DEAD WEIGHT: VALIDATION OF MASS REGRESSION EQUATIONS ON EXPERIMENTALLY BURNED SKELETAL REMAINS TO ASSESS SKELETON COMPLETENESS

Abstract

In very fragmentary remains, the thorough inventory of skeletal elements is often impossible to accomplish. Mass has been used instead to assess the completeness of the skeleton. Two different mass-based methods of assessing skeleton completeness were tested on a sample of experimentally burned skeletons with the objective of determining which of them is more reliable. The first method was based on a simple comparison of the mass of each individual skeleton with previously published mass references. The second method was based on mass linear regressions from individual bones to estimate complete skeleton mass. The clavicle, humerus, femur, patella, metacarpal, metatarsal and tarsal bones were used. The sample was composed of 20 experimentally burned skeletons from 10 males and 10 females with ages-at-death between 68 and 90 years old. Results demonstrated that the regression approach is more objective and more reliable than the reference comparison approach even though not all bones provided satisfactory estimations of the complete skeleton mass. The femur, humerus and patella provided the best performances among the individual bones. The estimations based on the latter had root mean squared errors (RMSE) smaller than 300 g. Results demonstrated that the regression approach is quite promising although the patella was the only reasonable predictor expected to survive sufficiently intact to a burning event at high temperatures. The mass comparison approach has the advantage of not depending on the preservation of individual bones. Whenever bones are intact though, the application of mass regressions should be preferentially used because it is less subjective.

Keywords: forensic anthropology; bioarchaeology; burned bones; skeletal scattering; skeletal relocation.

1. Introduction

The objective of this paper was to validate the mass regression equations proposed by Gonçalves and collaborators [1] on a sample of experimentally burned skeletons. These equations predict the total mass of a skeleton based on the individual mass of its bones. Such procedure is important to assess the completeness of a skeleton in cases involving extreme fragmentation. Frequently, fragmentation prevents the inventory of skeletal elements since anatomical identification of all fragments is impossible to achieve. This is an important problem that needs solving because information about skeleton completeness may be valuable in several circumstances. It helps recognizing situations of bones scattering during the search of victims and contributes to determine if some of the remains have been moved in forensic settings. Therefore, skeletal mass may often be the most reliable indicator to assess skeleton completeness in very fragmentary remains.

Mass regression equations may be particularly useful to assess the completeness of burned skeletal remains because their fragmentation is usually extreme. In these cases, as well as other ones involving considerable fragmentation, the most preserved skeletal elements are often the smallest ones such as the patella, carpal, metacarpal, tarsal and metatarsal bones [2-4]. Therefore, the equations proposed by Gonçalves et al. [1] that refer to some of these bones should theoretically be well suited to apply on burned skeletal remains. Such applicability is tested in this paper.

Mass is recurrently used to assess skeleton completeness in burned remains but this approach has been relying on simple comparisons with previously published values for individual cremations [5-12]. However, such mass comparison approach encompasses one major limitation. The masses reported in the varied papers present a large variation for adult cremations since it depends on many intrinsic variables such as age-at-death, sex, ancestry and body mass index [7,10-12] as well as extrinsic variables such as burning intensity or mass measuring method [6,12-15]. Based on published references, it may range from 688 g [12] to 5379 g [8] which makes it quite difficult to select an adequate reference to compare against in a case by case basis.

Another limitation of the procedure based on mass comparison is that published references invariably refer to calcined skeletons which hinder comparisons with remains that have been burned less intensively. This occurs because of heat-induced bone mass loss which has been demonstrated to be roughly positively correlated to temperature increase up to 1000^{o} C, although most of it occurs at temperatures below 450^{o} C [13-16]. In theory, the regression approach is not bound to those limitations since it assumes that, regardless of the intrinsic or extrinsic variables, the mass of a bone is significantly correlated to the mass of the complete skeleton. However, for that premise to remain true, the different elements of the skeleton must have ideally been subjected to similar burning intensities. This requirement avoids major mass loss variations across the skeleton that could bias the estimation of the complete skeleton mass.

The hypothesis tested in this paper states that the assessment of skeleton completeness through the regression approach performs better than the mass comparison approach. To test it, the performance of each approach was compared on a sample of experimentally burned human skeletons. If validated, it would give strength to our claim that the regression approach constitutes a valuable and more reliable alternative to the mass comparison approach.

