Implications of Heat-induced Changes in Bone on the Interpretation of Funerary Behaviour and Practice

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Abstract

Bones submitted to heat experience structural and chromatic modifications. In particular, heat-induced bone warping and thumbnail fractures have been linked to the burning of fleshed and green bones - where the soft tissues have been removed from the bones soon after death – in contrast to dry bones. Those have been suggested as indicators of the state of the individual before being burned thus allowing inferences about the funerary behaviour of archaeological populations. A large sample of 61 skeletons submitted to cremation has been examined for the presence of both of these heat-induced features. Although uncommon, bone warping and thumbnail fractures were present in some of the skeletons demonstrating that its presence is not restricted to the burning of non-dried bones as generally believed. Rather than being an indicator of the presence of bones with soft tissues, bone warping seems to be more of an indicator of the preservation of collagen-apatite links which can be maintained on dry bones with low collagen deterioration. In addition, our results also do not confirm thumbnail fractures as an exclusive sign of the burning of bones with soft tissues. As a result, these heat-induced changes should be used with caution when trying to infer about the pre-burning state of an individual.

Keywords: cremation; burned bone; bone warping; thumbnail fracture; funerary archaeology

1. Introduction

Bone modifications caused by exposure to heat interfere with anthropological analysis and so it is critical to understand how and to what extent they occur. With this in mind, several researchers carried out experimentations designed to document bone changes and find trends regarding heat-induced fracture patterns, bone warping, shrinkage and colouration (Baby, 1954; Binford, 1963; Shipman et al., 1984; Buikstra and Swegle, 1989; Spenneman and Colley, 1989; Etxeberria, 1994; Mays, 1998; Whyte, 2001). As a result of these efforts, workers are able to infer relevant conclusions concerning funerary behaviour that would be difficult to achieve otherwise. For instance, despite some variations, researchers have demonstrated an approximately direct correlation between burning temperature and subsequent bone colour thus allowing us to roughly estimate the minimum temperature at which a given corpse has been submitted (Shipman, 1984; Mays, 1998; Walker and Miller, 2005; Munro et al., 2007). In addition, previous work suggests that bone warping and fracture patterns are indicative of the condition of the individual before burning thus informing us if the individual was cremated right after death or if the burning of the remains was only a secondary process. All this information contributes for the description of the circumstances surrounding death and help to interpret funerary behaviour of a particular chrono-cultural environment. However, although research regarding heat-induced colour changes in bone has been more prolific and found some correlation between colour and temperature, the experimentation on the subject of bone warping and fracture patterns is more sparse and uncertain (Baby, 1954; Binford, 1963; Buikstra and Swegle, 1989; Spenneman and Colley, 1989; Etxeberria, 1994; Whyte, 2001). Although some researchers pointed out the absence of bone warping on cremated dry bone (Baby, 1954; Binford, 1963; Etxeberria, 1994), others have achieved contrasting results (Buikstra and Swegle, 1989; Spenneman and Colley, 1989; Whyte, 2001). Also, thumbnail fractures – curved transverse fractures – have not been observed on experimental cremation of dry bone (Binford, 1963; Buikstra and Swegle, 1989). However, all previous experimental research has either been carried out on small samples or has included only animal bones. Therefore, the analysis of larger samples of human skeletons may bring new and important light into this topic.

The aim of the present paper is to establish if heat-induced bone warping and thumbnail fracturing can occur on cremated dry bones. As part of a current PhD research, permission from a crematorium was obtained for the pre- and post-cremation analysis of several skeletons which had been previously inhumated for a minimum of five years until complete removal of soft tissues. Because this research was not originally part of the PhD project, the results lack some data regarding the skeletal location and description of the warping and thumbnail heat-induced changes for some of the bones. Nonetheless, the results presented here derive from the largest sample of burned known modern human skeletons analysed to date and therefore contribute for the better understanding of heat-induced bone changes and consequent interpretation of burning-related circumstances of archaeological contexts.

