The reliability of osteometric techniques for the sex determination of burned human skeletal remains

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Abstract

The influence of heat-induced shrinkage on the osteometric sexual dimorphism of human skeletons is still poorly known. In order to investigate this issue, a sample composed of 84 Portuguese individuals cremated at a modern crematorium was examined using standard measurements from the femur, the talus and the calcaneus. In addition, sex determination of the sample was attempted by using osteometric standards developed from the Coimbra collection of identified skeletons. This was carried out to assess the extent of the effect of heat-induced shrinkage on the correct classification of known-sex skeletons while using standards developed on unburned skeletons.

Results demonstrated that sexual dimorphism was still observable in the sample of calcined bones despite shrinkage. However, the application of conventional osteometric standards was unsuccessful. As expected, shrinkage caused most females to be correctly classified according to sex, but the sex allocation of males was very poor for all standard measurements.

The results were obtained on a small sample but suggest that univariate metric techniques specifically developed for calcined bones may be valuable for sex determination. This would bring new methodological possibilities for biological anthropology and would enlarge the set of techniques regarding sex determination of burned skeletal remains.

Resumo

O efeito da redução de volume térmico-induzida no dimorfismo sexual de esqueletos está parcamente documentado. De forma a investigar esta questão, algumas medidas-padrão do fémur, do astrágalo e do calcâneo foram examinadas num conjunto de 84 indivíduos Portugueses cremados em crematório moderno. A juntar a isto, a determinação sexual da amostra recorrendo aos protocolos de análise osteométricas desenvolvidos a partir da coleção de esqueletos identificados de Coimbra foi também ensaiada. O objectivo deste procedimento consistiu em avaliar o efeito da redução de volume térmico-induzida no índice de classificação correcta de esqueletos – cujo sexo é conhecido – a partir de protocolos de análise desenvolvidos em esqueletos não-queimados.

Os resultados confirmaram a preservação de dimorfismo sexual em ossos calcinados apesar da redução de volume térmico-induzida. No entanto, a aplicação de referências osteométricas convencionais não foi bem-sucedida. Tal como esperado, a redução de volume conduziu à correcta classificação sexual da maioria das mulheres, mas a mesma operação obteve reduzido êxito no caso dos homens independentemente da medida-padrão testada.

Apesar de obtidos numa pequena amostra, os resultados sugerem que técnicas osteométricas univariadas especificamente desenvolvidas a partir de ossos calcinados podem contribuir para determinações sexuais fiáveis. A sua eventual confirmação trará novas possibilidades metodológicas ao campo da antropologia biológica e por conseguinte ampliará o conjunto de técnicas actualmente adoptadas para a determinação do sexo em restos humanos queimados.

Introduction

The analysis of burned skeletal remains is very challenging because heat-induced changes and fragmentation severely interfere with bone examination and hamper analytical methods commonly used for biological profiling (Fairgrieve, 2008; Piontek, 1975; Thompson, 2002, 2004). Osteometric techniques are especially affected by heat-induced changes on bones, in particular by shrinkage which is caused by dehydration, loss of organic components and by recrystallization followed by fusion of hydroxyapatite crystals (Bradtmiller and Buikstra, 1984; Dokladal, 1962; Hiller et al., 2003; Holden et al., 1995; Grupe and Hummel, 1991; Stiner et al., 1995; Thompson, 2004).

The prediction of sex using osteometric techniques is affected by the differential shrinkage that bones undergo during burning events. Several authors state that percentage of shrinkage is related to the extent of the combustion, being negligible at low temperatures and occurring mainly at temperatures higher than 700º-800ºC (Buikstra and Swegle, 1989; Herrmann, 1977; Shipman et al., 1984; Thompson, 2004). At these temperatures, bones have experienced or are experiencing the four theoretical phases of heat-induced transformation: dehydration occurs at temperatures between 100º and 600ºC; decomposition is related to removal of organic components at 300º to 800ºC; inversion refers to removal of carbonates between 500º and 1000ºC; and shrinkage occurs during the fusion phase at temperatures above 700ºC. These temperature intervals have been revised by Thompson (2004) after Mayne Correia (1997). Buikstra and Swegle (1989) reported less than 6% of shrinkage at temperatures higher than 800ºC but values as high as 30% in size reduction have been observed by Grupe and Hummel (1991). Therefore, a considerable variation in the rate of shrinkage has been detected. This may be related to factors such as type of bone or bone mineral content (Herrmann, 1977; Mayne Correia, 1997).