2. Material and Methods

The masses of well preserved and non-pathological femora, humeri, clavicles, patellae, metacarpal, tarsal and metatarsal bones were recorded on a sample of 20 experimentally burned skeletons (10 females and 10 males) from individuals with ages-at-death between 68 and 90 years old. The samples used for each bone are given in Table 1. Although the complete femora, humeri and clavicles are seldom completely recovered when they have been subjected to high temperatures, they were nonetheless included in this research for the purpose of comparison with the remaining bones.

The mass measurements were carried out with a Kern digital scale which measures in 0.1 g increments. The 20 skeletons are part of the 21st Century Identified Skeletal Collection housed at the University of Coimbra [17]. To our knowledge, no other collection comprises identified skeletons that were experimentally burned so this research could not benefit from a larger sample. Maximum temperatures ranging between 500° C and 1050° C and durations between 75 and 195 minutes were attained by the burnings The latter took place in a three-phased electric muffle Barracha K-3 at incremental temperature. Bones from the same skeleton were therefore subjected to equivalent temperatures.

As a curatorial option, only some bones of each skeleton have been experimentally burned while the remaining ones were kept as a reference of the unburned skeleton. Single bones (e.g. sternum; vertebrae) as well as one antimere of each bilateral bone have been left unburned while the other antimere was burned. In some cases, one of the antimeres was absent or one or both of them presented pathologies or taphonomic changes that made them ineligible for experimental burning. This explains the differential sub-samples for each bone (Table 1). Although the entire skeleton mass before burning has been recorded, its after burning mass was not directly available for this study given that only part of the skeleton was actually burned. Only the post-burning mass of one antimere of all bilateral bones was indeed accessible. Therefore, to estimate the expected mass of each skeleton after burning, the mean percentage of mass loss obtained from its individual bones was used. By subtracting this percentage to the pre-burned mass of each skeleton, its theoretical post-burned mass was tentatively predicted. Although obtained indirectly, we believe that this predicted value was not considerably different from the actual value if each skeleton had indeed been entirely burned. Such belief results from the following facts: i) despite the large variation of temperatures and durations, relative mean mass loss of each of the 20 skeletons was similar and ranged between 38.2% and 42.7%; ii) the standard deviation of the relative mean mass loss of each skeleton, obtained from all of its burned bones, was small and ranged between 1.0 and 3.5 (mean = 2.4). With 99% of confidence, relative mass loss of bones from each skeleton was within 1.3 to 5.6 percentage points from the mean. Therefore, heat-induced mass loss presented small variation which gives support to the approach we used to predict the mass of burned skeletons.

The estimated post-burning mass of each complete skeleton was then compared against two kinds of estimates. The first one was composed of the sex-pooled as well as the sex-segregated mean masses of cremated complete skeletons from previously published sources [6-9,11,12]. For that purpose, the root mean square error (RMSE) was used. It refers to the standard deviation of the residuals between the observed (obs) and predicted (pred) values and has the following formula:

$$RMSE = \sqrt{\frac{\sum_{i=1}^{n}(X_{obs,i} - X_{pred,i})^2}{n}}$$

For example, the published reference for the sex-pooled mean mass from Bass and Jantz [8] is 2858.3 g. This value was therefore used as the predicted value for all 20 skeletons. The same formula was used for the second kind of estimates based on mass regressions of individual bones obtained through the regression equations proposed by Gonçalves et al. [1]. The mass of each individual bone taken into consideration in this investigation was used for that purpose. For the predictions, we used the MassReg application which is available at http://osteomics.com/MassReg.

Table 1. Sub-samples of each individual bone used for testing the regression equations.

