

Effects of Heat as a Taphonomic Agent on Kerf Dimensions

Abstract

The information that can be derived from the rate of preservation of cremated human remains is highly valuable for forensic anthropologists and bioarchaeologists. Especially when taphonomic agents, such as fire, are intentionally introduced to obscure lesions on the skeleton. When sharp force trauma is present on bones, one of the main questions that arise is whether it is possible to tell what instrument was used for trauma infliction. This study used quantitative methods to examine kerfs on bones treated with heat as a taphonomic agent. The experiment used three sharp-bladed weapons to inflict trauma on porcine long bones: a single bladed non-serrated kitchen knife, a hacksaw and a wood saw. The bones were de-fleshed and traumatised prior to maceration to produce trauma similar to that which occurs in the peri-mortem period. The traumatised bones along with control bones were burnt in controlled laboratory conditions at temperatures ranging from 300°C to 1000°C. Quantitative analysis was undertaken on both the macroscopic and microscopic (scanning electron microscopy) images. The cut-marks were clearly identifiable and distinguishable from heat related fractures at all temperatures. Shrinkage of the kerf dimensions were recorded only at 1000°C; all cut-marks' lengths shrank at this temperature, and all widths shrank as well, excepting marks from the wood saw, which instead showed an increase in maximum width. Individualisation of the saws was not possible using only the metric traits. However, the class of the weapons (knife versus saw) could always be identified. It has been concluded that burning may cause fluctuation in kerf widths.

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1. Introduction

Death by sharp force injury remains the number one type of homicidal acts in the United Kingdom, and number two in the United States (DOJ 2010; Lyn-Sue *et al.* 2006; Martin 1999, 1-2; Perkins 2009; Truman 2009;). As a result, sharp force trauma analysis has profound relevance in forensic anthropological and forensic pathological inquiry. Sharp force trauma (SFT) is caused by narrowly focused, dynamic compression forces that can leave a trace on the epidermis, the underlying subcutaneous fat, and potentially on the bone (Symes *et al.* 2010, 6; Thompson and Black 2007, 118). Obscuring these peri-mortem sharp force marks on the body might seem an obvious choice for the perpetrator, and illegal burning/cremation is a common method for this (de Gruchy and Rodgers 2002; Dirkmaat and Adovasio 1997; Stewart 1979). While bone retains a record of the trauma despite taphonomic alterations, and considering it is impossible to completely destroy a body by fire (Bass 1984, 159), the effects of heat on bones can obscure traces of trauma as bone undergoes a series of predictable stages. These stages are as follows: 1) dehydration is marked by the breakdown of hydroxyl-bonds of the apatite mineral, when water evaporates and fissures appear on the bone; 2) through pyrolysis the bone loses its organic elements and decomposes; and 3) inversion is marked by the loss of the carbonate elements, at which point the bone is calcined (de Gruchy and Rodgers 2002; Devlin and Herrmann 2015; Mayne Correia 1997; Shipman *et al.* 1984; Symes *et al.* 2012; Thompson 2004, 2005). It is by going through these processes that the bone loses organic matter and water, which might affect the dimensions of the kerf (Robbins *et al.* 2015, S186; Symes *et al.* 2012, 176; Tegtmeyer 2012, 32). The goal of this study is to explore this idea and aims to discover the extent of the contraction or expansion of kerf dimensions.

A single bladed non-serrated kitchen knife, a hacksaw, and a wood saw were chosen as agents of SFT in this experiment, based on their frequency in forensic cases and their commonality in households (Symes *et al.* 1998). While knives are primary used for murder acts, saws are generally used to dismember the victim post-mortem (Symes *et al.* 2002). The literature to date has focused on the morphological traits of cut-marks to reconstruct the type of weapon used (Bonte and Mayer 1973; Marciniak 2009; Saville *et al.* 2007; Symes 1992; Symes *et al.* 1992; Symes *et al.* 2010), while the metric assessment of the wound and its relationship to the type of weapon has been neglected, with a few exceptions (Blake 1985; Cerutti *et al.* 2014; Reichs 1998; Symes 1992; Symes *et al.* 2012). These exceptions include the reconstruction of the tooth size of saws (Reichs 1998), the association between the width of the saw blade and the kerf width in a case report (Blake 1985), the correspondence between the saw blade width and the minimum kerf width in an experimental study (Symes 1992), and an experimental approach to reconstruct the metrical traits of the blades from the cut-mark's measurements (Cerutti *et al.* 2014). Although there has been increasing research in the past years on the effects of burning on SFT (de Gruchy 2002; Emanovsky *et al.* 2002; Fairgrieve 2008; Kooi and Fairgrieve 2013; Pope 2008; Pope and Smith 2004; Robbins and Fairgrieve 2015; Smith 2003; Symes *et al.* 2012), there has only been one study where the dimensions of kerf widths were analysed on both thermally undamaged and burnt bones (Symes *et al.* 2012). These bones with SFT were burnt at 500°C until they reached the calcined stage and showed no significant difference in the kerf width dimensions, and as such, the diagnostic trait dimensions were concluded as resistant to heat (*ibid.*). However, it was not answered whether these metric traits would change with different temperatures of heating in controlled conditions.