Despite differential shrinkage, several authors have pointed out that an osteometric approach may have some use regarding the sex determination of individuals based on burned bones (Holck, 1986; Malinowski, 1969; Piontek, 1975, 1976; Rösing, 1977) although its limited potential has been recurrently stated (Dokladal, 1962; Fairgrieve, 2008; Holck, 1986; Strzałko and Piontek, 1974). Nonetheless, the work of several researchers indicated that there is potential for the use of osteometric methods on burned skeletal remains. Gejvall (1969) worked extensively with cremated bones and

pointed out the cranial vault thickness as a valuable sex predictor. Van Vark (1975) and Van Vark et al. (1996) also resorted to mathematical and statistical analysis using standard measurements of several human bones and achieved some success attempting sex diagnosis. Schutkowski (1983) and Schutkowski and Herrmann (1983) demonstrated that burned petrous bones maintain a reasonable degree of sexual dimorphism by using discriminant analyses. As a result of his analyses on modern human cremations, Wahl (1996) indicated the presence of sexual dimorphism in a number of measurements from the skull, the femur, the humerus and the radius (Wahl, 1996). Finally, Thompson (2002) experimentally heated sheep pelves and stated that uniform heat-induced shrinkage does not affect techniques regarding multivariate sex discriminating indices. However, the same author mentioned that differential shrinkage acting over both planes of measurement of a given index interferes with their reliability. Therefore, previous researches suggest that osteometric techniques may contribute considerably to the sex determination of burned skeletal remains despite heat-induced changes.

Although the scoring of morphological traits is not as affected by shrinkage as are standard measurements, in those cases sex determination depends heavily on the scoring of multiple traits. This is often hampered by the extreme skeletal fragmentation caused by heat (Fairgrieve, 2008; Piontek, 1975). If proven to be reliable, osteometric univariate analysis may be useful for burned remains, for which diagnostic features are frequently rare (Wahl, 2008). For unburned bones, several standard measurements allow for univariate analysis with rates of correct classification higher than 80-90%. Therefore, it is important to determine if osteometry is still of some use for burned bones despite differential shrinkage.

This research intends to assess whether the possible differential shrinkage completely eliminates sexual dimorphism from calcined bones, thus preventing the use of univariate metric methods specific to the femur, the talus and the calcaneus. In addition, we document the effect of heat-induced shrinkage on the sex classification rates by osteometric standards conventionally applied to Portuguese populations (Silva, 1995; Wasterlain and Cunha, 2000).

Materials and Methods

Permission was obtained from municipal authorities to carry out measurements of bones after cremation in a modern crematorium. A sample of 84 cremated Portuguese adult skeletons aged between 41 and 99 years was examined in order to assess the reliability of selected femoral, talar and calcaneal standard measurements for sex determination. The sample included 38 females and 46 males. Due to the nature of the sample, the average age of the individuals was extremely high (73.6 years). Although the sample was relatively large, sub-samples for each standard measurement were less numerous due to poor fire-related preservation. Figure 1 illustrates the standard measurements used for this research. These are: the vertical and transverse diameters of the femoral head, and the maximum length of the talus and the calcaneus (Martin and Saller, 1957). All these measurements allowed for rates of correct sex classification higher than 80% in previous studies (Cardoso, 2000; Silva, 1995; Wasterlain and Cunha, 2000). The standard measurements were selected due to their reliability regarding sex determination (Cardoso, 2000; Silva, 1995; Steele, 1976; Wasterlain and Cunha, 2000), their small size and to their trabecular structure which both maximise chances of preservation.