Bone	n females	n males
Clavicle	9	9
Humerus	10	10
Femur	9	10
Patella	6	7
Metacarpal 1	6	6
Metacarpal 2	8	9
Metacarpal 3	7	8
Metacarpal 4	7	9
Metacarpal 5	7	7
Calcaneus	9	10
Talus	10	9
Cuboid	10	10
Navicular	10	9
Cuneiform 1	10	10
Cuneiform 2	10	10
Cuneiform 3	10	10
Metatarsal 1	9	9
Metatarsal 2	10	10
Metatarsal 3	10	10
Metatarsal 4	9	9
Metatarsal 5	7	6

As for the published references, it should be noted that McKinley [6] and Gonçalves et al. [12] reported complete skeleton masses under two circumstances: before and after a 2 mm sieving of the burned remains. In addition, Gonçalves et al. [12] published complete skeletal masses resulting from the cremation of both fully bodied cadavers and dry skeletons. Expectantly, the latter would be fittest for comparison with our sample since the experimentally burned remains resulted from the burning of dry skeletons from Portuguese individuals that were contemporary to the ones comprising the sample used by Gonçalves et al. [12]. Despite not being completely fit to our sample, all the other above mentioned sources have also been used for comparison to provide a better illustration of the variation among them due to regional differences, distinct weighing methodological approaches (i.e. whether by including or excluding the 2 mm fraction) and differential pre-burning conditions of the remains (cadaver *vs* skeleton). The test of the sex-pooled means on the sex-pooled samples included 20 skeletons while the tests of the female and male means on the female and male samples, respectively, included 10 individuals each.

3. Results

The RMSE of each approach used to estimate skeleton completeness in the sample is presented in Table 2. The best sex-pooled approaches, i.e. those that should theoretically be applied whenever the sex of the individual is unknown, were the ones based on the mass regression of the femur, humerus, patella and clavicle. All had RMSE values below or equal to 400 g.

Whenever sex was known, and although the femoral regression still performed better as an estimator of the complete skeleton mass, the second and third best approaches were based on mass comparisons with published references. These referred to the mean mass values for dry skeletons from male individuals (after removal of the 2 mm fraction) and for cadavers from male individuals (including the 2 mm fraction).

4. Discussion

Generally, the performance of previously published sex-pooled references (RMSE interval between 472.0 and 1170.8 g) was not as good as the regression approach to estimate the mass of the complete skeleton (RMSE interval between 191.9 and 695.9 g). Therefore, the use of the latter whenever the sex of the individual is unknown seems to be advisable.

The performance of mass comparable references was acceptable only in the case of sex-specific ones. In such cases, the comparisons provided estimations that were among those with the smallest RMSE values. Although results seemed to indicate that such sex-specific approaches were equally viable, their application is not straightforward. The selection of comparable references lacks useful criteria. For example, it was logical to select the published mass references theoretically more similar to the case at hand but such procedure was unsatisfactory. For our test sample, the most analogous references were theoretically the ones from Gonçalves et al. [12] that refer to the sex-specific complete mass of dry skeletons (thus including the 2 mm fraction) from Portuguese contemporary individuals. These features were all shared by the test sample but the best performance was, unexpectedly, not provided by such sex-specific references. In fact, three other references performed better in comparison to the male reference. Two of them were actually from McKinley's [6] British sample of cremated cadavers. One of these references even referred to partial remains, i.e. excluding the 2 mm fraction. The performance was even worse for the Gonçalves et al. [12] female-specific reference which was only the 14th best performer among the previously published mass references and 32nd best overall. Therefore, the theoretical criteria did not guarantee the fittest selection of comparable references.

Table 2. Root mean squared error of both the mass regressions and the reference comparison approaches tested on a sample of experimentally burned skeletons (N = 20). Results are ordered from lowest to highest values and refer to grams.

