Journal of Forensic Radiology and Imaging 12 (2018) 5–10

Contents lists available at ScienceDirect

Journal of Forensic Radiology and Imaging

journal homepage: www.elsevier.com/locate/jofri

Morphoscopic observations in clinical pelvic MDCT scans: Assessing the accuracy of the Phenice traits for sex estimation in a Western Australian population

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ARTICLE INFO

Keywords:
Ventral arc
Subpubic concavity
Ischiopubic ramus
Forensic anthropology
Computed tomography
Population standards
Sex estimation

ABSTRACT

The formation of a biological profile (including the estimation of sex and age) is usually the first task undertaken when skeletal remains are analysed by a forensic anthropologist. Recent literature attests to a growing awareness of the value of research focusing on age and sex related morphoscopic features visualized in high resolution multiple detector computerized tomography (MDCT) scans. The present study provides insight into the analysis of MDCT scans, with a specific focus on quantifying the accuracy of the Phenice sex estimation method in a Western Australian population.

The sample comprises 448 clinical pelvic MDCT scans representing 226 male and 222 female individuals between 18 and 64 years of age. The scans (all ≤ 1.5 mm slice thickness) are reconstructed using three-dimensional volume rendered models in *OsiriX* software. A precision test was performed prior to data collection to quantify observer accordance; thereafter the accuracy of the identification of the Phenice pelvic traits (ischiopubic ramus; ventral arc; subpubic concavity) are statistically quantified.

Intra-observer accordance is above 0.81 (Kappa value) for each morphological attribute assessed. Congruent with previous research the single most accurate trait overall is the ventral arc (86.61%), albeit an age-related sex-bias in classification accuracy was demonstrated. Based on the combined assessment of the three features, it is demonstrated that the Phenice method facilitates a high degree of expected accuracy in the classification of sex (92.24%), thus indicating that the method can be successfully applied in MDCT scans and is suitable for forensic application in a Western Australian population.

1. Introduction

In the formulation of a biological profile, the estimation of sex is often the first assessment performed by the forensic anthropologist, as the accurate quantification of other biological attributes (e.g., age, ancestry and stature) are largely dependant on *a priori* assumptions of the former [1–3]. Sex can be estimated using either morphoscopic (visual) or morphometric (metric) methods depending on the specific case material referred. Some of the work performed by a forensic anthropologist can be subjective in nature, particularly morphoscopic analyses, as they can depend on observer experience of classifying the degree of expression of a trait, the presence or absence of a trait, or simply the shape of a bone [4].

The pelvis is a particularly relevant bone in the anthropological assessment of referred remains, as it is biologically significant for both locomotion and the transmission of weight [5]. The pelvis also demonstrates clear morphological indications of sex (specifically in adult remains) relative to differences in biological functioning (such as childbirth) [6–9]. Sexual dimorphism in the pelvis can be quantified using measurements that capture the larger size of the true pelvis (e.g., transverse pelvic outlet) and the sub-pubic angle, or based on morphoscopic observation of the shape of the greater sciatic notch and other sex specific features in the pubic bone [10,11] (and see below). Generally, morphoscopic sex estimation using the pelvis produces highly accurate classifications (e.g., 95–98% [12–14], albeit the approach is considerably more subjective (higher intra- and inter-observer error)) relative to the morphometric assessment of sex [15].

Phenice [13] identified the need for a simple and reliable method for assessing sex in adult pelves that could be used in various professional contexts by analysts with varying skill levels, and was not limited to requiring the complete bone. Until that point, although morphoscopic methods based on the analysis of pelvic morphology were widely known to correlate to biological sex, the criteria used were highly subjective and required considerable training and experience [13]. One

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https://doi.org/10.1016/j.jofri.2018.02.003
Received 11 July 2017; Received in revised form 16 January 2018; Accepted 1 February 2018
Available online 06 February 2018

of the few metrical approaches available at the time was the ischiopubic index (e.g., [16,17], which although having a high stated accuracy (> 90%)), is both population specific and next to impossible to apply in fragmented remains.

In consideration of the perceived limitations of the above methods, Phenice refined the criteria for the morphological assessment of three pelvic features; the ischiopubic ramus, ventral arc and the subpubic concavity. Based on his analysis of 275 individuals from the Terry Collection, the typical female morphological appearance of those features is described as follows: i) a bony ridge forming a ventral arc on the ventral surface of the pubic bone running from the pubic crest down to the subpubic concavity, blending with the medial border of the subpubic concavity; ii) a concave subpubic arch; and iii) a pinched ischiopubic ramus, forming a ridge on the surface. Conversely, the male pubic bone is described as generally being devoid of a ventral arc or subpubic concavity, and the ischiopubic ramus will be broad and flat [13].

While the original publication reported an accuracy rate of ~96% [13], many subsequent reviews have not succeeded in replicating these figures, generally achieving between 80% and 90% accuracy (e.g., Lovell 1989; MacLaughlin and Bruce 1990; Ubelaker and Volk 2002). The latter decrease in accuracy is likely attributable to some degree of population-specificity in the relative expression of the features assessed; clearly the individuals comprising the Robert J. Terry Anatomical Skeletal Collection (some individuals have 19th century birthdates – http://anthropology.si.edu/cm/terry.htm) are both temporally distant (non-contemporary) to extant American populations)), but also geographically and genetically removed from other global populations. Testament to the relative success and ease of application of the method, however, is that it is still widely applied in modern practice [18].

