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Comparing discriminant analysis and neural network for the determination of sex using femur head measurements

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ABSTRACT

The measurement of the femoral head is usually considered an interesting variable for the sex determination of skeletal remains. To date, there are few published reference measurements of the femoral head in a modern European population for the purpose of sex determination. In this study, 116 femurs from 58 individuals of the South of France (Nice Bone Collection, Nice, France) were studied. Three measurements of the femoral head were taken: the vertical head diameter (VHD), the transversal head diameter (THD) and the head circumference (HC). The results show that: (i) there is no statistical difference between the right and left femurs for each of the three measurements (VHD, THD and HC). Therefore we arbitrarily chose to use the measures from the right femurs ($N = 58$) to pursue our experiments; (ii) the measurements of the femoral head are similar to those of contemporary American populations; (iii) the dimensions of the femoral head place the measurements of the French population somewhere between Germany or Croatia, and Spain; (iv) there is no significant secular trend (in contrast with the femoral neck diameter); (v) the femoral head measurement as a single variable is useful for sex determination: a 96.5% rate of accuracy was obtained using THD and HC measurements with the artificial neural network; and a 94.8% rate of accuracy using VHD, both with the discriminant analysis and the neural network.

1. Introduction

Sex determination is of paramount importance in forensic anthropology, because it helps to exclude one sex among missing persons. Several measurements of the femur have been studied for sex determination, including supero-inferior femoral neck diameter [1], the proximal triangle distances [2], non-standard measurements of the proximal femur [3], the bi-epicondylar breadth of the inferior epiphysis [4], the subtrochanteric area [5], and the mid-diaphysis [6].

The femoral head diameter is considered a very significant variable of the femur for the purpose of sex determination [5,7–15]. Variations in sex dimorphism of the bones due to geographical origin [10,16–18], but also secular trends [1,19] justify the updating of published methods. In regards to the diameters of the femoral head, there are obvious differences between populations from Asia [10,17,20], Africa [21,22] and Europe [7,23].

The aim of this work was twofold. First, from a morphological point of view, we estimated the sexual dimorphism of the head of the femur using a contemporary collection of bones (Nice Bone Collection, Nice, France), and compared the dimorphism of this sample with those already published in the literature (from samples taken from other populations). Secondly, from a statistical point of view, we analyzed the predictive accuracy of several modeling techniques. We chose to compare discriminant analysis and artificial neural network because discriminant function

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analysis is a reference in anthropology, being a robust statistical method; and artificial neural network usually improves the accuracy of classification, especially when a single variable is utilized. Furthermore, discriminant analysis is a linear method that assumes that the relationship between a dependent variable and one or several independent variables is linear. However, nothing suggests that the relationship between each of the three measures in this study and the sex of a given human being is also linear. This is the reason why we used a neural network, which is a non-linear technique more likely to embody a non-linear relationship between variables than discriminant analysis.

All the models were built using just one of the three following variables: vertical head diameter (VHD), transversal head diameter (THD), or head circumference (HC).

2. Material and methods

2.1. Sample

A total of 116 right and left femurs from 58 French subjects of European origin (31 male and 27 female) were obtained from the Medical School of the University of Nice Sophia Antipolis (Nice Bone Collection). This collection was started in 1998 and is made up of contemporary individuals ranging in age (in years) from 70 to 95. The collection includes skulls, mandibles and long bones. To overcome ethical issues, the sample consists of bones collected from people who have willed their bodies to science, via a specific legislation. The sex of all specimens is documented. The collection currently includes 116 femurs from 58 individuals, and the collection will be extended in the future.

Bones that showed any type of morphological abnormality of the articular surface, such as arthritis, deformation or malformation, were excluded from the study.