Approach	RMSE	Approach (cont.)	RMSE (cont.)
Femur regression	191.9	Cuboid regression	590.6
Partial Skeleton ♂ (Gonçalves et al.)	225.2	Complete Skeleton ♀+♂ (Gonçalves et al.)	596.3
Complete Cadaver ♂ (McKinley)	266.2	Metacarpal 5 regression	598.3
Humerus regression	288.1	Cuneiform 3 regression	608.8
Patella regression	297.6	Metacarpal 1 regression	622.3
Partial Cadaver ♂ (McKinley)	351.7	Complete skeleton ♀ (Gonçalves et al.)	626.4
Complete Skeleton ♂ (Gonçalves et al.)	375.5	Navicular regression	615.2
Clavicle regression	400.2	Partial Cadaver ♀+♂ (Gonçalves et al.)	637.8
Complete Cadaver ♀ (McKinley)	401.4	Complete Cadaver ♀ (Warren and Maples)	654.6
Metatarsal 1 regression	411.6	Metacarpal 5 regression	666.7
Partial Skeleton ♀ (Gonçalves et al.)	416.2	Cuneiform 2 regression	695.9
Metacarpal 3 regression	418.8	Complete Cadaver ♂ (Chirachariyvej et al.)	705.9
Metatarsal 4 regression	440.1	Complete Cadaver ♀+♂ (Chirachariyvej et al.)	873.0
Metacarpal 2 regression	460.6	Complete Cadaver ♀ (Gonçalves et al.)	888.7
Metatarsal 3 regression	470.5	Complete Cadaver ♀ (Chirachariyvej et al.)	893.2
Partial Skeleton ♀+♂ (Gonçalves et al.)	472.0	Complete Cadaver ♀+♂ (Warren and Maples)	898.4
Complete Cadaver ♀+♂ (McKinley)	473.6	Complete Cadaver ♂ (Warren and Maples)	909.8
Partial Cadaver ♂ (Gonçalves et al.)	484.4	Complete Cadaver ♀ (Van Deest et al.)	1000.2
Partial Cadaver ♀ (McKinley)	496.0	Complete Cadaver ♂ (Gonçalves et al.)	1050.8
Calcaneus regression	510.4	Complete Cadaver ♀ (Bass and Jantz)	1104.0
Partial Cadaver ♂ (Gonçalves et al.)	518.5	Complete Cadaver ♀+♂ (Gonçalves et al.)	1119.8
Cuneiform 1 regression	523.1	Complete Cadaver ♀+♂ (Van Deest et al.)	1170.8
Metatarsal 2 regression	530.3	Complete Cadaver ♂ (Van Deest et al.)	1242.4
Talus regression	537.4	Complete Cadaver ♀+♂ (Bass and Jantz)	1282.4
Metacarpal 4 regression	557.5	Complete Cadaver ♂ (Bass and Jantz)	1387.1
Partial Cadaver ♀+♂ (McKinley)	587.9		

Key: Complete cadaver = mean mass of burned skeletal remains including the 2 mm fraction; Partial cadaver = mean mass of burned skeletal remains excluding the 2 mm fraction; ♀+♂ = sex-pooled mean mass applied to the sex-pooled sample; ♀ = female mean mass applied to the female sample; ♂ = male mean mass applied to the male sample.

The choosing of comparable references thus encompasses an important subjectivity since the use of selection criteria does not seem to reduce it. Therefore, the large mass variation observed among the different published references [5-12] is a serious shortcoming of the application of the comparative approach, simply because the selection of comparable sources is too arbitrary. The regression approach is not limited by such concerns. However, it also has its own limitations. The major one regards its applicability to burned skeletal remains. The femur, the humerus and the clavicle regressions were among the best performances but these bones are hardly recovered intact from contexts involving this kind of remains [3]. Regrettably, smaller bones such as the small tarsals provided some of the less useful performances at predicting complete skeleton mass (RSME higher than 523.1 g). Since these are usually expected to be among the better preserved bones after a burning event [3], their poor performance considerably reduces the applicability of the regression approach. Most of the other smaller bones did not yield much better performances either. The most notable exception was the patella whose regression resulted in a RMSE slightly lower than 300 g. This was somewhat unexpected since Gonçalves et al. [1] reported a RMSE larger than 400 g for this bone. Also, it is not a weight bearing bone so, when compared to other bones that serve such function, this stronger association to complete skeleton mass was somewhat surprising.

Another shortcoming of the regression approach is that, besides relying on intact bones, its correct use depends on their mass not being altered in any fashion. That is often the case with bones that have been inhumed. Additional post-depositional mass loss is expectable under such circumstances due to the loss of water and organics [18,19] that may have survived the burning event. Also, dirt can sometimes infiltrate the bone thus inadvertently inflating its mass [20]. However, these problems are not exclusive to the regression approach. It also affects comparisons with previously published references. This mass inflation issue is probably more problematic for archaeological remains though. Apparently, the skeletons of our sample were not considerably affected by dirt infiltration despite having been buried for 6 to 10 years. A similar situation would therefore be expectable in most forensic cases involving the burial of human remains. Besides that, many other forensic skeletal remains are not buried. For instance, that was the case of the recent Grenfell Tower fire in London (UK) and the Pedrógão Grande bushfires (Portugal) which caused the death of dozens of people.

