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Adult Sex Identification Using Three-Dimensional Computed Tomography (3D-CT) of the Pelvis: A Study Among a Sample of the Egyptian Population

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Abstract

Sex identification of unknown human skeletal remains is of great importance in establishing identity and individuality. In adults, the hip bone is the most reliable sex indicator because of its sexual dimorphism. Each population should have its own specific standards of identification. The objective of this study is to develop a logistic regression formula for adult sex identification using three-dimensional computed tomography (3D-CT) of the pelvis and to perform an assessment of its validity in sex determination among a sample of the Egyptian population in the Suez Canal region.

141 pelvic-abdominal CT images (free of any pelvic orthopaedic disorder) were included; they

Keywords: Forensic anthropology, Sex identification, 3D-CT pelvic images, Metric method, Phenice trait

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were reconstructed to produce 3D-CT pelvic images which were divided into a calibration group (47 male and 47 female) and a test group (47 CT images the sex of which was unknown to the observers). Twenty radiometric variables were measured for the calibration group. A logit response formula for sex prediction was developed and applied on the test group for sex prediction. The logit response formula for the test sample showed sensitivity, specificity, and an overall accuracy of 100%. The proposed method represents a quick and reliable metric method in establishing sex from a CT image of the pelvis bone.

الاستعراف على الجنس عند البالغين باستخدام الأشعة المقطعية ثلاثية الأبعاد المحوسبة (3D-CT) للحوض: دراسة على عينة من المجتمع المصري

المستخلص

يعتبر الاستعراف على الجنس بعد الوفاة خطوة مهمة نحو معرفة الهوية الخاصة بالبقايا الإنسانية المجهولة. وتتمتع دقة الاستعراف على الجنس بعد الوفاة للبالغين من بقايا الهيكل العظمي على الفروقات الجنسية للهيكل العظمي بين الذكور والإناث. وتتميز عظام الحوض بالاختلافات البارزة بين الجنسين خاصة للبالغين. وتختلف معايير الاستعراف على نوع الجنس للبالغين على

حسب الاختلافات الاقليمية والمناخية للانسان، لذلك لابد من توفر معايير مرجعية خاصة بكل منطقة سكانية.

تم اجراء هذا البحث بهدف مقارنة دقة استخدام طريقة قياسية و صفات غير قياسية للحوض باستخدام الأشعة المقطعية ثلاثية الأبعاد في الاستعراف على نوع الجنس لمرضى بالغين مترددين على قسم الأشعة التشخيصية بمستشفى جامعة قناة السويس - التي تستقبل مرضى من منطقة قناة السويس - لإجراء أشعة مقطعية على البطن والحوض. بلغ عدد المشاركين في الدراسة 141 مريضاً، تم تقسيمهم إلى ثلاث مجموعات (المجموعة الأولى تشمل 47 من الذكور، والمجموعة الثانية تشمل 47 من الإناث، والمجموعة الثالثة تشمل 47 وهي مجموعة عشوائية من المرضى 25 من الذكور و 22 من الإناث وكان نوع الجنس لها غير معروف للباحث ولكن معروف لطبيب الأشعة، وتمثل المجموعة الأولى والثانية العينة الأصلية وتمثل المجموعة الثالثة العينة الاختيارية).

تم إجراء الأشعة المقطعية على الحوض للمشاركين في الدراسة ثم إعادة تحويلها إلى صورة ثلاثية الأبعاد. وتم أخذ بعض القياسات على الأشعة المقطعية ثلاثية الأبعاد لكل المشاركين الذين يمثلون العينة الأصلية وتم استخراج معادلة من أفضل القياسات التي استخدمت في الاستعراف على الجنس للبالغين.

تم تطبيق تلك المعادلة - التي تمثل الطريقة القياسية في الاستعراف على نوع الجنس للبالغين باستخدام الأشعة المقطعية ثلاثية الأبعاد على الحوض- على العينة الاختيارية و أظهرت معدل دقة 100% في الاستعراف على نوع الجنس و 100% حساسية في الاستعراف على الذكور و 100% تخصصية في الاستعراف على الإناث. وتم تطبيق صفات فينيس الغير قياسية على العينة الاختيارية وأظهرت الدراسة أن صفة فينيس (القوس الأمامي) (Ventral arc) تمثل معدل دقة في الاستعراف على نوع الجنس أعلى من صفة فينيس (التقعر تحت العانة) (Subpubic concavity) يليهما صفة فينيس (بروز عظمي على الجانب الأنسي من الفرع الاسكي العاني) (ridge of elevated bone on the medial aspect of the ischiopubic ramus)

