample (males and females). Cut-off level (meaning that the measurements equal to or higher than that level were of a male while those less than it were of a female) was determined for each variable using the Receiver Operating Characteristic (ROC) curve, a graph of sensitivity (*y*-axis) versus 1 – specificity (*x*-axis).The goal of a ROC curve analysis was to determine the cut-off value. Then accuracy, sensitivity and specificity of the 15 femoral dimensions of the original sample were obtained, where:

$$\text{Accuracy} = (TP + TN/TP + TN + FP + FN) \times 100$$

Where:

- TP: true positive (meaning that the variable classified the radiograph to be of a male and the individual was actually a male)
- TN: true negative (meaning that the variable classified the radiograph to be of a female and the individual was actually a female)
- FP: false positive (meaning that the variable classified the radiograph to be of a male and the individual was actually a female)
- FN: false negative (meaning that the variable classified the radiograph to be of a female and the individual was actually a male)
- Sensitivity = True positive rate

  $(TP/TP + FN) \times 100$

- Specificity = True negative rate

  $(TN/TN + FP) \times 100$

Univariate discriminant analysis was performed to indicate the efficiency of each variable for sex discrimination.

Data of the study were transferred into a basic data sheet as numbers and percentages and evaluated statistically using the SPSS version 16 (SPSS Inc., Chicago, IL, USA), and MedCalc statistical program version 11.

In the test sample, each of the 15 distances was used to identify the sex of that radiograph according to the cut-off value made from the original sample including groups 1 & 2. Then, each distance was evaluated for its accuracy, sensitivity and specificity.

A comparison between the accuracy, sensitivity and specificity of both original and test samples was done to test the reliability of the usage of the cut-off value in sex identification of the proximal epiphysis of the femur using digital radiography. Study results were described in tables and figures.

3. Results

Table 1 shows descriptive statistical analysis of each of the 15 femoral dimensions of the original sample for both sexes,

Table 1 Descriptive statistical analysis of the femoral dimensions of the original sample.

Variable	Male (n = 24) Mean ± SD (mm)	Female (n = 24) Mean ± SD (mm)	T-score	P-value
AB	41.60 ± 2.31	40.22 ± 2.34	2.06	0.045[a]
AC	88.30 ± 5.25	77.48 ± 3.57	8.34	< 0.001[b]
AD	62.92 ± 5.52	54.98 ± 2.15	6.56	< 0.001[b]
AE	74.58 ± 6.83	64.83 ± 3.43	6.24	< 0.001[b]
AF	109.33 ± 7.97	96.99 ± 5.29	6.32	< 0.001[b]
BC	94.53 ± 5.98	85.08 ± 3.18	6.83	< 0.001[b]
BD	87.21 ± 5.62	79.07 ± 2.35	6.54	< 0.001[b]
BE	103.23 ± 6.65	92.53 ± 3.38	7.02	< 0.001[b]
BF	118.15 ± 8.27	106.11 ± 4.26	6.34	< 0.001[b]
CD	41.88 ± 2.69	36.14 ± 2.86	7.15	< 0.001[b]
CE	54.13 ± 2.39	45.23 ± 2.74	11.99	< 0.001[b]
CF	24.33 ± 6.95	21.68 ± 3.38	1.67	0.101
DE	18.25 ± 2.48	14.46 ± 2.46	5.32	< 0.001[b]
DF	54.10 ± 3.99	48.40 ± 3.51	5.25	< 0.001[b]
EF	59.12 ± 2.45	51.98 ± 2.98	9.08	< 0.001[b]

[a] P-value was significant < 0.05.
[b] P-value was significant < 0.001.

Table 2 The cut-off value, accuracy, sensitivity and specificity of the femoral dimensions of the original sample.