Beside further demonstrating the uneven correlation power that individual bones maintain with complete skeleton mass, this investigation made another interesting find. The regression approach based on the references from Gonçalves et al. [1] performed poorly whenever skeletons presented unusually small masses. That was the case of two female skeletons with complete masses of 718 g and 685 g who were 83 and 88 years old at the moment of death, respectively (the other 8 female skeletons presented a mean mass of 1476 g and all had ages-at-death above 77 years old). The regression approaches mistakenly doubled their complete skeleton masses. This result suggests that the application of regressions is not advisable whenever skeletal remains are unusually light, which may be a result of physiological bone mass loss which leads to osteoporosis and osteopenia [8,10,12,21,22]. While this could have been accounted for, by training models with spline regressions or similar techniques, doing so would most likely cause overfitting. Since the models presented in Gonçalves et al. [1] are intended to be the least restricted as possible, retraining models that would account for unusually light skeletal mass was not attempted. As expected, all individual bones regressions presented lower RMSE values when those two skeletons were removed from the sample. For example, the patella RMSE lowered to 225.3 g while the RMSE for long bones lowered 58 g for the clavicle, 55 g for the humerus and 35 g for the femur. Therefore, the detection of high levels of osteoporosis may prevent the prediction of mass. This may be difficult to determine however, especially in very fragmentary skeletons or in remains that have been subjected to taphonomic mass loss as is the case of those subjected to high temperatures or subjected to diagenetically intense inhumation periods leading to the loss of organics and water [14,18,19]. Other pathologies such as DISH or traumatic events such as amputation may also interfere with the evaluation of skeleton completeness and their identification may be equally challenging.

The apparent considerable loss of bone mass observed in the two female skeletons mentioned above reinforces Gonçalves et al. [1] claim that these regression equations may not be fit for all cases. The regressions were developed on an age-skewed sample [17], i.e. mainly composed of old individuals with a mean age of 76 years old and proved useful in our test sample which was also composed of older individuals. However, since bone mass depends on age, the equations may not be entirely representative of all age groups since the correlation between the mass of specific bones and the mass of the skeleton may differ in function of age. Therefore, an effort should be made to age diversify future modelling samples and provide a clearer picture on this issue.

Gonçalves et al. [1] proposed that the mass of each bone is sufficiently and significantly correlated to the complete skeleton mass to allow for the prediction of the latter regardless of age-at-death, sex, bone mineral density, pathologies or any other variables. This proposition was described as the "one for all" assumption. It is somewhat naïve because bone mass is multifactorial [8,10,21] and it has been demonstrated that some important variation may occur [23-24]. This was further supported by our test which found evidence that bone mineral density may interfere with the results. However, that assumption was deliberately designed to grant the regression approach a more general applicability [1] and our results seemed to confirm this claim. If the above mentioned variables were a pre-requisite for the application of specific linear regressions, much of its applicability would be lost since such information is seldom available for very fragmentary remains. That is often the case of burned skeletal remains as well. Also, we should note that our test demonstrated the usefulness of mass regression on bones burned dry, but no direct extrapolation can be made for bones burned fresh at this time, especially because differential exposure of bone to heat, as is the case in bones with soft tissues, may lead to different heat-induced bone changes as was observed by Ellingham et al. [25]. As a result, soft tissue may affect mass loss and the application of the regression formulae proposed by Gonçalves et al. [1] should be made with caution. Signs of heterogeneous exposure, such as those provided by the skeleton's colour pattern [26-27] may alert the examiner to this potential problem. However, we should restate that most mass loss occurs at low to medium temperatures. As a result, even a very diversified palette of colours representative of high and medium temperatures may not be impeditive of the MassReg application.

In addition, basing the estimation in single linear regressions can be misleading. It was not rare, within each skeleton, to find one or more bones providing complete mass estimations that were quite contrasting with the predictions from the remaining bones. Therefore, several bones should ideally be used to assess if the multiple intra-skeleton estimations are mutually consistent.

