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Estimation of sex in a contemporary Saudi population based on sternal measurements using multidetector computed tomography

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A B S T R A C T

Sex estimation is an essential step for identifying unknown individuals and usually depends on the presence of highly dimorphic bones, such as the pelvis and skull. Nevertheless, the body integrity can be compromised in certain circumstances, and these bones might be absent; therefore, the ability to use other bones for sex estimation is crucial. The aims of this study were to collect baseline data for sternal dimensions in Saudi adults, assess the existence of sexual dimorphism in the sternum, and generate population-specific equations to estimate sex using sternal dimensions. During 2014–2015, 200 thoracic/thoraco-abdominal computed tomography (CT) images (100 men, 100 women) were anonymously collected from King Abdulaziz Medical City. Six measurements were obtained and two indices calculated after 3D reconstruction of the CT scans. Descriptive statistics were calculated, and sexual dimorphism was assessed using independent t-tests. Discriminant function equations were developed for these measurements. Except for the sternal index, men had significantly larger dimensions than women. Sexual dimorphism was highly significant ($p < 0.001$). The best predictor was the combination of the manubrium and sternal body lengths (89.5%). In the stepwise analysis, the best predictors were the manubrium length, sternal body length, manubrium width, and corpus width at the first sternebra, with a cross-validated accuracy of 90.5%. Cross-validated accuracy for all measurements ranged between 62.5% and 90.5%. The findings of the study may have important anatomical, anthropological, and forensic applications.

Introduction

The construction of a biological profile gleaned from skeletal remains continues to be necessary to establish the identity of unknown persons. This process depends on highly focused knowledge and skills of students of human anatomy, especially osteology, and on establishing standards morphoscopically and/or morphometrically (Franklin et al., 2014). Estimation of sex is the initial step in any meaningful profiling, as it provides a more precise search of the identity by reducing the number of matches for unknown victims to approximately half (Krogman and İşcan, 1986; Scheuer, 2002). Furthermore, it determines the most suitable subsequent

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methods to estimate other inextricably linked variables such as stature, age, and limb parts correlations (Ahmed, 2016; Krogman and İşcan, 1986; Scheuer, 2002).

The accuracy of sex estimation from skeletal materials depends on the availability and completeness of the skeletal components and the degree of systematic differences in the skeletal form between men and women in the studied population. The precision of this accuracy can approach 100% with a complete skeleton; unfortunately, this is not often the situation in medico-legal practice. It is common to recover incomplete, damaged, or fragmented skeletal parts in criminal cases, mass disasters, airplane crashes, and explosions or during forensic and archeological excavations based on the taphonomic history. These conditions necessitate the development of reliable sexing criteria that use single bones or bone parts.

The most studied parts of the human skeleton are the pelvis and skull; the use of these bones results in accurate estimates of sex owing to the noticeable sexual dimorphic features in their structures (Giles and Elliot, 1963; Krogman and İşcan, 1986; Phenice, 1969). Although the best estimator for sex is the pelvis, its fragility may affect its preservation and integrity, and it may not always be present in skeletal materials (Walker, 2005). Estimation using the skull is poorer than using most of the postcranial bones (France, 1998; Spradley and Jantz, 2011). The possible absence of these bones has prompted researchers to explore the potential of using other bones to estimate sex. There is a generalized consensus that these studies should be based on population-specific skeletal characteristics because the relative expression and magnitude of sexual dimorphism are different between populations, which might reduce the prediction accuracy.

Quantification of the existence of sexual dimorphism of the sternum has been attempted using various methods, including morphoscopic assessment of sexually dimorphic features (Singh and Pathak, 2013b). Other published reports employed morphometric measurements and statistical analysis using either bones or radiological images (Bongiovanni and Spradley, 2012; Garcia-Parra et al., 2014; Jit et al., 1980; Macaluso and Lucena, 2014). The morphometric approach surpasses the morphoscopic approach regarding expediency, ease of application, and reliability. Moreover, the morphometric approach satisfies the requirements of legal admissibility by using robust statistical tests to quantify the accuracy and reporting the statistical confidence in the final estimation (Franklin et al., 2014; Rogers, 2005). Various linear dimensions of the sternum were investigated in different populations and showed high levels of sexual dimorphism and an overall classification accuracy $> 80\%$ (Bongiovanni and Spradley, 2012; Franklin et al., 2012; Macaluso, 2010; Macaluso and Lucena, 2014; Singh and Pathak, 2013a; Torimitsu et al., 2015). The sternum showed a $> 59\%$ recovery rate when inventorying the skeletal remains collection housed in the Forensic Anthropology Data Bank, and it is more resistant to physical damage than the ribs, indicating its potential usefulness as a skeletal element in forensic anthropological analyses (Torimitsu et al., 2015).

In Saudi Arabia, population-specific morphometric skeletal standards are limited, and there is a lack of contemporary documented osteological collections. This shortage encourages the use of other alternative methods such as radiological modalities. Medical images dimensions are valid and reliable when compared with direct measurements of osteological bone traits and offer an arguably more representative sample of the contemporary population (Franklin et al., 2013, 2014). Different body parts were assessed for estimation of sex in Saudis using different imaging techniques, for example, measurements of humeri using radiographs, achieved an overall accuracy of 68.0–94.3% (Shehri and Soliman, 2015). The potentiality of Saudis' mastoid triangle for sex estimation was assessed using 3D multidetector computed tomographic (MDCT) images, resulting in a cross-validated accuracy of 60.7–69.4% (Madadin et al., 2015). The foramen magnum dimensions showed the cross-validated accuracy of 51%-67.5% (Madadin et al., 2017). These studies revealed the usefulness of discriminant functions in establishing identity among Saudis. However, the potential of establishing sex based on sternal dimensions has not been assessed in a Saudi sample. Therefore, the primary objectives of this study were to assess sternal sexual dimorphism among contemporary Saudis and to develop population-specific discriminant function equations to estimate sex based on sternal measurements obtained via 3D CT.

Materials and methods

The sternal measurements were quantified from 3D volume-rendered MDCT scans randomly acquired from the Picture Archiving and Communication System database of the radiological department at King Abdulaziz Medical City for 200 patients (100 men, 100 women) who underwent a thoracic/thoracoabdominal MDCT scan during 2014 and/or 2015. The inclusion criteria were Saudi Arabian origin, age > 20 years, and no obvious acquired or congenital sternal pathology observed (such as, e.g., sternal fracture/trauma, unfused ossification centers). Sternae that lack fusion lines in the manubriosternal or xiphisternal junctions were also excluded. The study protocol was approved by the Institutional Review Board at the King Abdullah International Medical Research Centre, National Guard Health Affairs, Saudi Arabia (14/066).

Computed tomography data and measurements

Thorax/thoracoabdominal CT imaging was performed using the GE LightSpeed™ VCT 64-channel MDCT scanner (General Electric Company, USA) with an average slice thickness of 0.9 mm (range, 0.625-1.25 mm). All scans were received anonymously in the Digital Imaging and Communication in Medicine (DICOM) format, with only sex and age information retained. Post-processing of the DICOM files was performed with the MAC OS V. 10.7.2 operating system and the medical imaging and measurement software OsiriX MD (Pixmeo, Geneva, Switzerland). 3D anatomical sternal models were constructed from the CT image series. Following the standardized anthropometric techniques and use of OsiriX MD software, 10 anatomical landmarks were manually located on the surface of the 3D reconstructed model. From these landmarks, five linear inter-landmark dimensions were acquired to the nearest 0.1 mm