وبذلك نستنتج أن تلك الطريقة القياسية حين مقارنتها بصفات فينيس الغير قياسية للحوض منفصلة في الاستعراف على نوع الجنس للبالغين قد أظهرت أعلى معدل دقة وأعلى تخصصية في الاستعراف على الإناث وأعلى حساسية في الاستعراف على الذكور. ونستنتج أيضاً أنه يمكن استخدام الأشعة المقطعية ثلاثية الأبعاد التي تمتاز بأنه يُمكن أخذ القياسات ومعالجتها بواسطة الحاسوب، كما أن البيانات المخزنة يمكن تنسيقها لإجراء تحاليل هندسية محسوبة وخصوصاً في الحالات التي تتطلب تقنيات خاصة للاستعراف على الجنس باستخدام القياسات العظمية المختلفة خاصة عندما تكون البقايا الهيكلية مغطاة جزئياً بالأنسجة الرخوة

التبقيّة. وتلك الطريقة القياسية المستخدمة في الدراسة يمكن الاعتماد عليها وقد تمثل بديلاً سريعاً وموضوعياً عن صفات فينيس التقليدية الغير قياسية.

الكلمات المفتاحية: علم الإنسان الجنائي، الاستعراف على الجنس، الأشعة المقطعية ثلاثية الأبعاد، الطريقة القياسية، صفات فينيس

1. Introduction

Sex identification of human skeletal remains is an important issue in forensic medicine. The probability of achieving a high level of accuracy of sex identification is related to the skeletal components analyzed and the ability of the techniques employed to describe shape and size differences among the sexes [1]. The hip bone is one of the most reliable sex indicators because it is a highly dimorphic bone, particularly in adult individuals [1]. In humans, most differences between the sexes do not become apparent until after puberty [2]. Numerous techniques of sex identification have been proposed, based either on visual assessment or recording of linear metric variables [1].

Visual or morphological techniques of sex identification of the pelvis often focus on Phenice-defined traits. In the female these are: a bony ridge ('ventral arc') running down the ventral surface from the pubic crest, a concavity of the lower margin of the inferior pubic ramus immediately lateral to the lower border of the symphysis, and a ridge of elevated bone on the medial aspect of the ischiopubic ramus immediately lateral to the symphysis [3].

Although visual or morphological techniques are a quick means of assessment, they have been largely criticized because they are highly subjective, requiring an experienced observer and are often unreliable. Without quantifiable data, there are obvious implications for the certainty with which, even the most highly trained anthropologists can support their assessments in court [1, 4].

Attempts have been made to "metricize" or quantify nonmetric traits with success in regions of the body other than the pelvis. By "metricizing" specific nonmetric traits in the pelvis, more objective data for sex identification could be possible. Other pelvic indices such as those used in clinical medicine can be used to supplement measurements in the anthropological literature. Medical fields like obstetrics and gynaecology regularly use metric measurements of the pelvis in their assessment and treatment of patients [4]. Numerous attempts for metric classification have been published but often require complex or time-



consuming measurements [4].

Human remains recovered in mass disasters consist of commingled and charred body parts with fragmented and partially exposed skeletal elements. In these cases, applying standard osteometric methods for the reconstruction of the biological profile that will potentially lead to positive identification will require a special technique like maceration. However, the amount of work and the time limitations in severe mass disasters preclude the maceration of the recovered remains [5]. An alternative way to study such semi-fleshed remains is the application of image processing techniques such as computed tomography allowing the visualization of the bones independently of the state of the remains (semi-fleshed, mummified, or charred) [5].

Medical imaging modalities, like computed tomography (CT), are providing unique data sources for examining human variation in a more quantitative manner and extending osteological resources to researchers beyond actual contact. CT's speed and its ability to capture high-level detail of bony features without having to remove soft tissue makes it an ideal tool to save time and to protect remains from physical manipulation [4]. Three-Dimensional Computed Tomography (3D-CT) images of the pelvis reproduce complex curved features, and the stored data format facilitates computerized geometrical analyses allowing for the archiving of case-related data that can be used long after the remains have been buried [4, 6].

Population differences have been demonstrated in both the metric and morphological manifestations of sexual dimorphism. Therefore, each population should have specific standards to optimize the accuracy of identification [7-9].

The purpose of this cross-sectional comparative study was to compare between the validity of a metric method (based on a combination of obstetric measurements and metricized non-metric traits in the pelvis) and the traditionally nonmetric Phenice-defined traits in adult sex identification using 3D-CT of the pelvis among the Suez Canal regional population.