The test of the performance of two different methods to estimate the complete human skeleton mass on a sample of burned skeletal remains suggests that the regression approach offers considerable advantages over the mass comparison approach. It appears to be less subjective and therefore less prone to error. Whenever intact diagnostic bones are present, especially those demonstrated to perform better, the regression method should be preferentially used. The implications for the analysis of burned skeletal remains are of major consequence since this approach more reliably estimates the completeness of a skeleton. As a result, identifying eventual scattering or relocation of remains as well as recognizing the presence of more than one individual in any given assemblage based on its mass can be carried out more confidently than by merely comparing skeletal mass with previously published references. To accurately estimate the completeness of a skeleton is especially crucial during the recovery of human remains from disasters such as the ones of the Grenfell Tower and Pedrógão Grande. The efficacy of anthropological examinations is positively correlated with the efficiency of the field recovery [28] and determining that remains are incomplete may lead experts to revisit the scenes looking for the missing elements. That was the case in 2009, when 86 revisits to the Victorian bushfire scenes allowed to find 56 additional assemblages of human remains [29]. Since a comprehensive skeletal inventory may not be possible in cases of extreme fragmentation, skeletal mass may help the expert to determine if revisits to the scene are indeed necessary.

The benefits do not apply only to forensic settings but rather extend to archaeological ones as well. For example, skeleton completeness may be important to discriminate between primary and secondary funerary practices. Even though additional validations must be carried out to further demonstrate the usefulness of mass regression analysis, results obtained so far indicate that this kind of approach is quite promising.

Acknowledgments

References

[1] D. Gonçalves, J. d'Oliveira Coelho, M.A. Acosta, C. Coelho, F. Curate, M.T. Ferreira, M. Gouveia, C. Makhoul, D. Pinto, I.O. Santos, A. Vassalo, D. Navega, E. Cunha, One for all and all for one: linear regression from the mass of isolated bones to assess human skeletal mass completeness, Am. J. Phys. Anthropol. 160(3) (2016) 427-432.

[2] A. Defleur, T. White, P. Valensi, L. Slimak, É. Crégut-Bonnoure, Neanderthal Cannibalism at Moula-Guercy, Ardèche, Science 286 (1999) 128-131.

[3] D. Gonçalves, Cremains: the value of quantitative analysis for the bioanthropological research of burned human skeletal remains, Department of Life Science, University of Coimbra, Coimbra, 2011.

[4] S.M. Bello, P. Saladi, I. Cáceres, A. Rodríguez-Hidalgo, S.A. Parfitt, Upper Palaeolithic ritualistic cannibalism at Gough's Cave (Somerset, UK): The human remains from head to toe, J. Human Evol. 82 (2015) 170-189.

[5] A. Malinowski, R. Porawski, Identifikations Möglichkeiten menschlicher Brandknochen mit besonder Berücksichtigung ihres Gewichts, Zacchia 5 (1969) 1-19.

[6] J. McKinley, Bone fragment size and weights of bone from British cremations and the implications for the interpretation of archaeological cremations, Int. J. Osteoarchaeol. 3(4) (1993) 283-287.

[7] M.W. Warren, W.R. Maples, The anthropometry of contemporary commercial cremation, J. Forensic Sci. 42(3) (1997) 417-423.

[8] W.M. Bass, R.L. Jantz, Cremation Weights in East Tennessee, J. Forensic Sci. 49(5) (2004) 901-904.

[9] T. Chirachariyavej, C. Amnueypol, S. Sanggarnjanavanich, M. Tiensuwan, The relationship between bone and ash weight to age, body weight and body length of Thai adults after cremation, J. Med. Assoc. Thai. 89(11) (2006) 1940-1945.

[10] S.E. May, The Effects of Body Mass on Cremation Weight, J. Forensic Sci. 56(1) (2011) 3-9.

[11] T.L. Van Deest, T.A. Murhad, E.J. Bartelink, A re-examination of cremains weight: sex and age variation in a Northern Californian sample, J. Forensic Sci. 56(2) (2011) 344-349.

[12] D. Gonçalves, E. Cunha, T.J.U. Thompson, Weight references for burned human skeletal remains from Portuguese samples, J. Forensic Sci. 58(5) (2013) 1134-1140.

[13] G. Grupe, S. Hummel, Trace element studies on experimentally cremated bone. I. Alteration of the chemical composition at high temperatures, J. Archaeol. Sci. 18 (1991) 177-186.

[14] A. Person, H. Bocherens, A. Mariotti, M. Renard, Diagenetic evolution and experimental heating of bone phosphate, Palaeogeograph., Palaeoclimatol., Palaeoecol. 126 (1996) 135-149.

