THE ESTIMATION OF THE PRE-BURNING CONDITION OF HUMAN REMAINS IN FORENSIC CONTEXTS

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ABSTRACT

The determination of the original condition of human remains prior to burning is critical since it may facilitate the reconstruction of circumstances surrounding death in forensic cases. Although the use of heat-induced bone changes is not a completely reliable proxy for determining pre-burning conditions, it is not completely devoid of potential, as we can observe a clear difference in the occurrence of such features between fleshed and dry bones. In order to quantify this difference and determine its true value for forensic research, the frequencies of heat-induced warping and thumbnail fractures were documented on modern cremations of cadavers from recently deceased individuals and from the cremations of skeletons previously inhumed. The effect of age, sex, time span from death to cremation, duration and temperature of combustion on those frequencies was statistically investigated.

Results demonstrated that the heat-induced features were significantly more frequent in the sample of cadavers. In addition, warping was determined to be the most useful indicator of the pre-burning condition of human remains. Temperature of combustion was the only variable having a significant effect on the frequency of both features suggesting that fluctuation of temperature, along with collagen preservation and recrystallization of the inorganic phase, is paramount for their occurrence. Both warping and thumbnail fractures may eventually be used for the estimation of the pre-burning condition of human remains in lack of other indicators but their reliability is far from absolute. Ideally, such inference must be supported by other data such as skeletal representation, objects or defleshing marks on bones.

Keywords: Biological Anthropology; Forensic Anthropology; Taphonomy; Cremation; Burned Bones; Fractures.

INTRODUCTION

The determination of some of the circumstances surrounding death may allow for important inferences in both forensic and archaeological scenes. In the latter, this is partly done in order to reconstruct past funerary practices [1]. In forensic science, establishing the pre-burning condition of human remains is important to assess if fire or any other heat source was either used in perimortem or post-mortem moments. The criminal law implications of the two possibilities may be quite distinct. While the first one implies that burning of the human body was directly related to death, the second may have occurred several years after death and thus unrelated to the event that caused it. The length of the sentence may thus be considerably different, depending on the case. However, identifying this distinction is rarely straightforward.. One proposal to achieve it has been based on the premise that heat-induced bone changes vary according to the pre-burning condition of the human remains – especially bone warping and thumbnail fractures [1, 2-7]. However, it has been demonstrated that this alone is not enough to make such distinction [1, 4, 5, 7] and further research is needed before reliable inferences can be carried out. The present paper aims to take this debate a step forward in light of new data obtained on cremated remains from a modern crematorium.

As mentioned previously, warping (Fig. 1) may be used as a proxy for determining the pre-burning conditions of the remains [2, 3, 6], however, this claim has been disputed by several studies [1, 4, 5, 7]. Baby [2] experimentally burned a whole fleshed cadaver, some dissected green bones and some dry bones. Binford [3] used the corpse of a monkey, recently macerated bones and archaeological bones for his experimental burnings in a charcoal fire. These authors did not find any warping in the sample of dry bones. At that time, it seemed clear that warping only occurred in fresh bones and this was furthermore supported by Thurman and Wilmore [8] who had obtained the same results on 8 recent human humeri burned in an oak fire – half of them still fleshed and the other half defleshed by caustic methods. The first contrasting results were presented in 1986 at the V International Conference of Archaeozoology and later published by Spennemann and Colley [5]. These authors found warping on an experimentally burned archaeological human humerus and this observation was later confirmed by Buikstra and Swegle [4]. As a result of burning archaeological human bones, fleshed human bones and recently defleshed bones in open-air oak fires, bone warping was found in each of the three variants. Contrasting results kept on being obtained afterwards demonstrating that other factors beside the mere presence or absence of soft tissues have a significant effect on the occurrence of heat-induced warping. Etxeberria [6] only found warping on recently defleshed human bone, failing to do so in dry bones. As for Whyte [7], warping was equally present in fleshed, recently defleshed and dry faunal bones cremated on open-air experimental pyres. More recently, Gonçalves et al. [1] demonstrated that warping could be present in dry human bones burned at a modern crematorium fuelled by gas, thus not being exclusively linked to the burning of fleshed bones or to recently defleshed bones.