This study aims to verify whether the diagnostic trait dimensions of different SFT remains are stable or change in relation to temperature under the same temporal conditions. A secondary aim is to address the question as to whether it is possible to identify the class of the sharp force

tools that caused the trauma from the metric traits after thermal damage at each temperature stage.

2. Materials and Methods

In order to investigate the effects of heat damage on cut-marks, de-fleshed pig (*Sus scrofa domestica*) limbs were placed into an electric furnace. Pig bones are commonly used as an analogue for human bones in forensic anthropology studies (Humphrey and Hutchinson 2001; Lynn and Fairgrieve 2009; Thompson and Inglis 2009; Symes *et al.* 2012), and were shown to be an applicable proxy for studying sharp force trauma on human bones (Symes *et al.* 2012). Fleshed pig limbs were sourced from a local butcher. All soft tissues were carefully removed with the epiphyses partially cut off, making sure that the underlying bone did not come into contact with the knife. The bones were then uniformly traumatised with three different types of sharp force tools: a single edged, non-serrated kitchen knife, a hacksaw, and a wood saw (Table 1). A total of sixteen bones were used for the experiment and each instrument was used on four bones, while four were left un-traumatised, providing a control group for the fire events. The bones were halved by the hacksaw and were approximately each 3-3.5 cm wide in order to fit the platform of the scanning electron microscope (SEM). One individual inflicted all the trauma to ensure consistency in the magnitude of force and direction of the cutting action. Each bone was given a unique ID that contains a number and a letter, representing the temperature the bone was burnt at and the type of trauma inflicted, respectively (Table 1). Afterwards, the bones were simmered with a minimal amount of enzymes from biological detergent. This method of maceration, outlined by King and Birch (2015), was selected in an attempt to kill bacteria whilst minimising the damage to the bone at high temperatures. The protocol of sequence, starting from de-fleshing and terminating in maceration, was chosen in order to produce realistic-appearing peri-mortem trauma.

ID	Type of Trauma	Direction	Tooth Set	Teeth per inch (TPI)
A	Kitchen knife	-	Non-serrated	0
B	Hacksaw	Push/Pull	Wavy set	31
C	Wood saw	Push/Pull	Alternating set	10

Table 1. *The bone IDs with their associated weapons and their properties.*

A Hitachi S-3400N (Hitachi, Ltd., Tokyo, Japan) scanning electron microscope was used to acquire detailed images of the un-burnt and burnt wounds, as it provides a high-resolution magnified image and is frequently used in trauma studies (Alunni-Perret *et al.* 2005; Bartelink *et al.* 2001; Bello and Soligo 2008; Humphrey and Hutchinson 2001; Saville *et al.* 2007; Thompson and Inglis 2009). Variable pressure (VP-SEM) special settings, with 15.0 kV beam and 70Pa were used for the visualisation of the bones under the SEM as other studies have used these settings successfully in cut-mark studies (Ferlini 2012, Thompson and Inglis 2009). No gold or carbon coating was used during the procedure. Additionally, photographs were taken of the wounds in order to measure the length of the cut-marks before and after the fire events.

The bones were burnt in an electric furnace for 20 minutes at four different temperatures: 300, 600, 800, and 1000°C. Each fire event was performed on four bones, three with SFT and one control, that were placed inside crucibles with lids. The control bones' purpose was to observe whether the bones with trauma were affected the same way as the untraumatized bones macroscopically. The macroscopic and the microscopic images were measured before and after burning using the ImageJ program; the maximum width was measured on the SEM images, as those provided better-quality and highly magnified images of the cut-marks of interest. The mean of five measurements was calculated at and around the maximum width of each cut-mark (Fig. 1), so that the final measurement gave a more representative metric trait of the wounds. The lengths of the cut-marks were measured on the macroscopic images.