2. Materials and Methods

This cross-sectional comparative study involved 141 pelvic CT images of un-fractured and non-pathologic living individuals referred to the diagnostic radiology department of Suez Canal University Hospital in Ismailia to undergo pelvi-abdominal CT scans. The study was reviewed by the Research Ethics Committee of the Suez Canal University, and a written informed consent was obtained from

each participant. The 141 3D-CT pelvic images were divided into an original sample and a test sample. The original sample was divided into 2 groups: group 1 included 47 3D-CT pelvic images of male individuals aged 21-63 years (mean age = 44.7 ± 10.6 years) and group 2 included 47 3D-CT pelvic images of female individuals aged 21-63 years (mean age = 45.10 ± 11.10 years). The test sample represented group 3, which included 47 3D-CT pelvic images that were randomly selected and were not a part of the original sample. The sex of each image in group 3 was known to the radiologist but not to the researcher; group 3 consisted of 25 male individuals aged 22-69 years (mean age = 42.4 ± 12.6 years) and 22 female individuals aged 24-63 years (mean age = 44.2 ± 10.8 years). The pelvic CT axial images were reconstructed to produce 3D-CT pelvic images that were presented as DICOM (Digital Imaging and Communications in Medicine) images. These images were measured using DICOM viewer computer software.

Concerning the original sample, which included groups 1 and 2, traditional and novel measurements were selected to be used in establishing the sex of the pelvis. The measurements were chosen to meet one or more of the following criteria: a commonly used measurement, a "metricized" version of a traditional nonmetric trait, or medical indices not traditionally applied to anthropology. 20 variables (distances, angles, and anthropological and medical indices) were calculated using a computer software package.

These variables were as follows [4]:

1. Anterior breadth of the sacrum: Maximum transverse projection of the sacrum at the anterior projection of the auricular surface.
2. Anterior height of the sacrum: The distance between sacral promontory and sacral/coccyx border - where sacral promontory is the most superior, anterior point on the mid-sagittal plane and sacral/coccyx border is the mid-sagittal point on sacral/ coccyx border.
3. Anteroposterior pelvic outlet diameter: The distance from coccyx to inferior pubic symphysis - where inferior pubic symphysis is the point at the most inferior portion between both pubic symphyses.
4. Transverse pelvic outlet: Widest medio-lateral points on the plane created by the coccyx and the most inferior point of the pubic symphysis.
5. Transverse pelvic inlet: Widest medio-lateral points on the plane created by the sacral promontory and the most superior point of the pubic symphysis.



6. Conjugate pelvic inlet diameter: The distance between sacral promontory and superior pubic symphysis – where superior pubic symphysis is the point at the most superior portion between both pubic symphyses.
7. Pubic symphysis length: The distance between the most superior and inferior points of the pubic symphysis (taken at left side).
8. Sub pubic angle: Angle formed at pubic arch by the convergence of the inferior rami of the ischium and pubis on either side.
9. Transverse diameter of sacral segment: The distance between the two most lateral points of the first sacral segment.
10. Ischium-pubic index: The pubic length (X 100) divided by the ischial length

Bilateral measurements

1. Iliac breadth: The distance from the anterior to the posterior superior iliac spine.
2. Ischium length: The distance from the acetabulum junction to the deepest point on the ischial tuberosity - where acetabulum junction is the junction of ilium, pubis, and ischium in the acetabulum.
3. Pubis length: The distance from the point on the acetabulum junction to the superior point on the pubic symphysis.
4. Width of greater sciatic notch: The angle between the iliac spine, deepest portion of the greater sciatic notch and the ischial spine - where ischial spine is the base of greater sciatic notch”
5. Innominate height: The distance from the most superior point on the iliac crest to the most inferior point on the ischial tuberosity.

Statistical analysis was done, and standard parameters (including mean and standard deviation) were calculated for each of the 20 variables for both males and females. Student's t test and Mann Whitney U test were used for comparison between groups 1 and 2 (males and females). Eta statistic was used to assess the strength of association between variables and sex identification. The number of variables having the greatest association and highest significance was narrowed to 4, which were entered in a binary logistic regression model to develop a formula for sex estimation. Receiver operating characteristics (ROC) curve and a graph of sensitivity (y-axis) versus 1 – specificity

(x-axis) were used to find out the best cut-off value (which means that the measurements equal to or higher than that level were of a male while those less than it were of a female) for all other variables that showed significant correlation with sex identification and did not enter the equation. Then accuracy, sensitivity, and specificity of the cut-off values were obtained.