The reason for the occurrence of heat-induced warping is still unknown and several explanations have been proposed. Binford [3] suggested that it could be due to the contraction of muscle fibres. Bone bending due to the action of heat trapped in the shaft hollow has also been suggested [5]. Differently, Thompson [9] argued that warping could be the result of

differential periosteum contraction because of the anisotropic distribution of bone collagen within bone. In addition, Gonçalves et al. [1] also proposed that this event could be due to collagen contraction and be dependent of the preservation of the collagen-apatite bonds and therefore not completely related to the presence of soft tissues.

Thumbnail fractures have also been linked to the pre-burning condition of the remains. Symes et al. [10, 11] argue that the contraction of kinetically charged protective tissue during heating gradually exposes the wet bone surface to direct combustion. During this process, thumbnail fractures and concentric rings may occur. Although this may explain the occurrence of thumbnail fractures in fleshed bone, their occurrence in dry bone is yet to be explained. Gonçalves et al. [1] suggested that it may also be related to collagen preservation. Several authors did not observe thumbnail fractures after the burning of dry bones [2-3] in contrast to the observations of other researchers [1, 5], 2011). Other heat-induced fractures have been pointed out as indicators of the pre-burning condition of remains, but observations here have gathered even less consensus than thumbnail fractures (for a review, consult Gonçalves [12]).

Undoubtedly, the use of heat-induced warping and thumbnail fracturing for establishing the pre-burning condition of human remains is not completely reliable. However, there seems to be some potential in it. With this in mind, we analysed several modern cremations in order to determine the actual differences between cadavers of recently deceased individuals and dry skeletons regarding the frequencies of those features.

MATERIAL AND METHODS

Permission was obtained to carry out our observations on two different samples at a civil crematorium. A sample composed of 96 cadavers from individuals cremated soon after death was thus analyzed. It contained adults with ages ranging from 35 to 97 years-old (mean =71.4; sd = 14.7) and included 41 females and 55 males. The cremations lasted between 60 and 145 minutes (mean = 98.7 minutes; sd = 25.7) for 58 cadavers. The remaining cadavers were burned with the cremator switched off – that is, profiting from the accumulated heat from previous cremations. This was usually done for the last cremation of the day. The remains were then left to cool overnight therefore being removed from the cremator only on the subsequent morning. The remains resulting from this kind of procedure were, like on any other cremation, completely calcined. Although the heat-induced changes here investigated may happen at lower temperatures as can be seen for the tibia in Fig. 1 – burned at 600^{o} C – only skeletons subjected to maximum cremation temperatures that varied between 750^{o} and 1050^{o} C (mean = 944.0; sd = 60.7) were used in the analysis so that all remains were completely calcined. All cadavers were cremated fully dressed and enclosed in wooden coffins.

In addition, a second sample composed of 88 skeletons from adults was examined. Only 56 of these were of known age which ranged from 23 to 99 years-old (mean = 69.7; sd = 17.3) although the remaining individuals were all adults. Although the name of all individuals was known, unfortunately some were not found on the civil records thus preventing us to know their age-at-death. The sample was composed of 41 males and 47 females which had been previously inhumed for at least five years before exhumation and subsequent cremation.

The mean inhumation period was of 15.2 years (sd = 14.1; min. = 5; max. = 72). All macroscopic indications of soft tissue had completely decomposed during inhumation. The cremation of 79 skeletons ranged between 15 and 105 minutes (mean = 34.8 minutes; sd = 20.7) while the remaining skeletons were burned and left to cool overnight following the procedure described above. The mean maximum temperature was of 750.0º C (sd = 141.5). The skeletal remains were cremated in a rather diverse manner. Some were put inside plywood boxes, others were merely wrapped in a shroud and the remaining ones were placed directly on the cremator on top of a plywood board.