Variable	Cut-off (mm)	Accuracy (%)	Sensitivity (%)	Specificity (%)
AB	40.5	66.7 ↓	75	58.3
AC	82.8	91.2	83.3	100
AD	57.3	87.5	83.3	91.7
AE	66.4	83.3	83.3	83.3
AF	99.9	83.3	91.7	75
BC	88.3	91.2	83.3	100
BD	82.1	87.5	75	100
BE	97.3	87.5	75	100
BF	106	79.2	100	58.3
CD	40.2	91.2	83.3	100
CE	48.7	100 ↑	100	100
CF	22	70.8 ↓	66.7	75
DE	15.9	79.2	83.3	75
DF	52.9	79.2	58.3	100
EF	55.6	100 ↑	100	100

including mean (in mm), standard deviation (SD), T values and their significance (P).

All except the distance CF are found to be highly significantly different between the sexes at the level of $p < 0.001$, apart from the distance AB which is found significantly different at the level of $p < 0.05$.

These results demonstrate the existence of a strong sexual dimorphism in the analyzed original sample and presuppose that the variables apart from the distances CF and AB are useful in evaluating morphological differences between sexes.

Table 2 shows the efficiency of sex determination from each of the 15 femoral dimensions of the original sample using the ROC-curve to detect their cut-off values. The measurements equal to or higher than the cut-off level indicates a male individual while lower levels indicates a female individual.

Regarding the original sample; sensitivity, specificity and accuracy for each of the 15 femoral dimensions are represented.

The distances CE and EF are the most distinctive measurements for sexual dimorphism with the highest accuracy (100%)

Table 3 Univariate discriminant analysis of femoral dimensions of the original sample.

Variable	Standardized coefficient*
AB	0.2908↓
AC	0.7760
AD	0.6951
AE	0.6772
AF	0.6818
BC	0.7095
BD	0.6943
BE	0.7191
BF	0.6830
CD	0.7256
CE	0.8704* ↑
CF	0.2397 ↓
DE	0.6170
DF	0.6121
EF	0.8011*

* Higher values indicated the variable was better for sex discrimination.

Table 4 The accuracy, sensitivity and specificity of the femoral dimensions of test sample.

Variable	Correct classification			Accuracy (%)	Sensitivity (%)	Specificity (%)
	Male	Female	Total			
AB	7/10	6/14	13/24	54.2 ↓	70	42.9
AC	10/10	12/14	22/24	91.2	100	85.7
AD	8/10	13/14	21/24	87.5	80	92.9
AE	10/10	12/14	22/24	91.2	100	85.7
AF	9/10	11/14	20/24	83.3	90	78.6
BC	10/10	12/14	22/24	91.2	100	85.7
BD	8/10	10/14	18/24	75	80	71.4
BE	10/10	12/14	22/24	91.2	100	85.7
BF	10/10	10/14	20/24	83.3	100	71.4
CD	9/10	12/14	21/24	87.5	90	85.7
CE	10/10	14/14	24/24	100 ↑	100	100
CF	6/10	9/14	15/24	62.5 ↓	60	64.3
DE	8/10	11/14	19/24	79.2	80	78.6
DF	8/10	9/14	17/24	70.1	80	64.3
EF	10/10	14/14	24/24	100 ↑	100	100

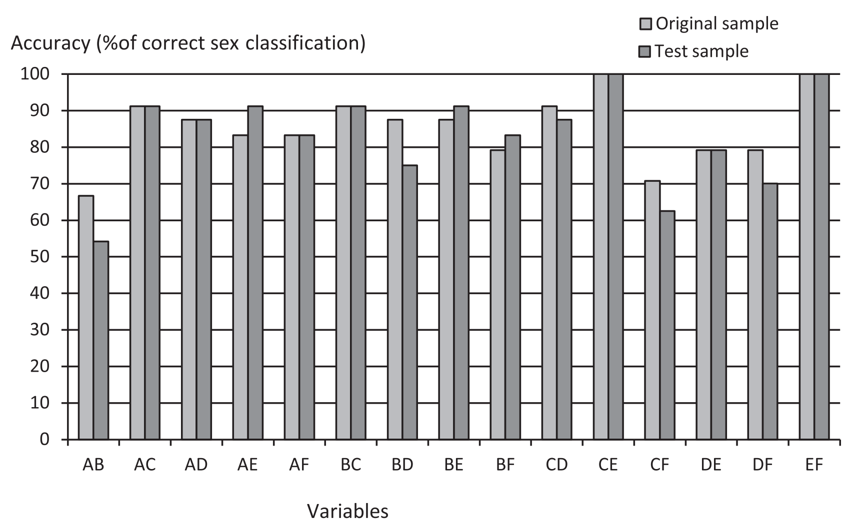

Figure 3 Comparison of the accuracy (% of correct sex classification) of the femoral dimensions between original and test samples.

followed by the distances AC, BC and CD with accuracy (91.2%).