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

Where

TP: true positive (meaning that the variable classified the 3D-CT pelvic image to be of a male and the individual was actually a male)

TN: true negative (meaning that the variable classified the 3D-CT pelvic image to be of a female and the individual was actually a female)

FP: false positive (meaning that the variable classified the 3D-CT pelvic image to be of a male and the individual was actually a female)

FN: false negative (meaning that the variable classified the 3D-CT pelvic image to be of a female and the individual was actually a male)

$$\text{Sensitivity (true positive rate)} = (\text{TP} / \text{TP} + \text{FN}) \times 100$$

$$\text{Specificity (true negative rate)} = (\text{TN} / \text{TN} + \text{FP}) \times 100$$

Concerning the test sample, the resultant formula was applied to identify the sex of the reconstructed 3D-CT pelvic images of the test sample. The validity of that metric method which was based on a combination of obstetric measurements and metricized non-metric traits in the pelvis in adult sex identification using reconstructed 3D-CT of the pelvis was then evaluated. The traditionally nonmetric Phenice-defined traits were used for sex identification of each reconstructed 3D pelvic image of the test sample and their validity was then evaluated.

Then, comparison was done between the validity of the metric method and that of the traditional Phenice-defined traits in adult sex identification. Statistical analysis was carried out using SPSS subroutines. Study results were described in tables and graphs.

3. Results

Table-1 shows descriptive statistics for the 20 radiometric variables of the original sample for both sexes including mean, standard deviation (SD), minimum-maxi-



mum (min-max), and their significance (*p values*).

All but antero-posterior pelvic outlet diameter, conjugate pelvic inlet diameter, and ischium-pubis index were

found to be highly significantly different between the sexes at the level of $p < 0.001$, apart from anterior breadth of sacrum which was found significantly different at the level

Table 1- Descriptive statistics for the 20 radiometric variables of the original sample for both sexes

Radiometric variables	Male		Female		<i>p</i> value
	Mean \pm SD	Min-Max	Mean \pm SD	Min-Max	
Anterior breadth of sacrum (mm)	113.9 \pm 3.2	108.1 – 119.7	111.8 \pm 11.1	105.9–119.3	0.005 ^{1*}
Anterior breadth of sacrum (mm)	117.3 \pm 7.4	103.1 – 129.1	110.9 \pm 5.5	99.8 – 119.7	<0.0012 [*]
Antero-posterior pelvic outlet diameter (mm)	106.1 \pm 7.1	93.2 – 119.7	106.5 \pm 5.4	95.5 – 114.1	0.7252
Conjugate pelvic inlet diameter (mm)	119.4 \pm 4.2	111.6 – 129.	119.8 \pm 2.9	114.2–124.6	0.5141
Pubis symphysis length (mm)	37.9 \pm 2.6	32.1 – 41.9	32.2 \pm 2.8	26.9 – 37.6	<0.0012 [*]
Sub-pubis angle ^o	75.8 \pm 3.7	67.9 – 83.1	107.4 \pm 2.8	102.3–113.7	<0.0012 [*]
Transverse diameter of sacral segment (mm)	54.5 \pm 3.2	48.7 – 59.4	48.7 \pm 2.9	42.7 – 54.1	<0.0011 [*]
Transverse pelvic inlet (mm)	121.9 \pm 4.3	114.6 – 129.7	130.3 \pm 4.5	121.3–139.1	<0.0011 [*]
Transverse pelvic outlet (mm)	104.1 \pm 2.2	99.9 – 5.7	114.6 \pm 2.2	110.7–119.6	<0.0011 [*]
Ischium – pubis index	97.3 \pm 4.7	86.3 – 107.7	99.1 \pm 4.6	88.5 – 109.9	0.0571
Iliac breadth – Rt (mm)	165.1 \pm 5.7	155.1 – 174.3	153.9 \pm 5.4	144.6–163.1	<0.0011 [*]
Iliac breadth – Lt (mm)	165.4 \pm 5.7	155.9 – 174.3	154.2 \pm 5.4	144.2 – 163	<0.0011 [*]
Ischium length– Rt (mm)	95.8 \pm 4.1	88.9 – 103.6	84.9 \pm 3.5	78.5 – 90.2	<0.0011 [*]
Ischium length– Lt (mm)	96.1 \pm 3.9	88.3 – 01.1	85.3 \pm 3.4	79.1 – 90.9	<0.0011 [*]
Pubis length – Rt (mm)	93.3 \pm 4.8	83.1 – 101.1	84.2 \pm 3.8	76.1 – 91.6	<0.0011 [*]
Pubis length – Lt (mm)	93.4 \pm 4.4	83.9 – 100.6	84.5 \pm 3.6	77.2 – 90.6	<0.0011 [*]
Width of greater sciatic notch – Rt (mm)	68.9 \pm 2.2	65.1 – 73.1	80.9 \pm 2.8	76.1 – 85.9	<0.0012 [*]
Width of greater sciatic notch – Lt (mm)	68.9 \pm 2.3	65.3 – 73.6	81.1 \pm 2.8	76.6 – 86.7	<0.0012 [*]
Length of innominate height – Rt (mm)	217.1 \pm 5.5	207.9 – 228.1	190.7 \pm 5.1	182.5–200.4	<0.0012 [*]
Length of innominate height – Lt (mm)	217.4 \pm 5.7	207.6 – 229.4	190.9 \pm 5.7	81.4 – 201.2	<0.0012 [*]