2. Material and Methods

The sample is composed of 61 Portuguese adult skeletons partially identified according to sex and age. It includes 28 females and 33 males. From these, 25 individuals had ages-at-death between 23 and 99 years-old. The mean age for the sex-pooled sample was of 68 years-old while the mean ages for both females and males was of 74 (n = 14) and 61 (n = 11) years-old respectively. We do not know the exact age for the remaining 36 individuals because the date of birth was not registered on the cemetery records, but all were adults. The sample is mainly composed of skeletons unclaimed by their relatives from a civil cemetery which have been selected for cremation in order to free some cemeterial space. The process of cremation was followed by one of the authors (DG). The skeletons had no soft tissues at the point of exhumation. They were processed at a modern crematorium after being inhumated for at least 5 years. Cremations lasted between 15 and 45 minutes and achieved temperatures ranging from 450º to 890º C (mean = 780.28ºC). After cremation and before cremulation, all skeletons were visually examined for warping in bone structure especially looking for unusual bending of the diaphysis and of the heat-fractured ends of bones. An example of a warped long bone is shown in Figure 1. The examination also included the search for thumbnail fractures on the dyaphyses of the long bones as seen in Figure 2.

[Insert Figure 1: A warped tibia from the Iron Age archaeological site of Altera in Portugal (photo: J.P. Ruas)]

[Insert Figure 2: A long bone displaying thumbnail fractures from the Roman archaeological site of Encosta de Sant'Ana in Portugal (photo: J.P. Ruas)]

3. Results

Almost complete calcination was observed on 19 individuals, while the remaining 42 skeletons displayed a more mixed set of carbonized and calcined bones. Bone warping was found on 4 out of the 61 burned skeletons which constitute 6.5% of all analysed individuals. This occurrence was documented for the long bones of 4 males (Figure 3 and 4). These long bones comprised a tibia, a radius, a humerus and an unidentified diaphysis. No warping was found in any of the 28 females examined. The cremation details for the 4 cases are provided in Table 1. From these, the longest inhumation period experienced by an individual prior to cremation was of 45 years and the shortest was of 7 years. The range of temperatures of combustion ranged between 450º and 890ºC. Only one of the four skeletons exhibited almost complete calcination. The remaining three displayed both pre-calcined and calcined shades.

Thumbnail fractures were found on the long bones of 5 out of the 61 burned skeletons (Figure 5) thus composing 8.2% of the sample (Table 2). The temperatures for these 5 cremations ranged between 450º and 730ºC with a duration between 15 and 40 minutes. Once again, the longest inhumation period was of 45 years. Individual 267 exhibited thumbnail fractures on the endocortical surface of a long bone. Skeleton 34 was almost completely calcined while the other 4 were partly carbonized and partly calcined.

[Insert Figure 3: Bone warping present on the tibia of the individual 323]

[Insert Figure 4: Bone warping present on the radius of the individual 148]

[Insert Figure 5: Thumbnail fractures present on the long bone of the individual 38]

Table 1 - Details of the four burned skeletons displaying bone warping.

Skeleton	Sex	Age	Cremation Time	Maximum Temperature (Cº)	Bone	Region	Colour of Bone	Inhumation Period
35	M	23	15	450º	NI long bone	Dyaphysis	Not recorded	7 years
38	M	-	20	450º	Humerus?	Dyaphysis	Not recorded	45 years
148	M	-	30	890º	Radius	Dyaphysis	Almost all white	7 years
323	M	-	45	600º	Tibia	Dyaphysis	Beige White	19 years

Table 2 – Details of the five burned skeletons displaying thumbnail fractures.

Skeleton	Sex	Age	Cremation Time	Maximum Temperature	Bone	Region	Colour	Inhumation Period
34	F	83	40	730º	NI long bone	Not recorded	Not recorded	7 years
35	M	23	15	450º	NI long bone	Not recorded	Not recorded	7 years
38	M	-	20	450º	Humerus?	Dyaphysis	Grey Beige	45 years
257	M	65	15	600º	NI long bone	Not recorded	Black on endocortex; White	7 years
267	F	54	30	720º	NI long bone	Dyaphysis Endocortex	Black on endocortex; White	7 years

4. Discussion

Bone warping was only detected in males. These were cremated at various temperatures for at least 15 minutes. Thumbnail fracturing was observed for both females and males cremated at various temperatures for at least 15 minutes. The period of inhumation before the cremation process was diverse as well. We do not have sufficient data for the age-at-death of the individuals exhibiting bone warping to allow for any inference, but both younger and older adults displayed thumbnail fractures after cremation. No statistical analyses were carried out because of the small size of the sub-sample presenting both forms of heat-induced changes, but our results indicate that its occurrence is not dependent on specific duration of cremation, temperature of combustion, inhumation period and age-at-death. In contrast, the sex of the individual may be an important variable for the occurrence of heat-induced bone warping because this feature was not found for the female sample. This might be related to the larger density/mineralization of males bones in relation to female ones. However, research on a larger sample is needed to confirm this result. Also, both features were only detected for the diaphysis of long bones so their occurrence may be at least more often linked to this kind of bone.