2.2. Measurements of the variables

Vertical head diameter (VHD), and transversal head diameter (THD) are defined as the maximum diameter of the femoral head, taken vertically and horizontally. They were measured using a digital calliper, accurate to the nearest 1/100 mm and recalibrated between each measurement. This definition suffers from some imprecision, because verticality and horizontality depend upon the true position of the bone, or at least of the diaphysis and the neck of the femur, while measuring the head. This is the reason why we defined these two variables thoroughly: (i) VHD was taken with the anterior part of the femur facing the observer, and the arms of the calliper in the same direction as the neck. We put both condyles against the vertical surface of a board, which allows the anterior part of the femur to face the observer in a reproducible manner, and then we put the diaphysis of the femur vertically; (ii) THD was taken by setting the diaphysis of the femur vertically and the arms of the calliper horizontally, with the head of the femur facing the observer, in order to be sure to measure the maximum horizontal head diameter. The head circumference (HC) was the maximum perimeter of the femoral head obtained using a measuring tape.

2.3. Intra- and inter-observer variability

The measurements of each variable was repeated three times by the same observer (intra-observer variability) at three different periods with at least 1 day between each set of measurements. To check whether an analysis of variance for repeated measures is valid and as a consequence interpretable, Mauchly's test for sphericity was used. For each variable, the variances between all possible pairs of groups (i.e., levels of the independent variable) did not show any statistical significant difference (THD: 0.802, VHD: 0.729 and PH: 0.946). The analysis of variance for repeated measures shows the absence of significant statistical difference for each variable.

In order to check inter-observer variability, two observers performed 10 measurements of each of the 3 variables on 10 randomly sorted femurs. The 10 measurements were achieved on 10 different runs with at least 1 day between each run. We did not use a Mauchly's test since there were solely two observers and in such a situation the sphericity assumption does not hold. The Levene's test shows that, for each variable, the variances within each group were statistically identical (p value >0.05). The analysis of variance for repeated measures states that there is no significant difference between the two observers for the THD and VHD variables (p-value >0.05). In contrast, the measurement of the head circumference cannot be reproduced between the two observers.

3. Modeling techniques

3.1. Discriminant function analysis

Discriminant analysis requires a few assumptions to be met for optimal discrimination ability. This method is quite robust against drifts from these assumptions. Optimal discrimination ability is met when the explanatory variable is normally distributed and when the variance–covariance matrices of each group are equal [24]. We therefore checked that: (i) in each group, the distribution of the independent variable was normal; and (ii) the variance–covariance matrices of each group were equal.

To test for normality, we used a Shapiro-Wilk test. The p-values were all greater than 0.05 and therefore the distribution of each variable within its group was normal. We then used a Levene's test to estimate whether the variances of a quantitative variable calculated for two groups or more than two groups were equal. A Levene's test is similar to a Bartlett's test, which is also used to assess the equality of the variance–covariance matrices, but a Levene's test is more robust than the latter to any departure from normality. The variables used in this study are all normally distributed; we chose the Levene's test rather than the Bartlett's test but they both lead to the same conclusions. The p-values of this test show that the variances within each group, for each variable, are statistically equal (p-value > 0.05). Therefore optimal conditions for discriminant analysis are met. Furthermore, the high correlation between variables (THD/VHD: 0.975, THD/HC: 0.986, VHD/HC: 0.985) explains why we were able to use a single variable to design our two models (discriminant analysis/artificial neural network).

Discriminant analysis is a classification technique that, using a set of independent variables, tries to find the linear combination of these variables that best discriminates between observations belonging to a small number of groups, such as male and female. When dealing with a two-group classification problem, the dependent variable is binary and represents each of the two groups. To build a classification model, discriminant analysis calculates a z score for each observation that can be expressed as a linear combination of a set of explanatory variables x_i, and then compares this score to a threshold that represents the boundary between the two groups (male and female). The score is computed as follows:

$$z = w_0 + \Sigma_{i=1 \text{ to } n} w_i x_i$$

where w is the vector of coefficients w_i of the function to be assessed.

A bone will be classified into one of the two groups depending on the value of its z score. The vector w is estimated using a method