Rt: right; Lt: left; 1. Student's *t* test; 2. Mann Whitney *U* test; * Statistically significant at $p < 0.05$.



Table 2- Four variable formula for sex identification

$$\text{Sex} = (1.090 \times \text{SPA}) + (0.567 \times \text{TPO}) + (0.348 \times \text{WGSN-Lt}) - (0.193 \times \text{LIH-Lt}) - 149.055$$

If the value is > 0, then the sex is “Female”

If the value is < 0, then the sex is “Male”

SPA: subpubic angle; TPO: transverse pelvic outlet; WGSN-Lt: width of greater sciatic notch – left; LIH-Lt: length of innominate height - left

Table 3- Validity of the statistical four-variable formula representing the metric method in sex identification for the test sample

Parameters	Gender		Total	p value
	Male	Female		
Statistical formula	Male	0	25	
	Female	22	22	
Total	25	22	47	< 0.001*
Sensitivity		100 %		
Specificity		100 %		
Overall accuracy		100 %		

* Statistically significant at $p < 0.05$.

of $p < 0.05$. These results demonstrated the existence of a strong sexual dimorphism in the analysed original sample and presupposed that the variables, apart from antero-posterior pelvic outlet diameter and conjugate pelvic inlet diameter, were useful in evaluating morphological differences between sexes.

After excluding the variables that showed insignificant difference between males and females, Eta statistic was used to assess the strength of association between variables and sex identification and identify the variables having the highest sex prediction. The variables with the highest influence were selected and narrowed down to innominate height (right and left), width of greater sciatic notch angle (right and left), subpubic angle, and transverse pelvic out-

let. Comparison was made between right and left innominate height as well as between width of right greater sciatic notch angle and width of left greater sciatic notch angle. Our results showed negligible variation. Therefore, only the left side of the pelvis was used for the statistical model to prevent any duplication or artificial inflation of the results.

A binary logistic regression model was performed using the four radiometric variables of the original sample with the greatest association and highest significance (left innominate height, width of left greater sciatic notch angle, subpubic angle and transverse pelvic outlet) with men coded as 0 and women coded as 1. This regression model was used to develop the four-variable formula for sex estima-

Table 4- The validity of Phenice traits individually in adult sex identification for the test sample

Parameters	Sensitivity	Specificity	Overall accuracy
Phenice ridge	96%	68.2%	82.9%
Phenice concavity	100%	68.2%	85.1%
Phenice ventral arc	100%	95.5%	97.9%



tion (Table-2).

The validity of the statistical four-variable formula, which represented the metric method and was based on a combination of obstetric measurements and metricized non-metric traits in the pelvis in adult sex identification using reconstructed 3D-CT of the pelvis, was evaluated.

Table-3 shows the overall classification accuracy, sensitivity, and specificity of the statistical four-variable formula in sex identification for the test sample. The statistical four-variable formula for the test sample showed an accuracy rate of 100% with 100% sensitivity and specificity for both male and female identification (Table-3).

Table-4 shows the validity of Phenice traits individually in adult sex identification for the test sample. The bony ridge ('ventral arc') running down the ventral surface from the pubic crest showed the highest classification accuracy rate, sensitivity, and specificity in sex identification. This was followed by the concavity of the lower margin of the inferior pubic ramus immediately lateral to the lower border of the symphysis (the phenice trait). Finally, the ridge of elevated bone on the medial aspect of the ischiopubic ramus, immediately lateral to the symphysis, showed the least classification accuracy rate in sex identification.

