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Geometric morphometric and traditional methods for sex assessment using the posterior ilium

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ABSTRACT

The human hip bone is generally accepted as the most reliable bone for sex estimation in forensic and bioarchaeological disciplines. However, it is seldom completely preserved. The best preserved region is typically around the sacroiliac joint and its auricular surface; it is therefore surprising that this surface has not been involved in standard sexing methods. The aim of this study was to explore the shape and size sexual dimorphism of the auricular surface in detail and to compare its sex estimation accuracy using the geometric morphometric (GM) and traditional methodological approach.

Our sample consisted of 121 specimens from 3 European osteological collections. The GM part of the study was based on 2D sliding semilandmarks that covered the outline of the auricular surface. Furthermore, several linear measurements and visual features (e.g. auricular surface elevation, postauricular sulcus) were chosen to test sex estimation accuracy using support vector machines. Concerning the GM analysis, the most notable sexual differences in the auricular surface outline relate to size. The best accuracy was achieved using form variables reaching 81.0%. Comparable accuracy (80.2%) was achieved using the metric approach, but combined with visual features the accuracy was increased to 93.4%. The GM approach was not very efficient in sexing the auricular surface outline, but the combination of visual features from the posterior ilium and metric variables of the auricular surface could be useful in sex estimation. Therefore, we provide a further testable linear discriminant equation based on this combination of variables.

1. Introduction

Sex estimation of human skeletal remains is a key step in forensic identification as well as in bioarchaeological studies. The most accurate sex estimation is provided by the hip bone because of the strong selective pressure on female pelvis during the evolutionary process of increasing encephalization [1]. The enlargement of pelvic canal dimensions after acetabular fusion is accompanied with changes in pelvic articulations as a pubic symphysis and sacroiliac joints [2]. This is in concordance with the fact that the highest accuracy of sex determination can be achieved using features of the ischiopubic and sacroiliac hip bone regions [3].

Sacroiliac joint (SIJ) provides a flexible connection between lower limbs and axial skeleton and therefore the upper-body weight is transferred through this articulation to the legs [4,5]. Increased biomechanical loading in males thus causes a great deal of sexual dimorphism in the size of the auricular surface [5–7]. Furthermore, the inferior (i.e. caudal or horizontal) arm of this surface lies along the posterior chord of the greater sciatic notch, which shows important shape differences between the sexes [8–10]. In males, the posterior chord is short in order to reduce the distance between acetabulum and SIJ, favouring bipedal locomotion. On the other hand, the longer posterior chord in females ensures backward position of the sacrum which increases obstetric canal dimensions [2,9]. Moreover, significant sexual dimorphism also exists in the angulation of sacrum [11]. All these indicators suggest that in addition to the size differences, the auricular surface can exhibit some sexual dimorphism in shape.

Auricular features have been studied and described in many forensic monographies [12–15]. Nevertheless, despite a good preservation state of this region compared to the pubis [15–18], the auricular surface is not included in the commonly used sex estimation methods which are based on features from the entire hip bone [3,19,20]. The reason is that a description of morpholog-

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ical differences and developing a sexing method are entirely different matters. First, it is necessary to explore the variation of a trait in the population and then to propose a manner of classification which is reproducible and further testable on different samples [21]. Furthermore, it is not possible to reliably determine sex using a single trait [22].

Various visual and metric features of the auricular surface and its surroundings have been explored and tested for sexual dimorphism: auricular surface angle [21,23–27], inferior arm constriction [21,24], auricular surface elevation [2,23,28–30], postauricular sulcus [23,29,31–33], postauricular space [31], iliac tuberosity [31], auricular surface size [26] or length and width of both auricular arms [25,26,28]. Most of the older studies did not reach satisfactory results and some authors even concluded that the features of the auricular region are unreliable indicators of sex [26,30]. Traditional visual and metric assessment is in fact often connected with a higher risk of subjectivity [34] and population specificity [1]. Fortunately, these problems can be at least partially removed by better specified definitions of morphological traits or by using more appropriate, often non-linear, classification methods [28,35,36]. We also encounter this approach in some of the recent studies concerning sexual dimorphism of the auricular surface that achieved considerably higher success than the previous studies [28,29].

Since the 1990s, geometric morphometrics (GM) has found many applications in the study of biological structures [37]. In its basic form, this approach relies on digitizing anatomically homological points (called landmarks) [38]. However, there are no anatomical landmarks on the outline of auricular surface. Anastasiou and Chamberlain [39] thus verified the sexual dimorphism of the auricular surface, both in shape and size, with geometrically defined points (type 2 or 3 following Bookstein's definition of landmarks [37]). Significant sex differences were found in both shape and size, but the shape component did not contribute very much to the accuracy of sex classification: it reached 87.5% based on the iliac auricular form (shape and size together) compared to 85.9% based solely on the size [39]. Nevertheless, further testing is necessary, particularly on a sample of known sex [39].