The distances AB and CF show the least accuracy (66.7% and 70.8% respectively). The distances BF, CE and EF are the most sensitive variables for identification (100%). While the distances AC, BC, BD, BE, CD, CE, DF and EF are the most specific variables for identification (100%).

Table 3 shows the efficiency of sex determination for each of the 15 femoral dimensions of the original sample using univariate discriminant analysis. Standardized discriminant function coefficients indicates the relative contribution of each variable to sex discrimination. The distance CE made the greatest contribution followed by the distance EF, but the distance CF contributes the least.

Table 4 shows the classification accuracy, sensitivity and specificity of the test sample. The distances CE and EF show 24 correct classification out of 24 giving an accuracy rate of 100%, followed by the distances AC, AE, BC and BE showing 22 correct classification out of 24 giving an accuracy rate of 91.2%. The distances AB and CF show the least accuracy (54.2% and 62.5% respectively).

The distances AC, AE, BC, BE, BF, CE and EF are the most sensitive for identification (100%) while the distances CE and EF are the most specific for identification (100%).

Fig. 3 shows comparison between the accuracy (% of correct sex classification) of the femoral dimensions in original and test samples. The accuracy of the distances CE and EF are 100% in both original and test samples.

The accuracy of the distances AC, AD, AF, BC and DE are 91.2%, 87.5%, 83.3%, 91.2% and 79.2%, respectively, in both original and test samples.

The accuracy of the distances AB, BD, CD, CF and DF drops from 66.7% in original sample to 54.2% in test sample; 87.5–75%; 91.2–87.5%; 70.8–62.5% and 79.2–70.1%, respectively.

The accuracy of the distances AE, BE and BF increases from 83.3% in original sample to 91.2% in test sample; 87.5–91.2% and 79.2–83.3%, respectively.

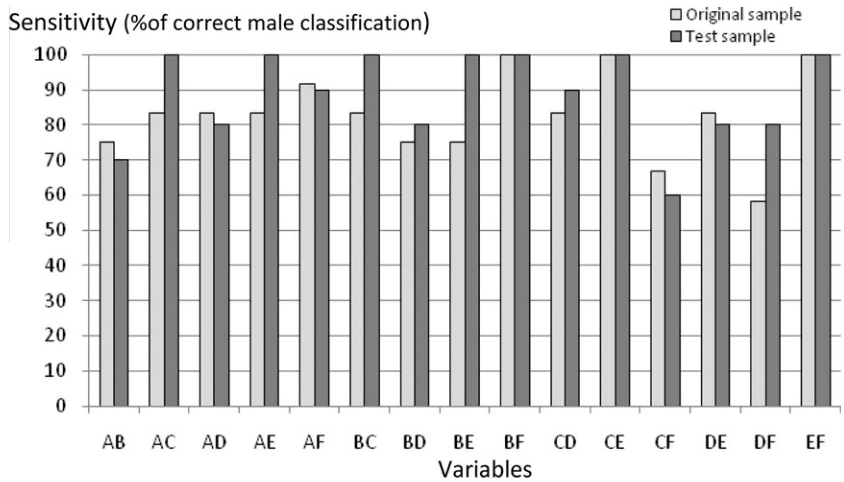

Figure 4 Comparison of the sensitivity (% of correct male classification) of the femoral dimensions between original and test samples.