In the present study, the statistical four-variable formula, which represented the metric method, showed 100% overall classification accuracy in sex identification for the test sample and an accuracy rate of 100% with 100% sensitivity and specificity for both male and female identification. The phenice traits, either each trait individually or collectively, did not show such high overall values and were unable to classify precisely the 3D-CT pelvic images into male or female individuals.

4. Discussion

Sex identification of skeletal remains is an important issue in forensic medicine. The probability of achieving a high level of accuracy of sex identification is related to the skeletal component analysed and the ability of the techniques employed to describe shape and size differences among the sexes [1]. The hip bone is the most reliable sex indicator because it is the most dimorphic bone, particularly in adult individuals [1].

The levels of sexual dimorphism vary geographically. However, no general criteria currently exist that safely allow for the transfer of diagnostic elements from one population to another. Therefore, forensic anthropologists are continually attempting to test existing methods and devel-

op more efficient and objective standards, both population-specific and forensic diagnostic, which could optimize the positive identification of human skeletal remains [10-11].

Conversely, Steyn and Patriquin in 2009 proposed that as far as the pelvis is concerned it may not be necessary to use population-specific formulae to determine sex, as the size of the pelvis is most likely constrained by the need for childbirth, and to a lesser extent, the weight of the upper body [12].

Visual or morphoscopic techniques have been largely criticized because they are highly subjective and require an experienced observer [1]. An alternative to sex estimation based on visual scoring is to quantify pelvis variation [1, 11].

The advances in imaging technologies have intensified the use of multislice computed tomography (MSCT) for anthropological purposes. It is a suitable tool for establishing sexually dimorphic characteristics in different anatomical areas. However, application of MSCT to analyse the pelvis has not been extensively investigated and standardized [6, 11]. This image based method offers highly accurate anatomical volume rendering models and multiplanar reconstruction, which make examinations less time-consuming and virtual manipulation of the bone easier. This method can be used without previous preparation or alteration to the material studied, and the stored data format facilitates computerized analyses as well [6, 11]. The 3D-CT machine employed in our study was an accurate and flexible device used routinely at the diagnostic radiology department of Suez Canal University Hospital in Ismailia. The pelvic CT axial images were reconstructed to produce 3D-CT pelvic images that were presented as DICOM (Digital Imaging and Communications in Medicine) images. These images were measured using DICOM viewer computer software.

In the present study, the mean values for all the 20 variables of both males and females were approximately close to those of Decker et al. (2011), except for subpubic angle for females (which was higher than that of Decker et al. [4]. This may be due to population differences.

In the present study, the variables with the highest influence were selected and narrowed down to innominate height (right and left), width of greater sciatic notch angle (right and left), subpubic angle, and transverse pelvic outlet. Our results agreed with those of Decker et al. (2011), who studied a randomly selected subset of abdominopelvic CT-derived models of patients at the University of South Florida College of Medicine (USA) to evaluate simple re-



peatable metric methods of sex estimation based on a combination of obstetric measurements and the traditionally nonmetric Phenice-derived traits using the same 20 variables [4] that we assessed in our study. Decker et al. (2011) also concluded that the variables with the highest loadings were innominate height, greater sciatic notch angle, subpubic angle, and transverse pelvic outlet [4].

Concerning the innominate height, our results agree with Djorojevic et al. (2014), who also concluded that the greatest differences between the sexes were found in innominate height (IHM). Since IHM reflects the overall size of the body, it is generally higher in men than in women [11].

Regarding the greater sciatic notch, our results support Steyn and Patriquin (2009), who reported that the next best discriminator between the sexes was sciatic notch breadth after the acetabular diameter [12]. However, our results disagree with an earlier report by Patriquin et al. (2005), who metrically assessed sex differences in the pelvis of South African whites and blacks. They concluded that the sciatic notch gave accuracies ranging from 73–77% and attributed that it was quite difficult to quantify the differences for the size, angle, and shape of the greater sciatic notch [13].

Concerning the transverse pelvic outlet, our results agree with Kolesova and Vetra (2011), who studied the retrospective pelvimetry of 3D-CT and demonstrated that the most visible differences are observed on the transverse diameter of the midplane and the transverse diameter of the outlet [14]. The observed differences in the variance of the transverse diameter can be explained by a hormonal effect at the end of pregnancy, which leads to softening of the pubic symphysis. This process allows the pubic bones to move apart 1 cm, thus increasing pelvic diameters [14].