As to the recorded presence of bone warping, Baby (1954) documented it on human fleshed bones but did not find it on human dry bones after burning. The same conclusion was obtained by Binford (1963) using a monkey cadaver and a human archaeological bone. Etxeberria (1994) experimented on a 10cm femoral fragment from an autopsied cadaver and another femoral fragment of the same size from an individual dead for more than 15 years and obtained the same results. In contrast, Whyte (2001) documented heat-induced bone warping while experimenting with archaeological deer bone. Also, Spenneman and Colley (1989) reported warping on an experimentally burned dry human humerus. Finally, Buikstra and Swegle (1989) also found warping in human and dog dry bones cremated in open-air oak fires..

Our results demonstrate that, although the occurrence of bone warping is rare, it is observable on dry bones submitted to heat. Our documented cases were heated at temperatures of at least 450º C and for a minimum of 15 minutes. The results reveal that heat-induced warping is not exclusively linked to the burning of fleshed and green bones as suggested previously by other researchers (Buikstra and Swegle, 1989; Spennemann and Colley, 1989; Whyte, 2001).

The explanation for the allegedly exclusive presence of heat-induced warping on fleshed and green bones in contrast to dry bones has been linked to the contraction of the muscle fibres (Binford, 1963). Alternatively, Spenneman and Colley (1989) link distortion to the presence of excessive heat trapped on the bone medullary cavity thus being able to occur in both fleshed and dry bones. Thompson (2005) argues that both statements are problematic because contracting muscles would hardly be capable to cause bones to bend, and the very porous nature of bone would not allow for the trapping of air in the medullary cavity. As an alternative, Thompson (2005) argues that the contractions of the periosteum or the anisotropy in the collagen distribution within the bone cortex are better candidates to shoulder responsibility. However, Thompson (2005) notes that there are no quantitative data to substantiate any theory.

Bone matrix is composed of a mineral component which grants it stiffness and a collagen component which contributes to bone toughness and to its resilience to mechanical forces (Zioupos et al., 1999; Viguet-Carrin et al., 2006). The decay of collagen in dry bones diminishes bone elasticity preventing significantly bending before eventually fracturing in contrast to fleshed and green bones. This means that the presence of warping on our dry bones sample is evidence of enough collagen enabling them with some elasticity. Otherwise, bones would simply become more brittle and susceptible to fracture and not warp at all.

A bone submitted to heat will experience a transformation of the crystalline collagen triple helical structure into an amorphous random coil form, a process known as collagen shrinkage (Zioupos et al., 1999). Collagen will contract if heated at a gradually increasing temperature, but will develop a contractile force which drags the mineral along if heated at a constant temperature (Zioupos et al., 1999). In dry bones, collagen-apatite bonds may have been weakened so the mineral component will not be dragged by the contractile mechanism of collagen (Bartsiokas, 2000). Both collagen content and temperature are probably related to bone warping but more research is needed to fully understand their role on this particular heat-induced event. The presence of soft tissues is probably not directly related to heat-induced bone warping and constitutes merely an indicator of good collagen preservation. Most likely, the latter enhances the possibility for the occurrence of bone warping events.

If collagen content is indeed related to bone warping, then age is a factor since collagen degradation begins during life (Collins et al., 2002; Zioupos et al., 1999). Sex is a factor as well because post-menopausal women are usually more affected by osteoporosis which causes architectural rearrangement of the bone tissue and subsequent loss of skeletal strength (Brickley, 2002). This may suggest that in older individuals, men are more likely to retain sufficient collagen to cause warping, and thus may explain why our four documented cases of bone warping belong to males.

