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Sex assessment using clavicle measurements: Inter- and intra-population comparisons

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ABSTRACT

We studied sexual dimorphism of the human clavicle in order to describe size variation and create population-specific discriminant tools for morphometric sex assessment. The studied sample consisted of 200 skeletons of adult individuals obtained from the University of Athens Human Skeletal Reference Collection, Athens, Greece. The specimens were well-documented and represented a modern population from cemeteries in the Athens area. Six dimensions typically used for clavicle measurements were recorded. For sexing clavicles, we used both traditional univariate (limiting, demarking and sectioning points) and multivariate discriminant function analysis. The accuracy of the best five classification equations/functions ranged from 91.62% to 92.55% of correctly assigned specimens. By testing new and previously published sexing functions (Greeks, Polynesians, Guatemalans) on four available population samples (English, Indians from Amritsar, Indians from Varanasi, and data from the present study) we found that, for some combinations of tested and reference samples, the accuracy of the sex assessment may decrease even below the probability given by random sex assignment. Therefore, measurements of the clavicle should not be used for sex assessment of individual cases (both forensic and archeological) whose population origin is unknown. However, significant metric differences were also recorded among three different Greek samples (i.e. within a population). As a consequence, application of a sexing method generated from one Greek sample and applied to another Greek sample led to negligible reduction in the success of sex assessment, despite general similarities in ethnic origin (Greeks), generation structure and presumed social background of the samples. Therefore, we believe that future studies should focus on understanding the nature of the differences among within-population reference samples.

1. Introduction

The determination of sex from a skeleton is a priority in forensic and archeological cases. Methods for sex assessment are based on the existence of morphoscopic features in the skeleton that manifest differently according to sex or statistical differences in skeletal measurements [1]. The human clavicle is considered relatively resistant to taphonomic factors and is frequently well-preserved both in the medico-legal and bioarchaeological context [2]. Due to its specific pattern of ontogeny and age-related changes of the sternal articular surface during adulthood, the clavicle is widely used in the estimation of age at death [2,3] and for age estimation in living people [4]. However, apart from morphological age changes, the human clavicle also exhibits a large degree of sexual dimorphism. Therefore, it comes into consideration for sexing when the skeleton is incomplete, especially when the pelvis and the skull are not available.

Sexual dimorphism is reflected both in the size and shape of the clavicle. According to some studies, sexes differ in the shape of the clavicle – male clavicles are more curved horizontally than those of females [5–9]. Sexual dimorphism in clavicle curvature is already present in childhood [10], suggesting that some aspects of shape dimorphism may have originated at an early stage of ontogeny. However, some authors [8,11] found significant sexual characteristics of curvature only in the medial and not the lateral clavicular angle in adults and, moreover, these differences were not consistent between different samples and differed between body sides [11]. The female clavicle is also less robust [5,7,11,12] and it has less marked muscle attachments [5,9,11,13]. No statistically significant sex differences in clavicular length were found in fetuses, newborns and children of all studied age groups [2,8]. Size dimorphism becomes progressively pronounced during puberty and adolescence [8,14,15] and originates predominantly from differences in growth timing and intensity between males and females. Consequently, in a given adult population, size measurements of clavicle are usually, on

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average, greater for males than for females and these differences are statistically significant and generally accepted [5,7–13,16–22].

Given the obvious size difference, clavicle measurements has been used as sex predictors, either separately [5,12,16,17,19,22,23], or in various combinations [12,17,19,22,23]. Traditionally, the overlap of distributions for male and female values is analyzed univariately. Data is visualized by histograms [e.g. 5,23], and/or specific points (sectioning, limiting, or demarking points). The specific points are presented as rules for sexing, together with the percentages of correctly assigned cases [16,18,19,22,24]. Apart from these basic methods, as well as for other parts of the human skeleton, e.g. [25–27], linear discriminant function analysis [28] is one of the methods which have been commonly used as rules (equations) for sexing by clavicle measurements for some time [12,17,29]. Some of these methods use only clavicle measurements themselves [12] and other methods use a combination of measurements of the clavicle and other body parts [17,23,30,31]. In these combined methods, some of the additional variables are, unfortunately, not always available, e.g. human body length [23], scapula [17,31], femur, ischium and humerus [30]. Moreover, in bioarchaeological cases, variables such as weight of clavicle [16,18,19,22], can be compromised by taphonomic factors.

In a given population, the accuracy of sex assessment on the basis of discriminant analysis of the clavicle measurements is very good. The best equations by Frutos [17] reached accuracy of 85.6–94.8% and the best twenty equations published by Murphy [12] reached accuracies ranging between 63.3% and 100%. These results indicate that the accuracy of these methods is comparable, or higher, than the accuracy determined for other limb bones, e.g. [26,27,32]. On the other hand, the existing prediction rules are specific for a given population. Any suitable population-universal morphometric method providing a practicable degree of accuracy, as is the case for pelvic bone [33], have not yet been developed for the clavicle. Published tests showed that sexing by clavicle measurements is valid when applied to another sample of the same population [29], but strongly non-valid when applied to different populations, where the overall percentage of correct sex assignment can even drop below 50% [17].

Goals of the study were to present the results of standard clavicle measurements of a sample originated in a recent Greek population. In addition to general metric descriptions and within-sample variations (body side, sex, age at death), we compared acquired data with available datasets and additional populations obtained from published studies. Furthermore, we attempted to create a discriminant method for sexing human clavicles using simple univariate as well as more complex multivariate approaches. Finally, the study focused on testing applicability of acquired discriminant equations on available population samples obtained from published original datasets.