[INSERT FIGURE 1 HERE]

Figure 1. *Examples of the measurements taken of the maximum widths of the cut-marks in ImageJ. The instrument used on these bones was the hack saw (samples 600B and 1000B).*

Intra- and inter-observer error analyses were performed to calculate the reproducibility of the study in SPSS. The intra-observer error analysis was performed by one researcher only and was considered successful when the newly measured values matched the original measurements to the closest millimetre. The results showed that two measurements of the same cut-mark did not deviate from each other by more than 10%, as the mean difference between the measurements was between -0.27 and 0.25 mm. A significance of 10% was used instead of the conventional 5% because of the small sample size and the difficulty of measuring cut-mark widths precisely. Three observers and the researcher performed the inter-observer error analysis on the lengths and widths of the cut-marks on the SEM and macroscopic images. There was a large discrepancy between the values due to one observer's inaccuracy in two measurements, due to incorrectly taken measurements. Therefore, these two measurements were not included in the final results. In all other measurements reported here, the maximum difference between the observers' and the researcher's measurements were 0.79 mm.

3. Results

As the metric traits of cut-marks are useful in determining the classes of weapons, instrument determination was attempted from both the thermally undamaged and burnt wounds.

3.1 Cut-mark Lengths

Changes to the length of the cut-marks were recorded and the percentage of the shrinkage has been calculated (Table 2). The cut-marks' lengths were considered to have exhibited fluctuation whenever the pre- and post-burning measurements differed more than 10%. The lengths of all the cut-marks that were burnt at 1000°C shrank significantly. From all other bones, only the

wood saw caused cut-mark burnt at 800°C (800C) was approaching the 10% rule with its 8% fluctuation.

When the lengths of the cut-marks are grouped by the type of tool and the coefficient of shrinkage, or relative standardised measure of dispersion is plotted (Fig. 2), the graph shows that only the hacksaw traumas' value alters post-burning. It also shows that as the temperature increases the wood saw cut-mark loses the least from their lengths. All wounds lost the largest amount of length at 1000°C. The standard deviation of the burnt kitchen knife and hacksaw traumas increased, while that of the wounds caused by the wood saw decreased (Table 2).

[INSERT FIGURE 2 HERE]

Figure 2. *Coefficient of shrinkage of cut-mark length by type of weapons at the four different temperature stages.*

Bone ID	Pre-burnt Length	Burnt Length	Coefficient Shrinkage (%)	Difference (%)	Reasoning (Length)	Pre-burnt width	Burnt width	Coefficient Shrinkage (%)	Difference (%)	Reasoning (Maximum Width)
300A	16.18	16.58	102.48	-2	Inaccuracy	8.99	8.73	97.02	3	Inaccuracy
300B	13.75	13.56	98.65	1	Inaccuracy	12.37	11.98	96.86	3	Inaccuracy
300C	15.03	15.47	102.95	-0.02	Inaccuracy	8.37	9.62	114.96	-13	Inaccuracy/possible change
600A	15.55	15.31	98.44	0.01	Broken	4.89	1.46	29.85	-	Broken
600B	13.17	14.17	107.54	-7	Inaccuracy	6.06	5.35	88.38	13	Inaccuracy/possible shrinkage
600C	12.82	12.74	99.33	1	Inaccuracy	10.00	10.24	102.44	-2	Inaccuracy
800A	16.85	16.71	99.14	1	Inaccuracy	2.47	2.10	84.98	18	Inaccuracy
800B	12.41	12.27	98.86	1	Inaccuracy	6.34	5.77	91.13	10	Inaccuracy/ possible shrinkage
800C	12.32	11.37	92.34	8	Inaccuracy	9.99	9.83	98.46	2	Inaccuracy
1000A	12.93	10.76	83.13	20	Shrinkage	1.09	0.73	66.80	50	Shrinkage
1000B	13.57	11.04	81.37	23	Shrinkage	8.01	6.36	79.41	26	Shrinkage
1000C	21.85	16.51	75.57	32	Shrinkage	9.00	9.15	101.68	-2	Inaccuracy/ possible change

Table 2. The measurements taken from the lengths and maximum widths of the cut-marks before and after burning and their associated and interpreted changes.