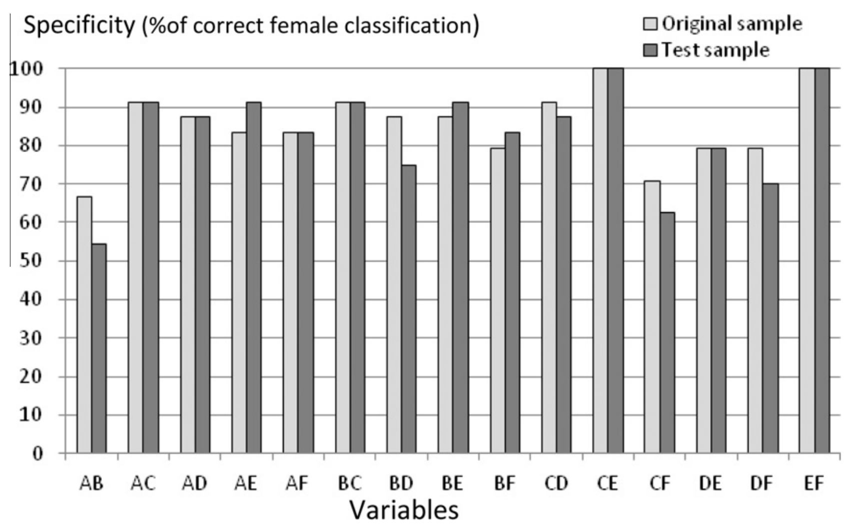

Figure 5 Comparison of the specificity (% of correct female classification) of the femoral dimensions between original and test samples.

Fig. 4 shows comparison of the sensitivity (% of correct male classification) of the femoral dimensions between original and test samples. Regarding the original sample; the distances BF, CE and EF are the most sensitive variables for identification (100%).

In the test sample, the distances AC, AE, BC, BE, BF, CE and EF are the most sensitive variables for identification (100%).

Fig. 5 shows comparison of the specificity (% of correct female classification) of the femoral dimensions between original and test samples. Regarding the original sample, the distances AC, BC, BD, BE, CD, CE, DF and EF are the most specific variables for identification (100%); while in the test sample, the distances CE and EF are the most specific variables for identification (100%).

4. Discussion

Determination of sex from human skeletal remains plays an important role in establishing identity and individuality.[14] The accuracy of sex determination from skeletal remains depends on the completeness of the remains and the degree of sexual dimorphism exhibited by the skeleton.[15]

Sexual dimorphism in the femur is enhanced by the effect of the difference in the relative axial skeleton weight of males and females. Therefore, there are combined effects of muscle action and body weight on sexual dimorphism of the proximal femur end.[16] One of the advantages of the measurements on the proximal end of femur is that they can be used on fragmented bone where the shaft and distal end are missing.[11]

Sex identification has been studied lately in the Egyptian population using deferent identification tools and different bones with interesting results forming a useful profile reference for sex identification for the Egyptians.[20–26]

The study results reveals that all anatomical distances except CF are significantly different between the sexes at the level of $p < 0.001$, apart from the distance AB which is found significantly different at the level of $p < 0.05$.

These results are similar with those of Kranioti (2009) [7] in that all but the distance CF are significantly different between the sexes at the level of $p < 0.001$ and that the distance DE is significantly different at the level of $p < 0.05$. these differences may be due to population differences and the different method used for data collection in kranioti's study (2009). Kranioti (2009) used radiographs of well-preserved adult femora of Cretan origin as an original sample but in the present study, we used radiographs of femora of living individuals from patients attending Suez canal University Hospital.

In the present study the mean values for all the 15 femoral dimensions of both males and females except for the distance DE for females are higher than those of Kranioti's values (2009).[7] These results can be because of population differences as Kranioti (2009) used 70 (36 males and 34 females). Also, Kranioti used a focus film at fixed distance of 54 cm from the plane of the radiographic table [7]; while in the present study the focus film distance was 100 cm (a standard radiographic technique in the diagnostic radiology department of Suez Canal University Hospital in Ismailia) and as the focus film distance increases, more magnification of the imaged object will occur, that explains the difference in the mean values of the femoral dimensions in both studies.

The results of the present study are similar with that of Kranioti [7] regarding the distances CE, EF and CD. These distances are proved to be the most distinctive measurements for sexual dimorphism with the highest accuracy (100%).

The distances CD and EF are projections of minimum neck diameter and maximum head diameter that are expected to differ between sexes, as they reflect the size of the articulation between femur and pelvis.

