Osteometric Sex Determination of Burned Human Skeletal Remains

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Abstract

Sex determination of human burned skeletal remains is extremely hard to achieve because of heat-related fragmentation, warping and dimensional changes. In particular, the latter is impeditive of osteometric analyses based on references developed on unburned bones. New osteometric references were thus obtained which allow for more reliable sex determinations.

The calcined remains of cremated Portuguese individuals were examined and specific standard measurements of the humerus, femur, talus and calcaneus were documented. This allowed for the compilation of new sex discriminating osteometric references which were then tested on independent samples with good results. Both the use of simple cut-off points and of logistic regression equations provided with successful sex classification scores.

These references may now be used for the sex determination of burned skeletons. Its reliability is improved for contemporary Portuguese and thus has important repercussion for forensic research. Nonetheless, the more conservative use of these references may also prove valuable for other populations as well as for archaeological research.

Keywords: forensic anthropology; bioarchaeology; burned bones; cremains; biological profile; sexual dimorphism.

Introduction

Assessing the biological profile of an individual from its burned remains is a very challenging task. The heat-induced fragmentation as well as other related bone changes considerably difficult bioanthropological analyses because those are extremely impeditive of the use of the conventional methods usually adopted in this field (Thompson, 2004 and 2005). Although the implications are also critical to the research of archaeological remains, this is particularly troublesome for forensic science since positive identification of victims is often only possible if focused on skeletal remains. This is so, because soft tissues are frequently too damaged to allow for facial recognition and also due to the usual degradation of DNA when subjected to high temperatures (Fairgrieve, 2008). As a result, forensic anthropology and forensic odontology often offer the best responses to achieve positive identification and have been quite successful in doing so in the past (e.g.: Schmidt, 2008; Lain et al, 2011).

Positive identification is based on the comparison of ante-mortem and post-mortem features but the assessment of the biological profile helps to narrow down the list of individuals that may be the object of that comparative approach. Biological profiling assumes a significant importance in this process because the determination of sex, age-at-death, stature or ancestry will allow narrowing down that list – through the elimination process of ineligible individuals – and thus save considerable time and resources. Determining the sex of unknown individuals is usually a straightforward procedure on unburned skeletons but the same cannot be said for burned skeletons. Besides fragmentation being particularly destructive of our more morphological sexually dimorphic bones – the pelvis and the skull – heat-induced warping and dimensional changes interfere with our conventional osteometric techniques. The latter is especially damaging because it can range from a bone expansion of 4.5% to a bone shrinkage of 40.1% depending on the type of bone, its mineralization and the temperature at which it was subject to (Strzalko and Piontek, 1974; Herrmann, 1976; Bradtmiller and Buikstra, 1984; Shipman et al, 1984; Holland, 1989; Huxley and Kósa, 1999; Thompson, 2005). Theoretically, this prevents the reliable use of osteometry. Nonetheless, it has been previously demonstrated that this is not necessarily true. Several authors found that sexual dimorphism was still present in the calcined bones of adults (Gejvall, 1969; Van Vark, 1975; Van Vark et al, 1996; Wahl, 1996; Gonçalves, 2011). As a result, it has long been argued that osteometric methods may be of some use for the analysis of burned skeletal remains (Malinowski, 1969; Piontek, 1975 and 1976; Rosing, 1977; Holck, 1986). The biggest problem seems to reside less in its potential but more in determining under which conditions those methods can be applied. It has been confirmed that heat-induced shrinkage is greatest in bones heated at temperatures leading to calcination than in bones that merely present pre-calcination burning. Therefore, osteometry should be more problematic when dealing with calcined bones.

This paper focuses on the potential of osteometry to achieve sex determination in calcined skeletons. It presents new references for the sex determination of unknown individuals through the use of standard measurements of the humerus, femur, talus and calcaneus. In order to investigate this problem, a comprehensive research was carried out in a modern crematorium. The main goal was to assess if osteometric sex determination is reliably achievable in calcined bones. If so, this would be of considerable importance for the bioanthropological analysis of burned bones because opportunities to determine sex in such cases are often rare. Although osteometric features should ideally maintain a supporting role in sex determination and thus leave the main role to the analysis of morphological features, the former may often be the only diagnostic features at our disposal. The validation of additional techniques for sex determination would enhance the probabilities of achieving this key parameter of the biological profile.

Material and Methods

Permission was granted by the municipal authorities of Porto to collect data at the local crematorium after its legal department approved our request. The cremator was a gas-fuelled Diamond Mark III model from J.G. Shelton. The research was carried out on the calcined skeletal remains of individuals that were cremated soon after death – 24 to 48 hours. The sample was not representative of the natural population for a number of reasons. First of all, only adults were chosen for this investigation. In addition, more skeletons from males than females were analysed because the former tended to preserve better thus allowing for a larger number of observations.

The full sample was composed of 401 individuals (168 females and 233 males) with ages ranging from 27 to 99 years-old (mean = 71.4; sd = 15.2). About 90% of the individuals was more than 50 years-old so young adults were poorly represented. When broken down by age cohorts, the 80-89 interval was the largest on the female sample and the 70-79 interval was the largest on the male sample (Table 1).