The aim of this study was to verify the sexual dimorphism of the auricular surface, in shape and size, by geometric morphometric methods. To that end, sliding semilandmarks were used, that describe the outline of a structure in more detail [40,41]. Simultaneously, several established visual and metric features of the posterior ilium were analysed and both (geometric morphometric and traditional) approaches were compared.

2. Materials and methods

2.1. Materials

The sample consisted of 121 casts of the posterior iliac region from specimens housed in three European osteological collections of known sex and age. The first subsample was composed of 20 females and 28 males from the Coimbra Identified Skeletal Collection (Coimbra, Portugal) which dates to the 19th–20th century [42,43]. The second subsample comprised 15 females and 22 males from the Olivier Documented Collection, Musée de l'Homme, Muséum National d'Histoire Naturelle (Paris, France) which dates to the first half of the 20th century [36,44]. Finally, the third subsample composed of 16 females and 20 males from the Spitalfields Collection, British Museum Natural History (London, United Kingdom) dates to the 18th–19th century [45]. We used a total of 51 females and 70 males of adult age. The exact age was known in 106 individuals (including all females) and ranged from 19 to 96 years. The average age of females and males was 52.0 (sd = 17.8) and 52.6 years (sd = 15.1), respectively.

The casts of the posterior iliac region were analysed to ensure that the visual assessment would not be biased by other sexually dimorphic features from the whole hip bone. High precision condensation dental silicon Reprosil Putty (DENTSPLY DeTrey GmbH, Germany) containing vinyl polysiloxane impression material was used to create moulds of the ventral aspect of the posterior ilium. Subsequently, these imprints ('negative' replicas) were filled with dental gypsum to produce casts that were coloured to gain a natural appearance. Standard procedure for skeletal material replication was followed [46,47] and the used materials were chosen to preserve the properties of the original bone [46,48–50].

2.2. Geometric morphometric approach

2.2.1. 2D imaging

The auricular surface is a relatively flat structure suitable for a two-dimensional analysis [51]. The GM analysis was therefore performed on photographs. They were acquired with a digital camera Canon EOS 600D (Canon Inc. Tokyo, Japan) and a lens EF-S 18-55 mm. The camera was in a fixed position with the focal length of 55 mm and the focal plane 60 cm above the photographed specimen. The cast was placed in a sandbox and photographed in a standardized position. A small 3 cm long and 1.5 cm wide photographic two axis double bubble spirit level was placed on the superior arm (demiface) of the auricular surface which was positioned to be in the horizontal plane (Fig. 1).

The superior arm was chosen because of the relatively flat surface in comparison with the caudal arm [27].) A linear scale was placed directly on the caudal arm so that the landmark locations could be defined in millimetres. A second image of the same cast was subsequently taken in the same position without the linear scale which was finally introduced into the second picture from the previous image.

2.2.2. Semilandmark localisation

Semilandmarks on closed curves were employed in this study due to the lack of anatomical landmarks on the auricular surface [39]. The geometric morphometric procedure was executed in the software Morphome3cs (www.morphome3cs.com) developed in the Department of Software and Computer Science at the Charles University. First, the outline of the auricular surface was manually traced in each image. To initially orient the curves, two points were placed on the top of both arms (Fig. 1) and curves from left-sided specimens were mirrored to the right side. The points served as a base in the floating base registration which was the first step in the superimposition of the curves [38]. The semilandmarks were then placed on the roughly superimposed curves using an iterative process; in its first step, 20 preliminary semilandmarks were automatically placed on the curves at equal curvilinear increments. Next, the semilandmarks were allowed to slide along the curves minimizing the Procrustes distance between a configura-

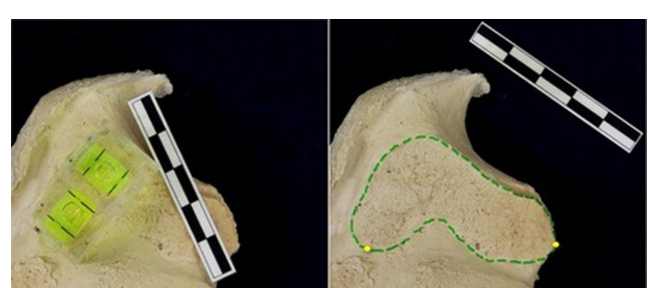

Fig. 1. Acquisition of photographs in standardized position achieved by a spirit level with a 5 cm scale (mediolateral view).