Pre-cremation measurements were not taken. Nonetheless, differential shrinkage between individuals was assumed to be present based on previous research results. According to those results, differential shrinkage has been attributable to the different combustion conditions, to which different bones have been submitted to (Buikstra and Swegle, 1989; Shipman et al., 1984; Thompson, 2002, 2005). Only bones burned at temperatures over 800ºC were measured. The duration of cremation was 60 to 180 minutes depending on the case. The difference in the duration of combustion was mainly due to differential pyrolysis of the soft tissues. In all cases, cremation occurred until complete removal of the soft tissues and bone tissue calcination leading to a typical white colour. Measurements were carried out using a digital caliper (0.01 mm). Each bone was measured three times and the median value was used. Left-sided bones were used for the measurements. Right-sided bones were used when the left ones were absent. However, bilateral asymmetry was not calculated for each standard measurement because poor preservation seldom allowed for the measuring of bones from both sides.

Intra-observer error was assessed by calculating the absolute and relative technical error of measurement and the coefficient of reliability. Two measurements were carried

out, usually with an interval of only a few minutes between them due to time constraints.

Sexual differences for each standard measurement were calculated using an independent-samples t-test. Sex determination was attempted by using cut-off points developed from Portuguese non-burned skeletons of the Collection of Identified Skeletons housed at the University of Coimbra. These standards are conventionally adopted for Portuguese populations. Bones with measurements larger than the cut-off point were allocated to males and measurements smaller than the cut-off point were allocated to females. The statistical analysis was carried out using the SPSS software, version 14.0 (SPSS Inc., Chicago IL).

INSERT Fig. 1 ABOUT HERE

Results

The results for intra-observer variation are presented in Table 1 and demonstrated good repeatability. The descriptive statistics for each standard measurement are presented in Table 2. The results of the t-test for independent-samples showed statistically significant differences between female and male mean dimensions (Table 3). All standard measurements presented statistically significant mean differences at the level $p<0.01$ with a large size effect. Males consistently presented larger measurements than females. Results demonstrated that calcined bones maintained sexual differences in size after cremation.

The results for correct sex determination using the osteometric standards developed for non-burned skeletons are presented in Table 4. The percentage of correct classification was very different between females and males. Most females were correctly classified while most males were incorrectly classified.

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Discussion

Statistically significant differences between female and male mean sizes in burned bones were found for femoral and tarsal standard measurements and could therefore allow for successful sex determination. In these cases, possible differential shrinkage affecting the bones did not eliminate sexual dimorphism. This conclusion refers to calcined bones, which have experienced the dehydration, decomposition, inversion and fusion phases (Mayne Correia, 1997; Thompson, 2004). However, this outcome was obtained on a small sample and further research on a larger sample is required to confirm the current results.

Our results are in compliance with previous research, which have found sexual dimorphism in the size of burned bones (Gejvall, 1969; Schutkowski, 1983; Schutkowski and Herrmann, 1983; Van Vark, 1975; Van Vark et al., 1996; Wahl, 1996).

Standardised osteometric techniques developed using bones from the Coimbra Collection of Identified Skeletons did not successfully determine sex for most of the individuals in the studied sample. The Coimbra standards were developed based on individuals who lived in the 19th century and the first half of the 20th century. A positive secular trend of 89.3 mm was detected for the stature of the Portuguese male population between 1904 and 2000 (Padez, 2003, 2007). No data for Portuguese females are available. However, these have probably also experienced a positive trend, although their increase in height may not have been as substantial as it was for males. Such sexual dimorphism in secular trend was detected in previous studies (Cole, 2000; Kuh et al., 1991). Nonetheless, and given this increase, heat-induced shrinkage could hypothetically act as a correction factor in order to adapt the Coimbra standards to the analysis of burned bones. In other words, because our current cut-off points were calculated based on a population, which has been most probably smaller in size than the present one, bone shrinkage could eventually lead those cut-off points to be somewhat adapted to the latter. However, our results demonstrated that this was not so. Although, all females were attributed to the correct sex, the same did not occur for males. This was an expected outcome of heat-related bone shrinkage (Bradtmiller and Buikstra, 1984; Grupe and Hummel, 1991; Hiller et al., 2003; Holden et al., 1995; Stiner et al., 1995; Thompson, 2004). Although the effect of shrinkage led the dimensions of female bones to keep a smaller size than the cut-off point, it led the bones of several males to move below that very same cut-off point. Only the maximum length of the calcaneus with

69.6% (n = 23) allowed us to obtain a score better than chance on male sex determination.