2. Materials and methods

2.1. Skeletal sample

The source of skeletal materials used in this study was the University of Athens Human Skeletal Reference Collection [34] which is housed at the Department of Animal and Human Physiology, at the University of Athens, Greece. In total, the collection includes 225 individuals from a modern Greek population, who died between 1960 and 1996. Documented skeletons were acquired from cemeteries in the Athens area. The first part of the collection was built between the years 1996 and 1997 by Lagia and includes 72 skeletons; the second part was accumulated between the years 2001 and 2003 by Eliopoulos and contained 153 skeletons at the time the present study took place. Documentation that includes individual's age, sex, occupation, and cause of death is available for almost all of the skeletons in the collection. According to the authors [34], at least the lower and middle socioeconomic classes are represented in the collection.

The studied sample consisted of 375 clavicles of 200 adult individuals with 90 females and 110 males. In this paper we refer to this sample as *the Athens sample*. The adult status of specimens was ascertained using the provided documentation and was subsequently verified by the observing fusion of the *synchondrosis sphenooccipitalis* (this observation was provided by the second author). Cases with any evident pathological conditions (e.g. healed fractures) were excluded from the study. The age at death ranged between 19 and 99 years with a mean age of 58.9 years (median was 60 years).

Two studies of clavicles in documented samples from Greece were known to us at the time of writing this publication. The first was Apostolakis [6], which included both a skeletal sample from cadavers of children ($n = 22$) and adults ($n = 94$, 25 females and 69 males). The sample of clavicles probably originated from anatomical dissections. The study deals with a complex assessment of morphological and functional aspects of the clavicle, in particular its thickness, weight and shape. The population affinity (ethnic origin) of the sample was not explicitly stated in the text and it can only be inferred from the author's affiliation (i.e. l'Institut Anatomique de l'Université d'Athènes). The second Greek sample used for comparison originated from the so-called *Cretan collection* [31], consisting of individuals, who died between 1968 and 1998 and were interred at Konstantinos and Pateles cemeteries in Heraklion, Crete. We compared results of these studies with our measurements obtained in the Athens sample. Additionally, we compared the Athens sample with other published samples from around the world. For comparison of the Athens sample with other published samples, we chose the two most commonly used measurements (maximum length, circumference of midshaft) which have well-established and unambiguous definitions.

2.2. Measurements

The following set of measurements was taken by traditional anthropometric instruments directly on each clavicle. Five of the measures defined in the anthropological standards [35,36]; one measure (PHYL) was defined by the authors.

The following measurements were taken on the clavicle:

Maximum length (MAXL) – maximal distance from sternal articular end to acromial articular end measured on the osteometric board.

Physiological length (PHYL) – the distance between sternal articular surface and acromial articular surface measured at the center of articular surfaces using a spreading caliper. (Note: We proposed PHYL after a measurement applied by Parsons [5] but his "*central axis of clavicle on contour*" was obtained with the aid of a dioptrograph, without a clear relationship with the articular surfaces.)

Superior–inferior diameter of midshaft (SIMD) – linear distance connecting the superior and inferior surfaces of the diaphysis measured in the middle of bone length using a sliding caliper.

Anterior–posterior diameter of midshaft (APMD) – linear distance connecting the anterior and posterior superficies of the diaphysis measured in the middle of bone length using a sliding caliper.

Circumference of midshaft (MCIR) – the circumference of the bone measured in the middle of bone length using a tape measure.

Sternal articular surface height (SASH) – distance from the highest to the lowest point of the sternal articular surface measured by sliding caliper.

All measurements were measured with an accuracy of 1 mm and given in mm.

Robustness of the clavicle was expressed using the index of robusticity (RI). Various authors call this index by different names: "*length-circumference index*" [11], "*the thickness index*" [13], "*clavicular robustness*" [23], "*robustness index*" [22] or "*l' indice de robustesse*" [7]. In any case, however, this index represents the ratio between MCIR and MAXL (expressed in %):

$$\mathrm{RI} = \frac{\mathrm{MCIR} \times 100}{\mathrm{MAXL}}.$$

Throughout this study, we evaluated clavicles for each sex and body side separately, and not for pooled samples. So (except when testing measurement error) we always compared and analyzed clavicles divided into four groups: males right, males left, females right, and females left.

2.3. Measurement error

Measurement errors of the six measurements were determined in two ways. Initially, the first 42 individuals in the collection (first set) were re-measured after the first measurement. All measurements were taken on the left clavicle, subsequently on the right clavicle and then it was repeated on left and right clavicles of the same specimen again. Two weeks later another 30 individuals (second set) were measured once again. These skeletons were selected by random sampling (via random number function in Microsoft Office Excel 97). (Note: Four pairs of clavicles were included in both sets because of random sampling.) Measurement error for both sets was expressed as the difference between the first and second measurements. For each measurement, TEM, %TEM, and the coefficient of reliability were assessed [37,38]. Because all measurements were taken by the third author, measurement error represents only intra-observer error.

2.4. Side asymmetry

Side differences in the Athens sample were expressed as a proportion of individuals with a greater value on the right side than on the left side. Furthermore, a simple difference between values for both sides of each individual (Dif = $R - L$, in

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