The cremation itself varied widely due to the requirements of each assemblage of human remains. The number of active burners and the oxygen intake was often altered by the technicians during the cremation according to its progress. Cremation efficiency could depend, among other factors, on the biological profile of the deceased, the pre-cremation condition of the remains, the pre-cremation heating status of the cremator and the type of container used for the confinement of the remains.

The skeletal remains were inspected after cremation and before pulverization for heat-induced features. Bones were checked for unusual bending of the diaphyses and at their heat-fractured ends to assess warping (Fig. 1). Thumbnail fractures were searched for on the diaphyses of long bones (Fig. 2). Other bone regions may eventually display these features, but those were not systematically observed for this investigation. Age, sex, duration and maximum temperature of combustion, bone and the bone region where the heat-induced feature was detected were recorded whenever possible. Time span between death and cremation was also documented for the skeletons from the second sample.

Differences between the group of skeletons presenting warping and the group of skeletons not presenting it were investigated by using non-parametric Mann-Whitney tests. Age, time span from death to cremation and maximum temperature of combustion were taken into consideration but sex and duration of combustion were not analysed due to small sample sizes. Multivariate associational statistics were not used due to undersized sub-samples. Age, time span and maximum temperature were used as ratio scaled variables.

Two logistic models were tested for significant association to thumbnail fractures. The sample-size requirements were calculated according to Peduzzi et al. [13]. The first model (biological model) considered age, sex and time span from death to cremation and was tested to investigate if biological parameters had a significant effect on the frequency of thumbnail fractures. Time span was added to this model as a proxy for post-depositional degradation of collagen, since no account of this variable could be carried out at the crematorium. Sex was used as a dichotomous variable (male; not male). The second model (combustion model) included duration and maximum temperature of combustion and thus referred to the intensity of combustion. Logistic regression was used for this analysis and post-hoc testing was carried out using the two independent samples Student t-test. The main goal was to assess if the interaction of several factors had any significant effect on the frequency of thumbnail fractures rather than to find any predictive models. Duration of combustion was divided into three ordinal groups (0-25’; 26-110´; overnight cremation). This was done for statistical purposes –

to make sure that all sub-samples were well sized. The statistical analyses were carried out using the Statistical Package for the Social Sciences (SPSS), version 14.0.

RESULTS

As expected, bone warping and thumbnail fractures were found in both samples of cadavers and skeletons but their frequencies were very contrasting. All the 96 cadavers (Sample 1) but one presented warping (99.0%) while only 7 out of 88 skeletons (Sample 2; 8.0%) did so. As for thumbnail fractures, these were present in all cadavers but four (95.8%) and in only 19 skeletons (21.6%). Therefore, thumbnail fractures were more frequent in skeletons than warping. For the cadavers, only one 64 years-old female did not present warping and three females (aged 44, 71 and 64) and a male aged 63 did not present thumbnail fractures. Nonetheless, all cadavers presented either one or both changes.

Statistical analysis was carried out only for skeletons since cadavers presented little variation. Skeletons displaying warping were not significantly different from skeletons not displaying warping in terms of mean age and of mean time span from death to cremation (Table 1). In contrast, a significant difference ($\alpha = 0.05$) was found in terms of the mean maximum temperature of combustion at which each group was burned and the magnitude of that difference was large [14]. According to these results, the skeletons displaying warping were thus burned at much lower temperature than the skeletons not displaying warping. As mentioned above, the other variables – sex and duration of combustion – were not investigated due to small sample sizes.