Along with sex, it would be worthwhile to include age as a factor in order to check whether accuracy in sex determination varies according to age groups. Along with the abovementioned secular trend detected by Padez (2003, 2007), age-related differences in the content of bone minerals (Hiller et al., 2003; Ravaglioli et al., 1996) may be responsible for age variation in heat-induced shrinkage. For these reasons, it would be important to establish whether age and sex together are better correlated with bone measurements than sex alone. This was not carried out because of our very aged and limited sample, which did not allow for an age group analysis.

The results support the development of new univariate osteometric standards specific to the sex determination of calcined bones. Such an achievement would have important implications for both archaeological and forensic sciences. However, the application of such standards may be problematic because the identification of calcined bones is not straightforward. Although macroscopic inspection of bones may be sufficient to identify calcined bones through colour, fractures and warping, it is also prone to error. This is mostly because of taphonomic processes that can mimic those heat-induced changes. One solution it is to rely on techniques such as X-ray Diffraction (XRD) or Fourier Transform Infrared Spectroscopy (FTIR). These techniques have the potential to identify burned bones and to grossly estimate the time and temperature of combustion to which the bones were exposed (Piga et al., 2009; Thompson et al., 2009). If we manage to determine calcination of bone with certainty, then the application of osteometric techniques specific to burned skeletal remains may soon become reliable.

Although the preservation of osteometric features may be uncommon for burned archaeological materials, the same could be stated for morphological features (Fairgrieve, 2008; Piontek, 1975). However, univariate osteometric techniques do not require the multivariate approach that is mandatory for the scoring of morphological features. Therefore, it would improve chances of achieving sex determination of unidentified individuals by enlarging the set of methods suitable for the analysis of burned bones.

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Figure legend

Fig. 1. Standard measurements from the femoral head, the talus and the calcaneus.

Table 1. Results obtained for the Absolute Technical Error of Measurement (TEM), Relative Technical Error of Measurement (%TEM) and the Coefficient of Reliability (R).

Standard Measurement	**TEM (mm)**	**%TEM**	**R**
Femur Head Transverse Diameter	0.12	0.78%	.99
Femur Head Vertical Diameter	0.18	0.84%	.99
Talus Maximum Length	0.13	0.91%	.99
Calcaneus Maximum Length	0.15	0.45%	.99

Table 2. Descriptive statistics for each standard measurement (mm).

Standard Measurement	Sex	N	Mean	Standard Deviation
Femur Head Transverse Diameter	Female	20	34.9	2.83
	Male	22	40.4	2.83
Femur Head Vertical Diameter	Female	20	37.5	2.81
	Male	30	42.6	3.12
Talus Maximum Length	Female	13	45.9	2.06
	Male	17	50.3	3.76
Calcaneus Maximum Length	Female	21	69.4	4.34
	Male	23	77.9	4.94