The intensity of combustion was recorded for every cremation and the descriptive statistics according to three age cohorts are given in Table 2. The duration of the cremation of cadavers ranged between 50 and 250 minutes (mean = 93.8). The maximum temperature of the cremations ranged between 750º C and 1050º C (mean = 925.8). The statistics presented in Table 2 do not include 160 individuals because, in these cases, the cremation procedure was somewhat more intricate thus complicating its codification in terms of the duration of the combustion. More specifically, an important part of the cremation was carried out while the cremator was switched off and taking advantage of the heat that had been previously accumulated inside the chamber. This allowed for the completion of the cremation without resorting to any additional fuelling. Given this, such cremations benefiting from this procedure were not used to calculate the mean durations and maximum temperatures of combustion. The latter was recorded by using 25º C increments.

Only bones free of major osteoarthritic alterations in joint contour and major entheseal changes of the calcaneal tendon and of the distal humerus were measured after cremation. This was done because these alterations are susceptible to interfere with dimensions. In addition, only the measurements carried out on bones presenting the typical colours of calcination – white, light grey and light blue (Shipman et al 1984; Walker and Miller, 2008) – on more than 90% of its surface were selected for this investigation. Bones were subjected to three measurements with a digital calliper and the median value was then recorded in millimetres. The standard measurements included the transverse and vertical head diameters of the humerus (HHTD and HHVD), the epicondylar breadth of the humerus (HEB) and the transverse and vertical head diameters of the femur (FHTD and FHVD) as defined by Martin and Saller (1956).

In addition, the maximum lengths of the talus and the calcaneus (TML and CML) as defined by Silva (1995) were also included. The selection of the standard measurements used in this research followed two main criteria. Firstly, measurements focusing on spongy bone were chosen because this tends to preserve better than compact bone when subject to heat. Secondly, sex discriminating features with associated success rates over 80% were selected. That is the case for the abovementioned humeral and femoral measurements (Wasterlain and Silva, 2000) and for the talar and calcaneal measurements (Silva, 1995).

The intra-observer variation regarding each standard measurement was determined by calculating the technical error of measurement (TEM) on samples of 20 bones (Ulijaszek and Lourie, 1994). Inter-observer variation was not assessed because only one of the authors was daily present at the crematorium. Nonetheless, the standard measurements used in the present research are extensively used by bioanthropologists and theoretically do not raise many replicability problems.

Bilateral asymmetry was investigated in order to determine if left and right measurements presented no significant differences and thus dispense the analysis of both sides. This analysis was not carried out for the humeral epicondylar breadth because the sample size was not sufficient. Sexual dimorphism was investigated on a sub-sample of 370 individuals (154 females and 216 males). For all features, an equal number of females and males was used. The sex-pooled mean values obtained for each standard measurement were used as cut-off points for the sex discrimination of an independent test-sample of calcined skeletons. This was done with the aim of avoiding any possible bias resulting from carrying out the test on the same sample from which the mean values were obtained. In addition, logistic regression equations were also created and tested on an independent test-sample. Logistic regression allows for the analysis and prediction of a dichotomous variable. It is more robust than discriminant function analysis and its use does not require normal distribution of the factors or the equality of variance-covariance matrices in the sub-samples – which in this case, refer to the two sex groups (Saunders and Hoppa, 1997; Cardoso, 2008). The amount of individuals composing the test-samples varied between each standard measurement due to differential preservation of the diagnostic features. Most were mainly composed of males rather than females due to poorer post-cremation preservation of the latter.

All statistical analyses were carried out by using the Statistical Package for the Social Sciences (SPSS, version 14.0).

Results

The absolute TEM for the intra-observer measurements ranged between 0.12 and 0.23 mm while the relative TEM ranged between 0.45% and 1.76%. The coefficient of reliability was of 0.99 for all standard measurements indicating that only a small portion of the measurement variance present in the sample was the result of measurement error. These results demonstrated good repeatability of observations.

Right and left bones were not significantly different at the .05 level (Table 3). The exception was the femoral head vertical diameter but even in this case the difference between antimeres was small – only 0.51 mm with an associated TEM of 0.12 mm. Therefore, the measurements from the right side were selected for the analysis regarding sexual dimorphism and the dimensions of left-sided bones were only used when the right ones were absent. This approach was also followed for the humeral epicondylar breadth although the bilateral asymmetry was not investigated in this case due to small sample sizes. However, and given the results obtained for the other standard measurements, it was assumed that the same outcome was also to be expected in this particular case.

Significant differences at the .01 level were found between females and males in all standard measurements (Table 4). The effect size was very large according to Cohen (1988). The use of the sex-pooled mean values as sex discriminating cut-off points was very successful in all cases but the talar maximum length (Figure 1). The latter was the only one not allowing for correct sex classification above 80%. In this case, although females were correctly identified in all cases, only 75% of the males were attributed to their proper sex.