3.2 Cut-mark width

Only the knife and the hacksaw cut-marks that were burnt at 1000°C showed shrinkage of the metric properties as defined by the previously used 10% significance (Table 2). 600A broke during the natural cooling process after burning, thus its metric traits are not considered accurate. 1000C's wood saw-caused cut-mark showed a slight (2%) increase in its width.

In the pre-burnt stage, the knife caused the narrowest cut-mark, followed by the hacksaw and then the wood saw. Therefore, the knife-caused wounds do not show overlap with the marks caused by the saws pre- or post-burning, unlike the pre-burnt hacksaw and wood saw marks. While at 300°C, the coefficient shrinkage was very similar no matter which weapons were used, the difference in percentage increased proportionally with the temperature (Fig. 3). The widths of the knife cut-marks shrank the least at all temperature stages.

[INSERT FIGURE 3 HERE]

Figure 3. *Coefficient of shrinkage of cut-mark width by type of weapons at the four different temperature stages.* Note that all marks overlap at 300 degrees.

In summary, all cut-marks' length shrank at 1000°C, while only the knife- and the hacksaw-caused defects decreased in width at the same temperature. The biggest lengths lost were seen with the wood saw cut-marks. However, the same cut-mark showed increase in its width at 1000°C. There was no overlap between the widths of the knife and saw cut-marks pre- or post-burning.

4. Discussion

Contrary to Symes *et al.* (2012), who concluded that there were no metric changes of the average kerf widths on the pre- and post-burnt bones, the present study showed that the widths

of two defects did contract. Both of these wounds were burnt at 1000°C and were caused by the knife and the hacksaw. A 1000°C is usually only reached by crematoria and car fires. Nevertheless, if the body is soaked with petrol in a car fire, the outer surface of the osseous material only chars. The heat from housefires can go up to 700-800°C, and camp fires to 400°C (Buikstra and Goldstein 1973, Eckert *et al.* 1988, Tylecote 1962).

It is not possible to draw a comparison with the knife trauma, as Symes *et al.* (2012) only used saws for their experiment. The saw-caused defects, however, were only burnt at one temperature stage (500°C) in an electric furnace in their study, with a much longer exposure than in the present experiment in order to completely calcine the bones. Therefore, the different results of the two studies with calcined bones demonstrate that the maximum temperature and the length of time the bones were burnt at can clearly influence the patterns of change on the metric traits of the kerf dimensions. This current experiment showed that 20 minutes at 1000°C was enough to contract the kerf widths of the knife and hacksaw lesions, while the saw kerf widths did not contract at 500°C even if they were exposed to heat for more than an hour, as in Symes *et al.* (2012). This might be explained by the fact that in the above mentioned study the temperature did not reach high enough temperatures for recrystallisation of the mineral phase of the bone.

Although Symes *et al.* (2012) do not discuss the changes to the length of the lesions, this current study demonstrated that the cut-marks burnt at 1000°C caused by all types of sharp force instruments decreased in size by an average of 25%. In addition, 800C's length shrank 8%, which would make the wood saw lesion the only one that also lost length at 800°C. Cut-mark 1000C lost the most length at 1000°C. Its maximum width did not contract, but rather expanded by 0.15 mm (Table 2, Fig. 4). Though this might appear to be due to inaccuracy in the measurement process, two other wood saw marks (300C and 600C) also show increases in their post-burning width values, strengthening the assumption that the increase in the width value of

1000C was genuine. This expansion might be explained by some qualitative traits, namely the petal-like projections that had a tendency to burn off from the edges and walls of the wounds after the fire events (Fig. 4). Thus, the kerf floor became more visible on the SEM images, causing the measured values of the floor to increase by 0.15 mm. This would mean that the type of saw used, namely the set of teeth, can influence the changes to the metric traits of the kerfs after burning.

[INSERT FIGURE 4 HERE]

Figure 4. *SEM images of bone 1000C before (left) and after (right) burning at 1000°C. Upper row: the whole cut; lower row: close up on the same area.*

It was not possible to clearly differentiate between all three types of trauma considering only the metric traits of the kerf dimensions. It is clear that the knife cut-marks are distinguishable from the saw marks pre- and post-burning by its maximum kerf width, but the hacksaw and the wood saw marks' metric dimensions largely overlap before burning (Table 2). Although the measurements of the maximum widths of the wood saw marks became more distinct post-burning, the maximum value of the hacksaw marks still overlap the whole range of measurements of the wood saw marks (Table 3). This suggests that the qualitative features of the cut-marks need to be examined in addition to the metric traits in order to differentiate between the two types of saw marks.