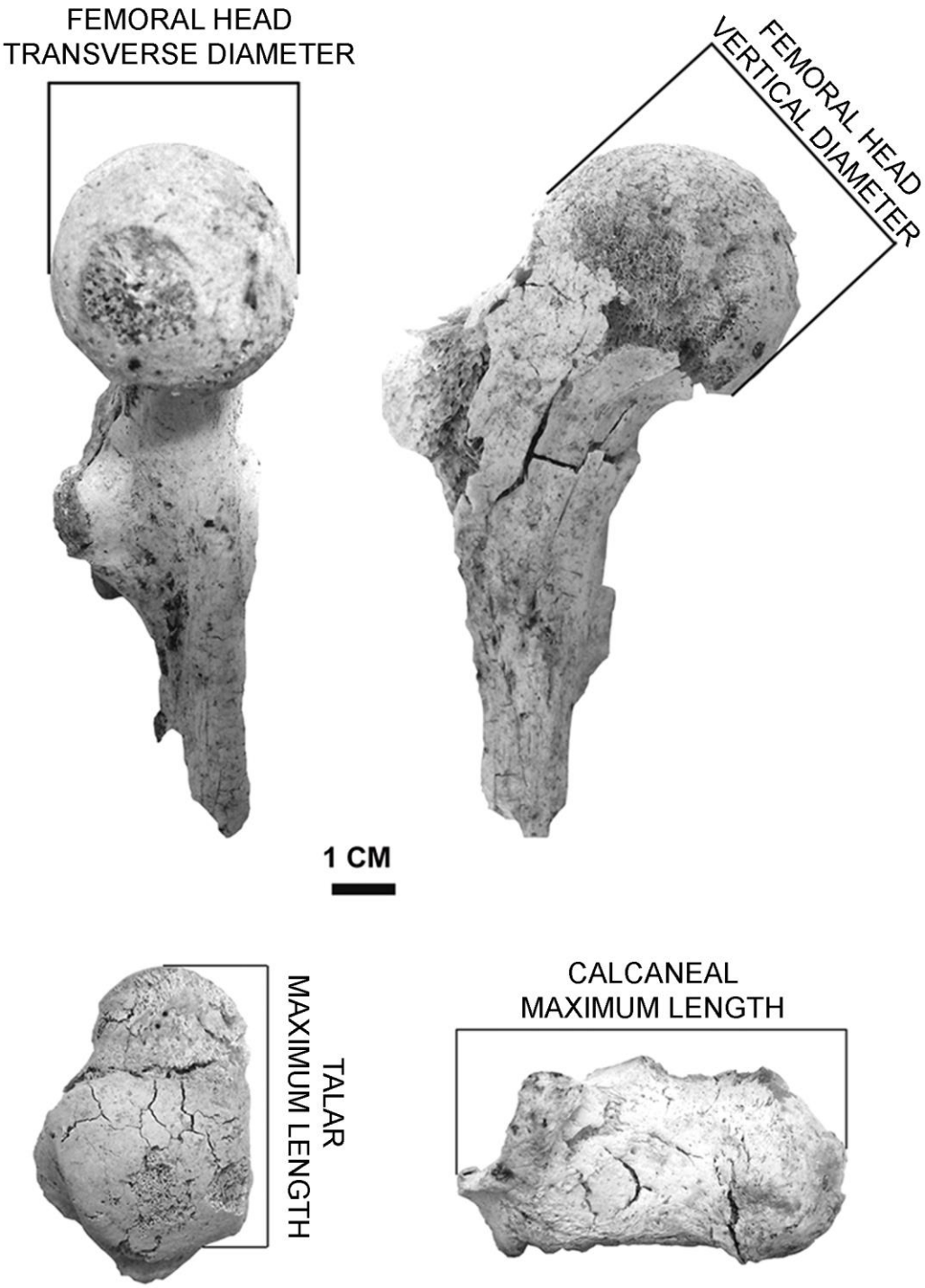
Table 3. T-test results for each standard measurement according to mean measurements for each sex.

Standard Measurement	T-test	df	Sig. (two-tailed)	d
Femur Head Transverse Diameter	6.21	40	.000	1.92
Femur Head Vertical Diameter	5.88	48	.000	1.72
Talus Maximum Length	3.80	28	.001	1.45
Calcaneus Maximum Length	6.09	42	.000	1.85

Table 4. Correct sex classification (C.C.) using standard cut-off points recommended by Wasterlain and Cunha (2000) and by Silva (1995).

Standard Measurement	Sex	N	C.C. (%)
Femur Head Transverse Diameter	Female	20	100.0
	Male	22	22.7
Femur Head Vertical Diameter	Female	20	100.0
	Male	30	53.3
Talus Maximum Length	Female	13	100.0
	Male	17	47.1
Calcaneus Maximum Length	Female	21	95.2
	Male	23	69.6

Fig. 1


FEMORAL HEAD
TRANSVERSE DIAMETER
FEMORAL HEAD
VERTICAL DIAMETER
1 CM
TALAR
MAXIMUM LENGTH
CALCANEAL
MAXIMUM LENGTH