Concerning the subpubic angle, our results agree with Duric et al. (2005), who reported that the most reliable pelvic sex indicators are the subpubic angle and the ventral arc, showing correct sexing in 99.22% of cases by experienced anthropologists. They also found that the most reliable pelvic sex indicator among inexperienced anthropologists was the subpubic angle, showing correct sexing in

99.61% of cases [15]. Our findings are in agreement with Igbigbi and Nanono-Igbigbi (2003) who concluded that the accuracy percentage of measuring the subpubic angle was 94.74% for females and 95.45% for males. These percentages are high enough for medicolegal cases because only one parameter (subpubic angle) was used [16].

In our study, a four-variable formula for sex estimation was developed using the four radiometric variables of the original sample with the greatest association and highest significance.

Decker et al. (2011), developed a four-variable discriminant function for sex estimation based on statistical analyses using the same variables used in the present study to develop the formula for sex identification (Table-5).

In this study, the resultant four-variable formula was applied to identify the sex of the reconstructed 3D-CT pelvic images of the test sample. It showed an accuracy rate of 100% with 100% sensitivity for male identification and 100% specificity for female identification. The results of the present study agreed with those of Decker et al. (2011), who concluded that the accuracy for the formula was 100% in both men and women with 100% sensitivity for male identification and 100% specificity for female identification [4].

The four-variable formula derived in Decker's study illustrated the strength of combining "metricized" traits with medical indices and that it is possible to estimate sex accurately (100%) in 3D virtual pelvic models derived from CT scans [4].

Females tend to exhibit an increase in growth during the adolescent growth phase in the region of the pubis and ischium, which results in a longer pubis, a larger pelvic outlet, and a more obtuse subpubic angle. These differences in growth are related to the sexual dimorphism between males and females associated with parturition [17].

This study utilized medical image data from 16-slice CT scanners. The CT's speed and its ability to show bony features without the need to remove soft tissue makes it an ideal tool to save time and to protect remains from physical manipulation. Virtual models of the pelvis can be analyzed

Table 5- Decker's four variable formula for sex identification [4]

$$\text{Sex} = (0.859 * \text{LGSN}) + (-1.799 * \text{LIH}) + (3.867 * \text{TPO}) + (1.786 * \text{SPA}) - 244.41$$

If the value is > 0 , then the sex is "Female"

If the value is < 0 , then the sex is "Male"

LGSN: left greater sciatic notch width; *LIH*: length of innominate height; *SPA*: subpubic angle; *TPO*: transverse pelvic outlet



beyond contact with the actual bone. Therefore, the speed with which the virtual bone models and measurements were generated made the method a practical alternative to traditional analyses, and this agreed with Decker et al. (2011) [4].

Our results support Djorojevic et al. (2014), who reported that CT scans offer a useful tool for compiling metric data which can yield highly accurate and statistically robust classification of sex comparable to (and in some cases better than) those achieved when the traditional linear measurements are carried out on real bone material [11].

Our results also agree with that of Djorojevic et al. (2014) and Biwasaka et al. (2012), who concluded that 3D-CT images of the pelvis reproduce complex curved features. Moreover, 3D measurements using these data could elucidate subtle differences of morphological features which have not been demonstrated clearly by conventional 2-dimensional (2D) methods [6,11].

In many forensic cases, the remains may be incomplete or fragmented. Our study revealed that the most important characteristics in sex identification require only the presence of one innominate bone and the sacrum. This is in agreement with Patriquin et al. (2005), who concluded that measurements of specific sections of the innominate bone, such as the pubis and sciatic notch, did not yield results as good as measurements for the bone as a whole, ranging from an average of 73–86% in whites and 72–84% in blacks [13]. Our findings are also in agreement with Vacca and Di Vella (2012), who showed that the combination of metric characteristics from various regions of the coxal bone is a valid approach in the correct attribution of skeletal sex [10].

Phenice traits in the pelvis have been shown to play a significant role in the identification of sex [4]. In the present study, the phenice traits were applied to identify the sex of the reconstructed 3D-CT pelvic images of the test sample. The bony ridge ('ventral arc') running down the ventral surface from the pubic crest showed the highest classification accuracy rate, sensitivity, and specificity in sex identification. This was followed by the concavity of the lower margin of the inferior pubic ramus immediately lateral to the lower border of the symphysis. Finally, the ridge of elevated bone on the medial aspect of the ischio-pubic ramus, immediately lateral to the symphysis, showed the least classification accuracy rate in sex identification.

