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Sex determination by three-dimensional geometric morphometrics of the vault and midsagittal curve of the neurocranium in a modern Greek population sample

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ABSTRACT

The aim of this study is to assess sexual dimorphism of adult crania in the vault and midsagittal curve of the vault using three-dimensional geometric morphometric methods. The study sample consisted of 176 crania of known sex (94 males, 82 females) belonging to individuals who lived during the 20th century in Greece. The three-dimensional co-ordinates of 31 ecto-cranial landmarks and 30 semi-landmarks were digitized using a MicroScribe 3DX contact digitizer. Generalized Procrustes analysis (GPA) was used to obtain size and shape variables for statistical analysis. Shape, size and form analyses were carried out by logistic regression and three discriminant function analyses. Results indicate that there are shape differences between sexes. Females in the region of the parietal bones are narrower and the axis forming the frontal and occipital bones is more elongated; the frontal bone is more vertical. Sex-specific shape differences give better classification results in the vault (79%) compared with the midsagittal curve of the neurocranium (68.8%). Size alone yielded better results for cranial vault (82%), while for the midsagittal curve of the vault the result is poorer (68.1%). As anticipated, the classification accuracy improves when

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both size and shape are combined (89.2% for vault, and 79.4% for midsagittal curve of the vault). These latter findings imply that, in contrast to the midsagittal curve of the neurocranium, the shape of the cranial vault can be used as an indicator of sex in the modern Greek population.

Introduction

There are four major factors that lead to a variation in human skeletal anatomy. The first source of this variation is the ontogeny or growth, while the second one is the sex of the individual. The third factor is geographic or population-based and the fourth factor is due to the individual, or idiosyncratic, variation (White et al., 2011). Sex determination is an important feature of establishing the biological profile of an unidentified human skeleton. Environmental factors influence the degree of sexual dimorphism and thus differ in each population (Bigoni et al., 2010).

A number of skeletal elements, for example, the skull (Giles and Elliot, 1963), the pelvis (Steyn and İşcan, 2008), the humerus (Falys et al., 2005), the ulna (Cowal and Pastor, 2008) and other postcranial elements, can be used to determine the probable sex of a human skeleton. However, the accuracy of those sex determinations varies considerably between different osteological elements, and also between different human populations (Franklin et al., 2005).

Traditional approaches to determine sex from skeletal remains include qualitative morphological examination and morphometric methods, followed by uni- and multivariate statistical analyses. Implementing morphological methods requires thorough training by the examiner but the evaluation of such traits is still subjective (Bookstein et al., 1985; Slice, 2007). Morphometric methods use dimensional measurements of skeletal remains (Giles, 1964; Giles and Elliot, 1963; Henke, 1974). The disadvantage of morphometric methods is that the geographical origin of the test specimen must also be known to find a suitable comparative sample (Barrio et al., 2006; Franklin et al., 2005; Gualdi-Russo, 2007; Rösing et al., 2007).

In the second half of the 1980s, a new approach to quantify and analyze morphological data began to develop (Adams et al., 2002). This led to geometric morphometrics.

Geometric morphometrics is a landmark based method, which has been developed to analyze biological form variation and, therefore, morphological changes, in bi-dimensional or tri-dimensional spaces. Geometric morphometrics aims to separate shape information from overall size by calculating a specific measure of size, centroid size, which can always be obtained from a set of landmarks and is comparable between specimens. Most frequently, three-dimensional geometric morphometric (3DGM) applications are used to determine population affinity or origin of skeletal remains (Buck and Viðarsdóttir, 2004; Ross et al., 1999), to determine sex (Franklin et al., 2006a,b, 2007a,b; Kimmerle et al., 2008; Oettle et al., 2005; Pretorius et al., 2006; Ross et al., 2006; Steyn et al., 2004) and to estimate age at death (Braga and Treil, 2007). Geometric morphometrics is widely used (Bigoni et al., 2010; Bulygina et al., 2006; Giles, 1964; Kimmerle et al., 2008; Ross et al., 1999), while there are only few references for Greek populations (Harvati and Weaver, 2006; Kranioti et al., 2008, 2009).

In this paper we investigate the application of tri-dimensional geometric morphometrics to crania of a modern Greek skeletal sample. More specifically, this study aims to assess sexual dimorphism of adult crania in the vault and midsagittal curve of the neurocranium.

Materials and methods

For the purpose of this research 176 crania (94 males and 82 females) of adult individuals from the modern skeletal reference collection, known as the Athens Collection, have been studied. The selected individuals are well preserved and have no evidence of pathology or taphonomic deformation.

The Athens Collection is housed in the Department of Animal and Human Physiology (Faculty of Biology, National and Kapodistrian University of Athens). The entire collection consists of