It is well documented that disparate populations have genetic variations [19,20] that are often manifested in morphological skeletal differences [21], such as robusticity, degree of sexual variation, and body size. This can result in reduced accuracy when applying anthropological standards to an individual that is genetically (or temporally) distant from the original population used to devise the statistical models [22]. It is thus important to have a clear understanding of the latter effect in relation to potential forensic practice. To-date there has been no empirical testing of the Phenice method in a Western Australian population; the accuracy and precision, and thus forensic applicability, of this method is unknown. Furthermore, there are presently no Western Australian specific standards for the morphoscopic estimation of sex based on the analysis of pelvic morphology [23,24].

In the absence of contemporary documented (known age, sex and ancestry) skeletal collections in Australia, appropriate biological data must be acquired from alternative sources, such as clinical multiple detector computed tomography (MDCT) scans. So, in relation to facilitating an increased understanding of the broader implications of the practical application of morphoscopic sex estimation methods in different global populations based on medical imaging modalities, the specific aim of this study are as follow: i) to statistically quantify intra-observer precision of the Phenice morphoscopic method relative to the assessment of MDCT scans; and ii) statistically quantify the accuracy of the Phenice sex estimation traits in a Western Australian population.

2. Materials and methods

2.1. Materials

This study involves the analysis of pelvic MDCT scans of individuals who presented to various Western Australian hospitals for pelvic clinical evaluation. The sample is drawn from a Picture Archiving and Communication System (PACS) medical database and comprises scans of 448 adult individuals; 226 male and 222 female between 18 and 64 years of age. All scans have a slice thickness of between 0.625 and 1.5 mm. Any scan that presented trauma (or abnormalities) in the areas of interest (e.g., obvious asymmetry, osteoporosis or fractures) were duly excluded from the study. All identifying features were anonymised from the scans, with the exception of sex and age. Data specific to patient ancestry is not recorded during clinical evaluation as it is deemed to not be of medical relevance. It is assumed, therefore, that the ethnic composition of the sample is generally representative of the Western Australian population as a whole, and thus mainly of Caucasian descent [25]. Research ethics approval was granted by the Human Research Ethics committee of the University of Western Australia (Project No: RA/4/1/4362).

2.2. Methods

2.2.1. Visualization

The anonymised MDCT scans are reconstructed using the 3D volume rendering options in *OsiriX* software [26,27]; scans are visualized using a low-contrast setting for most individuals, however a glossy setting was applied in cases that showed some loss of bone density. The scan was orientated according to a set of predetermined views (anterior, lateral and posterior) accordingly selected because they facilitated observation and assessment of the required sex attributes of interest in this study (Fig. 1). The anterior surface of the bone was used to assess the ventral arc, while the posterior surface of the pubic bone (obtained by removing the sacrum) was used to assess the subpubic concavity. Following this, the left and right pubic bones were separated in order to generate a lateral view of each pubic symphysis and ischiopubic ramus. For consistency in analysis, and as a visual record of the collection, a series of five images were taken of each pelvis for subsequent assessment following the Phenice method.

2.2.2. Data acquisition

Prior to data collection all scans are completely blinded of all demographic data (no sex or age details) by a third party to minimise potential assessment bias. Each os coxa is then assessed by a single evaluator (EJB – postgraduate forensic anthropology student with 15 h training and supervision in the method relative to application in MDCT) based on the set of images previously acquired for each individual, with the right and left side scored simultaneously. For each pelvis the three Phenice traits are scored as either absent (0) or present (1), with the former more commonly associated with male, and the latter female, sex [13]. An estimate of sex is thus derived from the tabulation of a 2/3 majority of the traits, for example: ventral arc (1); sub-pubic concavity (1); and ischio-pubic ramus (0) estimates female sex.

2.2.3. Intra-observer error

Prior to primary data collection a precision test is performed (by EJB) to test the consistency of repeat assessments. A Fleiss-Kappa test is used to evaluate intra-observer error [28] for the scoring of the three pelvic traits following the method outlined by Phenice. The required data for the precision test are based on the repeat assessments (three in total) of scans representing 40 individuals, with a minimum of one week between each re-analysis. Fleiss-Kappa values are then calculated and subsequently interpreted according to Landis and Koch [28].

2.2.4. Statistical analyses

A series of paired *t*-tests are used to compare left and right scores to ascertain if there is any significant intra-individual bilateral variation in the expression of the Phenice traits [29]. As no significant bilateral asymmetry was detected (see below), only the left os coxa is used for further analysis. The scores assigned for each left os coxa were then compared to the known sex of that individual. The ventral arc, subpubic concavity and ischiopubic ramus are all accordingly marked as correctly or incorrectly scored depending on alignment with known sex. An overall sum of correct assessments was then determined for each trait; this is then used to determine the most and the least commonly correctly identified trait. The number of overall correct estimations of