As for the logistic regression equations (Table 5), this method also allowed sex classification scores over 80% while using any standard measurement (Figure 2). The investigation regarding the combination of two measurements was carried out for both the humerus and the femur. In the first case, the sample was composed of 26 females and 28 males (Table 6). When considered together, the transverse and vertical humeral head diameters significantly predicted whether or not an individual was a male ($\chi2 = 43.03$; $df = 2$; $n = 54$; $p < .001$). This model correctly predicted the sex of all females ($n = 10$) and males ($n = 10$) in an independent test-sample. In the case of the femur, the sample was composed of 32 females and 37 males (Table 7). When considered together, the transverse and vertical head diameters significantly predicted if an individual was a male or not ($\chi2 = 56.17$; $df = 2$; $n = 69$; $p < .001$). The testing of the equations on an independent sample was successful for 90% of both the females ($n = 10$) and males ($n = 10$). No other logistic models were tested due to the small size of the samples.

Discussion

Following the preliminary paper previously published (Gonçalves, 2011), the present results confirmed that sexual dimorphism was still present in calcined bones despite heat-induced dimensional changes. This significant difference was sufficient to allow for the correct sex classification of most individuals although not all diagnostic features were equally successful. The maximum length of the calcaneus was the most sex discriminating feature for both approaches using the millimetric cut-off points and the logistic regression equations. The maximum length of the talus was not very successful while using the first approach but allowed for better sex classification scores while using logistic regression. The combination of two standard measurements (HHTD and HHVD) into a logistic model resulted in additional accuracy regarding the sex classification of the test samples while using the humeral features. In the case of the femur, no additional accuracy was documented by combining FHTD and FHVD into one logistic model.

The findings demonstrated that osteometric sex determination is not impeded by heat-induced dimensional changes of calcined bone. Therefore, this research confirms what was already determined previously by other investigations such as the ones from Van Vark et al (1996) and Wahl (1996). Rather than due to the elimination of sexual dimorphism, part of the problem of using osteometry stands on the lack of references from which reliable assessments may be carried out. Another problem is to decide when those references should be used since heat-induced dimensional changes may be extremely variable. In this research, we relied on the colour of burned bone to select calcined ones. This criterion was very easy to use. As a result, possible differential heat-induced shrinkage between calcined bones was not sufficient to eradicate sexual dimorphism. In addition, another difficulty regarding the use of diagnostic features is related to the fragmentation often present on burned skeletal remains. In this research, the remains of 118 individuals were thoroughly examined and at least one measurable feature was preserved in 92 (78%) of them. Worse preservation is likely to occur for cremains from forensic and archaeological contexts but some applicability of osteometric methods may nonetheless be expected.

It is expectable that population differences prevent these osteometric references to be used on other than Portuguese individuals. The mean dimensions of the humeral and femoral vertical head diameters of Swedish and American samples obtained on previous investigation (Van Vark et al, 1996; Warren and Maples, 1997) were indeed larger than the Portuguese ones (Table 7). Although those studies were carried out several years before ours, the mean stature of both the Swedish and American populations was at the time already larger than the mean stature of present-day Portuguese. That may in part explain the differences observed between the standard measurements of the formers and of the latter. Apart from the American mean stature values – which were recorded by Warren and Maples (1997) for adult individuals with a mean age of 69.8 years old – the other values are only approximate. The Swedish ones were taken from the Level of Living Survey from 1991 and refer to adults with ages between 20 and 56 years-old by 1971, because this was the date at which Van Vark et al collected their data. The Portuguese values were taken from Barroso et al (2005) whose sample was mainly composed of industrial workers with ages ranging from 17 to 65 years-old. As a result, the data presented in Table 7 may not be completely comparable.

They must then be regarded as merely indicative and are here used for rough comparisons.

Contrary to what should be theoretically expected, male Swedish have smaller mean humeral head vertical diameters than Americans while the reverse scenario was found for the femoral head vertical diameter. Other than stature, activity patterns or differential shrinkage may then be in the origin of these differences. This furthermore indicates that osteometric references are population-specific.

The observations were carried out on a large sample but the sub-samples referring to each standard measurement were regrettably much smaller. Although some were indeed composed of a large number of bones – HHVD, FHTD, FHVD and CML – the others presented smaller sub-samples. All allowed for the calculation of sex-pooled means and logistic regression coefficients that led to good sex classification scores but the compilation of larger assemblages would have been advisable. This was not done due to time constraints. The same can be said about the test-samples, especially those referring to females. Larger samples would have allowed for more reliable testing. Even so, it is our understanding that the present test-samples provided good indication of the potential of our osteometric references for calcined bones.

Several authors stated that osteometry has a limited potential for the analysis of burned skeletal remains (Dokladal, 1962; Strzalko and Piontek, 1974; Rosing, 1977; Holck, 1986; Thompson, 2002 and 2004; Fairgrieve, 2008). This is still somewhat true but the present research demonstrated that sex can be osteometrically determined from calcined bones thus following the findings of previous investigations (Gejvall, 1969; Van Vark, 1975; Schutkowski, 1983; Schutkowski and Herrmann, 1983; Holland, 1989; Van Vark et al, 1996). Although the examination of morphological features should be preferentially used for sex determination, heat-related fragmentation of bone often prevents this multivariate approach. As a result, osteometric methods may then assume an important role in these cases.

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