As for thumbnail fractures, the biological model had no significant effect on their occurrence in skeletons (Table 2). None of the variables was significant either when considered out of the model. In contrast, the combustion model was found to have a significant association with thumbnail fractures, although it merely explained 12% of the variation and only maximum temperature had a significant effect (Table 3). The skeletons displaying thumbnail fractures (mean = 684.2; sd = 151.2) were burned at lower temperatures than the skeletons not displaying this feature (mean = 768.7; sd = 134.0). This difference was statistically significant ($t = 2.357$; $df = 84$; $p = .021$; $d = .59$) and this difference had a small to medium effect size [14]. Therefore, this variable seems to have had a significant role both in the occurrence of warping and thumbnail fractures. However, it should be noted that, for the combustion model, the required sample size was of 90 cases [13] and the logistic regression was actually carried out using a somewhat smaller sample of 85 cases. Therefore, results must be interpreted with caution. The details of the skeletons presenting heat-induced warping and thumbnail fractures are given in table 4.

DISCUSSION

The results confirmed that heat-induced warping and thumbnail fractures can occur in dry bones, a conclusion already attained in previous findings [1, 4, 5, 7]. This was expected, but the data demonstrated that their frequencies were much larger in cadavers than in skeletons and that, for the latter, thumbnail fractures were almost thrice as frequent as warping. This means that, although not completely reliable, warping was nonetheless a better indicator of the pre-burning condition of the remains than thumbnail fractures. Whatever the case though, the use of heat-induced features allows only the estimation and not the absolute determination of that condition. The co-existence of warping and thumbnail fractures was also not a completely reliable indicator of the burning of cadavers because this scenario was observed in four skeletons (35; 38; 339; 490).

Sex and age did not seem to have any effect on the occurrence of the heat-induced features and this result was somewhat unexpected. It goes against our proposal in an earlier paper suggesting that the preservation of collagen-apatite bonds could have a significant role in this, and that collagen is dependent of sex and age [1]. Collagen degradation is negatively correlated with age [15, 16] and it is known that menopausal women are more prone to osteoporosis and loss of skeletal strength [17]. However, apparently this had no apparent effect on the occurrence of the heat-induced features here investigated for both the samples of cadavers and skeletons – warping and thumbnail fractures did not occur mainly in younger males, which is what was expected. Of course, this may in part have been due to the age composition of the sample. Most individuals were quite aged thus impeding a true comparison between young and old individuals. Such comparison could have held different results. As for the time span between death and cremation on the sample of skeletons – our proxy for collagen degradation – no significant effect on the occurrence of the heat-induced features was found as well. They were equally displayed by skeletons that had been inhumed for only 5 years or by skeletons that had been inhumed for 50 years. Therefore, the results demonstrated that collagen degradation is probably not the only significant factor in play.

Contrary to duration of combustion, the temperature of combustion was a significant factor, at least for the cremation of dry bones. Skeletons displaying warping and thumbnail fractures were burned at lower temperatures than those for which no such features were present. This may sound strange at first, because even the skeletons burned at higher temperatures had to experience lower temperatures at a given point of the cremation. Therefore, many more skeletons should present warping and thumbnail fractures if low temperature was indeed a requirement. This suggests that it is the fluctuation of temperature during the cremation that is important and not the maximum temperature. Indeed, Zioupos et al. [16] state that collagen will contract when submitted to gradually increasing temperature and will develop a contractile force when submitted to a more constant temperature – a force that may be able to drag the mineral fraction of bone. Of course, this will only be the case if the collagen-apatite bonds are well preserved [18]. For the present research, the data collection did not include the complete record of temperature fluctuation during the cremations, so it is only possible to speculate about this issue. However, it seems logical to assume that this fluctuation was much more substantial for the cremations where higher temperature was attained. In these cases, the considerable increasing temperature may have prevented collagen to develop the contractile force probably required for the occurrence of warping and thumbnail fractures. That is, when high temperature was attained too quickly,

collagen was destroyed before warping and thumbnail fractures could occur. In alternative, or synchronically with the first hypothesis, the recrystallization of the inorganic phase at higher temperature [19] may have led to the strengthening of the bone and thus stopped warping.