In the present study, the distance EF which is described as maximum femoral head diameter is the most distinctive measurement for sexual dimorphism with accuracy 100%.

These results are similar to that of Igbigbi and Msamati (2000) who carried out a study on sex determination from femoral head diameters in black Malawians. X-ray films of pelvis of adult black patients were studied and concluded that the vertical and transverse femoral head diameters for males were significantly greater than the corresponding values for females. This indicated that femoral head diameters could be used for sex differentiation among black Malawians.[17]

The results of the present study are different from those of Ashmawy (2004) who carried out a study on determination of sex from osteometric measurements of femur in Egyptians using six variables; maximum length, distal breadth, head diameter, anteroposterior diameter, transverse diameter, circumference, and concluded that the distal breadth was the most reliable variable for sex prediction with accuracy rate 99.1% followed by circumference with accuracy rate 97.6%. There is differences between the two results because the present study is carried on the proximal epiphysis of the femur only while the above study was done on the whole femur comparing the proximal end, shaft and distal end of femur as sex discriminators.[18]

In the present study, the distance AB which is described as sub-trochanteric transverse diameter and is found not useful in evaluating morphological differences between sexes. This result is in accordance with that of Özer and Katayama (2008) who carried out a study on osteometric sex determination using the femur in an ancient japanese population using eight measurements; maximum femur length, trochanter length, transverse diameter, maximal anteroposterior diameter, perimeter, Subtrochanteric transverse diameter, Subtrochanteric anteroposterior diameter and Condyle breadth. The authors concluded that the condyle breadth was the best discriminant factor, resulting in 93% level of accuracy for Japanese population.[19]

It must be stressed that even though the variables AB, CD and EF are described as sub-trochanteric transverse diameter, minimum neck and maximum head diameter, respectively, they do not represent the homonymous measurements on the actual (dry) bone, because X-ray measurements are two-dimensional and they cannot be compared to three-dimensional actual bone measurements without some error.[7]

Concerning the test sample, the present study reveals that the distances CE and EF show 24 correct classifications out of 24 giving an accuracy rate of 100%, followed by the distances AC, AE, BC and BE showing 22 correct classification out of 24 giving an accuracy rate of 91.2%. The distances AB and CF show the least accuracy (54.2% and 62.5% respectively).

Kranioti (2009) used a sample of 36 femoral radiographs as a test sample and sex was correctly identified in 32 cases out of 36, giving an accuracy rate of 88.9%, 20 out of 22 for males with accuracy rate of 90.9%, 12 out of 14 for females with accuracy rate of 85.7%.[7]

Regarding the original sample in the present study, the distances BF, CE and EF are the most sensitive variables for identification (100%). The distances AC, BC, BD, BE, CD, CE, DF and EF are the most specific variables for identification (100%).

In the test sample, the distances AC, AE, BC, BE, BF, CE and EF are the most sensitive variables for identification (100%). The distances CE and EF are the most specific variables for identification (100%).

Therefore, males present the higher classification accuracy than females in the test sample, contrary to the original sample where females were more accurately classified. Perhaps this is due to the disproportionate number between males and females in the test sample (10 males and 14 females).

5. Conclusion

The present study concluded that digital radiography of the proximal epiphysis of the femur using the parameters previously mentioned in the study can be an alternative and accurate measurement technique that can be used in adult sex identification which can be applied in cases of semi-fleshed or charred bodies, such as ones recovered from mass disasters or crime scenes, when maceration is not an option.

But we did not aim to propose a method that would replace the osteometric techniques but to offer an alternative method applicable in certain circumstances in which osteometry cannot be applied; acknowledging that the method of choice in forensic anthropology is always case driven.

Population specific aspects of sexual dimorphism must be taken into consideration when using this method, as is the case in classical methods and so, the results of this study could not be applied on different population with the same accuracy.

we recommend further studies to be done specifically on the proximal epiphysis of the femur and to use either the right or the left femur as they show different measurements in the same individual. Also to do further studies using the parameters mentioned in this study on greater sector of the Egyptian population to get a radiometric standard specific for the Egyptian population.

We recommend increasing the application of digital radiography in sex identification in forensic cases.

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