These results agree with Phenice (1969), who indicated that the use of the ventral arc, subpubic concavity, and

medial aspect of the ischio-pubic ramus as sexing criteria allows one to sex the Os pubis with an accuracy in excess of 95%. He also highlighted that the method can allow the new researcher to sex hip bones accurately while requiring the presence of only a small fragment of the bone. He also concluded that the medial aspect of the ischio-pubic ramus is the criterion most likely to be ambiguous whereas the ventral arc is more dependable and is the least likely to be ambiguous [18]. This result also agreed with that of Sutherland and Suchey (1991), who reported that the ventral arc, when used alone, provided 96% accuracy in sex determination [19]. The above result agreed with that of Klales et al. (2012), who reported, with results similar to Phenice [18], that the ventral arc (88.5% correct classification) proved to be the best trait for separating males and females followed by the subpubic contour (86.6% correct classification) and the medial aspect of the ischio-pubic ramus (75.8% correct classification) [17].

However, our results disagree with that of McLaughlin and Bruce (1990), who reported that the subpubic concavity feature, when used alone, proved to be the most reliable variable for sex identification [20]. This may be attributed to population differences and the often highly irregular surfaces on bones of aged individuals, which sometimes masks the expression of the ventral arc feature [21].

Phenice based his method on visually scoring Os pubis for sex differences and achieved an accuracy score of 96% [18]. However, other studies have failed to achieve such high values using Phenice's method. In this way, percentages ranging from 60% to 90% have been found using different European samples, a sample from British Columbia and a sample from Ontario. These differences in accuracy could be attributed to either population variation or the degree of experience possessed by the observer [1]. Lovell (1989) carried out a study to test the accuracy of Phenice's visual method for determining sex from the Os pubis. An accuracy of 83% in determining sex was recorded, compared to 95% reported by Phenice. This accuracy difference may reflect the different age distribution of the two samples [21].

In the present study, the statistical four-variable formula which represented the metric method showed 100% overall classification accuracy in sex identification for the test sample (100% sensitivity for male identification and 100% specificity for female identification) while the phenice traits method did not show such high overall values.

Bruzek (2002), pointed out that sexual dimorphism of



the whole hip bone should be considered, and observations should not be restricted only to the pubis [22].

Despite the results of the present study, the traditionally nonmetric Phenice-defined traits in adult sex identification can be performed quickly, do not require specialized equipment, and can be used even with fragmented remains when damage does not allow a complete set of measurements. However, the drawbacks of the visual techniques should be taken into account - 1) The high degree of observer subjectivity, 2) a lack of consistency in the evaluation of traits, 3) a strong dependence on the results of previous experiences of the observer, 4) observations forced into only a few character states that do not often accommodate the range of variation, and 5) the estimated sex not being associated with a posterior probability to quantify uncertainty [17, 22].

Traditional metric analyses of the human skeleton have been claimed by some researchers to be a more reproducible and more case-inclusive method of determining sex, which can be performed by less experienced practitioners and can sometimes expose significant areas of variation that may not be readily recognizable via visual observation. In addition, using more quantifiable methods in forensic science, "metricizing" nonmetric traits, can allow researchers to move away from subjective analyses toward more objective methodologies [4, 23].

5. Conclusion

The present study concluded that the statistical four-variable formula, which represented the metric method, showed the highest overall values concerning the classification accuracy when compared to the phenice traits method. This result was found by examining each trait individually or collectively.

This study demonstrated the value of 3D-CT data for making detailed virtual models of the pelvis that can be analyzed beyond contact with the actual bone and can be used in adult sex identification, especially in cases of semi-fleshed or charred bodies such as ones recovered from mass disasters or crime scenes when maceration is not an option.

The metric method proposed in this study can represent a quick, reliable, and more objective alternative to traditionally nonmetric Phenice-defined traits used in sex identification from the pelvis. Whether this method is actually better or not should be tested with meta-analysis statistical approaches, which exceeds the purpose and scope of the current study, 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; therefore, the results of this study cannot be applied on different populations with the same accuracy. Therefore, it is suggested to conduct further research on combined group data from other populations on the pelvis to assess whether it is necessary to develop population-specific formulae for pelvic measurements.

Based upon our present findings, it is recommended to conduct further studies using the parameters mentioned in this study on a larger section of the Egyptian population, especially in subjects of a younger age group, to get a radiometric standard specific to this population. It would be interesting also to look at 3D-CT scans of the pelvis of living individuals to explore, verify and expand a number of anatomically relevant features whose effective combination would provide novel and reliable patterns practically useful when applied to skeletal remains in archaeological and/or forensics contexts. Further studies based on 3D-CT scans of fragmented remains of the pelvis should also be conducted.

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