The significant effect of temperature on warping and on thumbnail fractures suggests that these two features have the same aetiology and could even be two sequential manifestations of the same event – a bone response to mechanical force. Speculating, this bone response may be differential according to the preservation of collagen-apatite bonds – warping if very well-preserved, thumbnail fractures if slightly less well-preserved and neither of these features if poorly preserved – and the latter must be the case for most dry bones. This sequence is somewhat in accordance with bone biomechanics observed in vivo for bending fractures [20], although thumbnail fractures are actually not produced in living patients. This is not surprising if we take into consideration that heat-induced warping and antemortem bone bending are very different events. The latter is the result of mechanical loading that is extrinsic to the bone and we know for sure that this is not the case for the former. Further research may be able to determine if warping and thumbnail fractures are indeed two different manifestations of the same event.

CONCLUSION

Although a clear difference between cadavers and skeletons was found in regards to the frequency of warping and thumbnail fractures, none of these is a completely reliable indicator of the pre-burning condition of the remains. Nonetheless, warping seems to be the more useful for that matter. In both forensic and archaeological contexts, such estimation should ideally also be based on other data besides heat-induced features. In forensic cases, clothing-related objects such as buttons or zippers and devices such as pacemakers or intrauterine devices also suggest that the remains belonged to a cadaver. Skeletal representation should be taken into consideration as well, paying special attention to the presence of bones with labile joints. Generally, the presence of smaller bones such as the distal phalanges is more indicative of primary depositions [21, 22]. Their presence in human remains is thus more probable if they resulted from the burning of a cadaver than from the burning of dry and disarticulated bones because they would hardly be included in the latter. The analysis of these three parameters – presence or absence of heat-induced features, presence or absence of objects suggestive of a complete body and skeletal representation – is important to support either possibility. Also, in cases of combustions affecting the skeleton heterogeneously, the burning pattern may also give important insights about the pre-burning condition of the individual as was described by Symes et al. [10, 11]. Abnormal burning patterns may indicate that the skeleton was already disarticulated when subjected to heat. The eventual identification of burning over dry bones can rule out fire or other heat-source as a cause of death thus helping on the forensic investigation.

The distinction between burning carried out over fleshed bones and burning carried out over recently defleshed bones is also critical to reconstruct the circumstances of death. However, it is a trickier matter and was not directly investigated in this project. Previous research indicates that such discrimination cannot be made strictly based on bone heat-

induced features since both seem to display the same ones [3, 4, 6-8]. Marks on the bone resulting from disarticulation and defleshing are crucial for such distinction and can be detected following burning. For instance, this was recently demonstrated by Lara et al. [23] on their study of a cremated skeleton presenting several cut marks, scrape marks and impact scars of an individual from Palawan (Philippines).

As DeHann [24] stated, commercial cremations may not correctly replicate real fire conditions because they take place at relatively constant heat exposure while an on-and-off exposure is more usual in the latter. Therefore, the results here presented may not apply to all forensic contexts. Future and larger-scale research will need to be based on the investigation of the association between collagen preservation and heat-induced features using a more direct approach – instead of using proxies. This will require burning experiments of bone with previous collagen assessment in order to investigate the correlation between this variable and the occurrence of warping, thumbnail fractures or any other feature.

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ETHICAL STANDARDS

This research does not infringe any Portuguese law.

CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

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Captions

Fig. 1 Comparison between a heat-induced warped tibia (left) and an unburned tibia (right). The burned dry tibia was from a female with 71 years-old displaying warping after cremation that lasted 30 minutes and reached a maximum temperature of 600^{o} C. This skeleton was not included in the analysis because it was not completely calcined

Fig. 2 Heat-induced thumbnail fractures. Diaphysis of a dry long bone of a male of unknown age displaying thumbnail fractures after cremation that lasted 40 minutes and reached a maximum temperature of 800^{o}C. This skeleton was not included in the analysis because it was not completely calcined