Another bone alteration systematically linked to the burning of corpses with soft tissues regards the fracture pattern. The thumbnail fractures are pointed out in the literature as a distinctive feature between fleshed/green bones and dry bones although no explanation for this differential occurrence has been provided. These have been observed in previous experimental burnings (Binford, 1963; Buikstra and Swegle, 1989) and its absence from dry bones has led to the wide-spread conviction that thumbnail fractures are in fact an indicator of the cremation of bodies with soft tissues (Binford, 1963; Guillon, 1987; Herrmann and Bennett, 1999; Whyte, 2001). As a result, the interpretation of funerary behaviour has often been supported by these beliefs (Bartsiokas, 2000; Gonçalves, 2007; Ubelaker and Rife, 2007; Curtin, 2008; Duncan et al., 2008). However, although experimental research so far supported this assumption, the quantitative data available here did not allow for such reliable distinctions to be made.

Our analysis confirmed the presence of thumbnail fractures after the burning of dry human bones. The bones exhibiting this heat-induced change were submitted to temperatures of at least 450ºC with combustion lasting for at least 15 minutes. As with bone warping, heat-induced thumbnail fractures were infrequently observed on our sample of dry bones but the results demonstrate that it can not be considered an exclusive occurrence of fleshed and green bone cremations. Therefore, the present research does not corroborate previous results pointing to thumbnail fractures as an indicator of cremated non-dry bones (Binford, 1963; Buikstra and Swegle, 1989). Similarly to bone warping, thumbnail fractures could be related to collagen as well but we do not have data to support this allegation. As a result, the state of the skeleton prior to cremation is not necessarily directly related to the emergence of thumbnail fractures, although previous research leads us to state that it is more frequent for burned fleshed/green bones than for dry bones.

The limitations of our study are related to the lack of controlled laboratorial conditions. The combustion protocol followed by the crematorium adapts itself to each specific cremation. It depends on numerous factors such as resilience to fire of the skeletal remains, use or dispense from using a wooden container and the pre-heated condition of the furnace. Here, the state of the combustion was constantly checked by the technicians and the number of active burners or the oxygen intake is set according to the needs of each cremation. Therefore, temperature and duration is not the same for all cremations. This complicated the attempt to identify combustion-related factors playing a part over the presence or absence of heat-induced warping and thumbnail fracturing. As a result, possible relations between these changes and specific heat patterns should be taken with caution.

This is the largest human sample ever scrutinized for heat-related bone changes of this type and this fact may explain why its occurrence was not perceived on some of the previous studies. Because of its rarity, the samples available for earlier analyses were probably not large enough to allow for its detection. The 6.5% of individuals displaying bone warping is probably an underestimation. Most likely, its actual occurrence is even more common but fragmentation may have prevented us from detecting additional cases in our sample.

In short, the results obtained by this research help deconstruct some of the preconceived beliefs regarding the analysis of burned bones. These beliefs resulted from experiments on small samples which were unable to provide for a large enough perspective of the heat-induced changes affecting human bone. In the past, these have been used for the interpretation of the funerary behaviour of palaeo-populations (Bartsiokas, 2000; Gonçalves, 2007; Ubelaker and Rife, 2007; Curtin, 2008; Duncan et al., 2008). Fortunately most researchers have been aware of the lack of significant experimental research regarding this topic and refrained from pointing out these heat-induced changes as unequivocal indicators for the burning of fleshed and green bones. A review of all related research reveals that warping and thumbnail fractures tend to occur more frequently on fleshed and green bones than on dry bones. Instead of being the direct result of the presence of soft tissues *per se*, these changes are probably related to loss of specific mechanical properties in the bone such as those provided by collagen. As a result, the interpretation of funerary behaviour based on the attribution of bone warping and thumbnail fracturing events to the cremation of fleshed and green bones can be misleading and must be made with caution.

5. Conclusions

The analysis of 61 modern skeletons burned at a modern crematorium allowed to clarify this issue of bone warping and thumbnail fracturing as events indicating the cremation of fleshed bones and green bones. These heat-induced changes were also found on dry bones thus demonstrating that its occurrence is not directly related to the presence of soft tissues and that interpretation of the state of the individual before its cremation should be made with prudence.

Skeletal collagen content and the maintenance of the collagen-apatite bonds guarantee the elasticity and toughness of bone, so the loss of these mechanical properties probably impedes the warping response of bone to heat. As for thumbnail fractures, an explanation for its cause is more uncertain. However, the results obtained in the present investigation suggest that the clarification of the causes for these heat-induced changes must be achieved microscopically rather than by using the macroscopic analysis used in the present research.

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