***ONE FOR ALL AND ALL FOR ONE*: LINEAR REGRESSION FROM THE MASS OF ISOLATED BONES TO ASSESS HUMAN SKELETAL COMPLETENESS**

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Abstract

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Introduction

The objective of this paper is to investigate the potential of linear regression to estimate the mass of a human skeleton based on the mass of some of its bones. In some cases involving human skeletal remains, it may be difficult to assess how complete the skeleton is due to fragmentation. The implications of this inventory problem are quite obvious in the case of burned skeletal remains. For example, ending forensic searches for the victims remains is difficult to decide if it is impossible to determine if the recovery was complete or not, especially if the vestiges are very fragmented and scattered (for burned, Fairgrieve, 2008?). For example, in the case of archaeological cremations, an exhaustive inventory based on the amount of bones is also often impossible to carry out due to the usually large fraction of anatomically unidentified fragments (Gonçalves et al, 2015). Therefore, alternative methods to assess completeness must be explored.

To our knowledge, the only alternative method to assess skeleton completeness is based on skeletal mass. For that purpose, remains are weighted thus providing an estimation of mass. Then, this value is compared with references obtained from samples of skeletons (e.g. Lowrance and Latimer, 1957; Silva et al., 2009). However, it is forcibly compared against references that are too general and which application is thus uncertain. This happens because skeletal mass is very variable at the population level. It is dependent of several variables such as age at death, sex, stature or ancestry (REF). In addition, skeletal mass is also variable at the individual level and this is mainly the result of different body mass indices and different bone mass densities (REF). Therefore, we can say that the selection of a specific reference for comparison is a leap of faith because it may be completely unadjusted to the case under analysis. Given this problem, we propose to solve it by developing a method to estimate the mass of a skeleton in a case by case basis.

The approach presented in this paper consists in obtaining the mass of the complete skeleton by weighting some of its specific bones. To accomplish this goal, equations of linear regression must be developed from a sample of rather complete skeletons. This approach has the advantage of allowing comparing the mass of the recovered remains against its original estimated mass. Only then, the appraisal of skeletal completeness and scattering can be reliably established. This approach has never been followed before although similar attempts to estimate total skeleton mass have been carried out by Matiegka (1921) and Trotter (1954). However, in these cases, the estimation was based on the metrics of long bones.

If regression analyses are proven to be of value, this method may bring an important benefit to the analysis of human skeletal remains. In archaeological and forensic contexts, it will help estimating their completeness in cases where fragmentation is severe. Another possible contribution of this method is related to the topic of sex estimation, since skeletal weight is sexually dimorphic.

Material and methods

The investigation focused on the 21st century collection of identified skeletons (CEI/XXI) housed at the Department of Life Sciences of the University of Coimbra (Ferreira et al., 2014). The fact that these skeletons are from individuals who died very recently is relevant to this research, since it avoided possible major biases in skeletal mass that may be related to post-depositional differential skeletal mass loss.

A sample of 61 skeletons of both sexes was examined. It comprised 33 females with ages ranging from 38 to 96 years old (mean = 79.0; sd = 14.1) and 28 males with ages ranging from 31 to 95 years old (mean = 74.0; sd = 15.5). The sample comprised skeletons that were complete or almost complete. All skeletal elements were ideally present and well preserved but exceptions were taken into consideration for the following: teeth, hyoid, sternum, hand and foot phalanges. Due to the old age of the individuals composing the sample, skeletons were often edentulous or almost edentulous so the presence of teeth had to be overlooked. As for the remaining non-dental elements, they usually represent less than 3-4% of the overall skeletal weight (based on the results of Silva et al., 2009) so their absence expectantly did not interfere much with the results.

To investigate the correlation of the weight of each bone with the overall skeleton weight, attention was given to certain bones that usually preserve better in very fragmented assemblages such as the ones composed of burned remains (Gonçalves, 2011). Others were selected because they are total body weight bearing bones and may thus be more significantly correlated with skeleton mass. The following isolated bones were weighted: the tarsal bones (body weight bearing bones); the patella; the MCs and MTs. The femur and tibia were also weighted, although they do not meet the two above mentioned criteria. This was merely carried out to allow for a comparison between both groups.

The mass of each separate bone included in the research was documented by weighting it in a Kern digital scale which measures in 0.1 g increments. The total skeleton mass was obtained by... As a pre-analysis procedure, significant bilateral asymmetries in each bone were investigated. This was carried out to determine if both sides of the skeleton had to be treated separately during statistical analysis. If differences from both sides were not substantial, then it would be possible to overcome the absence of a bone by replacing it by its antimere, if available. Bilateral asymmetry was not investigated through inferential statistics such as paired-samples tests or correlation tests because these either look at differences between the means or to the linear dependence of both samples. These tests do not give a real account of bilateral asymmetry in a case by case basis which was more important to assess in this investigation. Therefore, relative directional asymmetry (%DA), which has been often used previously (Steele and Mays, 1995; Mays, 2002; Auerbach and Ruff, 2006), was calculated for each individual instead. The formula used was the following: %DA = (right – left) / (average of left and right) x 100

Linear regression was carried out by using the R software. Regression analysis did not take age and sex into consideration because we assumed that total skeleton mass was directly reflected by the mass of each isolated bone regardless of those variables. In other words, the premise was that any significant effect that age, sex or any other variables may have in the mass of the skeleton has a similar effect on each of the isolated bones investigated in this paper. Therefore, the mass of isolated bones should always be significantly correlated with the total mass of the skeleton to which they belong to. The advantage of such an approach is that, if the regression equations significantly predict skeleton total mass, they can be applied to all cases involving human remains. This is a major benefit because the age at death and sex of the individuals is often unknown in both archaeological and forensic contexts.

Discussion

Skeletal weight may help on the estimation of that parameter, at least in those cases where post-depositional skeletal weight loss is not to be expected (e.g. recent forensic cases; archaeological cremations).

Advantages:

* Applicable to all cases, regardless of age, sex, ancestry, stature, body mass index, etc.