[15] S. Enzo, M. Bazzoni, V. Mazzarello, G. Piga, P. Bandiera, P. Melis, A study by thermal treatment and X-ray powder diffraction on burnt fragmented bones from tombs II, IV and IX belonging to the hypogeic necropolis of ‘‘Sa Figu’’ near Ittiri, Sassari (Sardinia, Italy), J. Archaeol. Sci. 34 (2007) 1731-1737.

[16] L.E. Munro, F.J. Longstaffe, C.D. White, Burning and boiling of modern deer bone: effects on crystallinity and oxygen isotope composition of bioapatite phosphate, Palaeogeograph., Palaeoclimatol., Palaeoecol. 249(1-2) (2007) 90-102.

[17] M.T. Ferreira, R. Vicente, D. Navega, D. Gonçalves, F. Curate, E. Cunha, A new forensic collection housed at the University of Coimbra, Portugal: The 21st century identified skeletal collection, Forensic Sci. Int. 245 (2014) 202.e1-202.e5.

[18] M.J. Collins, C.M. Nielsen-Marsh, J. Hiller, C.I. Smith, J.P. Roberts, R.V. Prigodich, T.J. Wess, J. Csàpo, A.R. Millard, G. Turner-Walker, The survival of organic matter in bone: a review, Archaeometry 44(3) (2002) 383-394.

[19] L.P. Karr, A.K. Outram, Bone degradation and environment: understanding, assessing and conducting archaeological experiments using modern animal bones, Int. J. Osteoarchaeol. DOI: 10.1002/oa.2275 (2012).

[20] D. Gonçalves, V. Campanacho, T.J.U. Thompson, R. Mataloto, The weight of the matter: examining the potential of skeletal weight for the bioarchaeological analysis of cremation at the Iron Age necropolis of Tera (Portugal), in: T.J.U. Thompson (Ed.), The Archaeology of cremation: Burned human remains in funerary studies, Oxbow Books, Oxford, 2015, pp. 63-96.

[21] A.M. Silva, E. Crubézy, E. Cunha, Bone Weight: new reference values based on a modern Portuguese identified skeletal collection, Int. J. Osteoarchaeol. 19(5) (2009) 628-641.

[22] F. Curate, A. Albuquerque, J. Correia, I. Ferreira, J.P.d. Lima, E.M. Cunha, A glimpse from the past: osteoporosis and osteoporotic fractures in a portuguese identified skeletal sample, Acta Reum. Port. 38 (2013) 20-27.

[23] B.L. Riggs, H.W. Wahner, W.L. Dunn, R.B. Mazess, K.P. Offord, L.J. Merton III, Differential changes in bone mineral density of the appendicular and axial skeleton with aging: relationship to spinal osteoporosis, J. Clin. Invest. 67(2) (1981) 328-335.

[24] B.L. Riggs, L.J. Merton III, Involution osteoporosis, N. Engl. J. Med. 314(26) (1986) 1676-1686.

[25] S.T.D. Elligham, T.J.U. Thompson, M. Islam, The Effect of Soft Tissue on Temperature Estimation from Burnt Bone Using Fourier Transform Infrared Spectroscopy, Journal of Forensic Sciences, 61 (2016) 153-159.

[26] S.A. Symes, C. Rainwater, E. Chapman, D.R. Gipson, A. Piper, Patterned thermal destruction of human remains in a forensic setting, in: C. Schmidt, S. Symes (Eds.) The Analysis of Burned Human Remains, Academic Press, London, 2008, pp. 15-54.

[27] S.A. Symes, E.N. L'Abbé, J.T. Pokines, T. Yuzwa, D. Messer, A. Stromquist, N. Keough, Thermal alteration to bone, in: J.T. Pokines, S.A. Symes (Eds.) Manual of Forensic Taphonomy, CRC Press, Boca Raton, Florida, 2014, pp. 367-402.

[28] A.J. Hill, R. Lain, I. Hewson, Preservation of dental evidence following exposure to high temperatures, Forensic Science International, 25 (2011) 40-43.

[29] S. Blau, C.A. Briggs, The role of forensic anthropology in Disaster Victim Identification (DVI), Forensic Science International, 205 (2011) 29-35.