The importance of the sequence of material preparation cannot be overemphasised. In this study the bones were de-fleshed, traumatised, and finally simmered at low temperatures, which produced lesions on fresh bone. It is an important point to make, because the process of degreasing by boiling or bleaching can change the viscoelastic structural integrity of fresh bone (King and Birch 2015). Previous trauma analysis and burning studies (de Gruchy and Rodgers 2002; Emanovsky *et al.* 2002; Kooi and Fairgrieve 2013; Marciniak 2009; Pope 2008; Robbins

and Fairgrieve 2015; Smith 2003; Symes *et al.* 2012) did not follow the sequence outlined in this study. Instead, they traumatised the bones after maceration producing trauma to the bone, the peri-mortem nature of which can be questioned. This way of conducting experiments on bones is one of the reasons why there may be limited applicability of the results of experimental trauma analysis studies to actual forensic cases. This issue is a major concern, since the motivation behind all trauma analysis studies is to be able to detect, classify, and analyse peri-mortem trauma on skeletal material. Given the previously mentioned infrequency of studies dealing with the quantitative changes to kerf widths on both unburnt and burnt bones, only Symes *et al.*'s (2012) results can be compared with the findings here.

Furthermore, classification of the two saw types by only the metric traits of the kerfs was not possible either before or after burning, even though they had different saw sets and teeth per inch (TPI). However, the knife wounds were distinct enough to differentiate from the saws in all cases. A comparison of this study's results with Symes *et al.*'s (2012) findings shows that relationship between the stages the bone undergoes during burning (dehydration, decomposition, inversion, fusion) and the metric traits of the kerf is not clear-cut and is not only influenced by these stages outlined by the literature (Mayne Correia 1997; Shipman *et al.* 1984; Symes *et al.* 2012; Thompson 2004). Therefore, it is evident that factors other than the ones already discussed by the literature (Schmidt and Symes 2005; Symes *et al.* 1996; Symes *et al.* 2005; Symes *et al.* 2012; Symes *et al.* 2015) play a critical role in the metric changes of kerfs when burnt in controlled laboratory conditions. These include the amount of heat, the time exposure, the weapons used for trauma infliction, and the sequence and preparation techniques of the bones.

Based on the results of this experiment it can be concluded that increased heat exposure may cause fluctuation in kerf widths. This fluctuation might be caused by the actual saw blade and the skeletal kerf dimensions should be approached with caution. Future studies should

reproduce this study with a larger sample size and to identify the extent to which the previously mentioned factors alter the metric dimensions of peri-mortem cut-marks.

5. Conclusion

This study confirmed that cut-marks on bones caused by a single 'fine' bladed knife, a hacksaw, and a wood saw survive at temperatures ranging from 300°C to 1000°C. Both the lengths and the widths of the wounds were measured and the pre- and post-burnt values were compared on the macroscopic and microscopic (SEM) scale. Classification of the weapons from metric traits was only possible to a limited extent; only the knife-caused wounds could be differentiated from the other weapons at all temperature stages, and the width measurements of the two saws overlapped. The present study showed that both the widths and lengths of the cut-marks burnt at 1000°C changed, but only the length shrank consistently. This finding contradicts the existing literature on the quantitative assessment of burnt saw mark analysis and showed that only 20 minutes is enough to trigger metric changes of kerf dimensions at 1000°C. Future studies should concentrate on identifying the reasons and extent to which the different factors affect the widths of the wood saw trauma differently from other trauma types at 1000°C. The authors of this paper suggest that one of the reasons could be the different ways of producing peri-mortem trauma. Since our material preparation included de-fleshing and traumatising before maceration, the produced defects can be truly considered as peri-mortem trauma. This is a unique step in the experiment, as in other trauma analysis studies the bones are macerated and degreased before trauma infliction. This can alter the bone's structural properties and therefore its peri-mortem nature is questionable. Thus, it is recommended that future experiments keep this manner of processing when de-fleshing is necessary for the experiment.

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