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Effects of heat on cut mark characteristics

Lukas Waltenberger[a], Holger Schutkowski[b,*]

[a] Department of Archaeology, Anthropology and Forensic Science, Bournemouth University, UK
[b] Department of Archaeology, Anthropology and Forensic Science, Faculty of Science and Technology, Bournemouth University, Fern Barrow, Poole, UK

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ABSTRACT

Cut marks on bones provide crucial information about tools used and their mode of application, both in archaeological and forensic contexts. Despite a substantial amount of research on cut mark analysis and the influence of fire on bones (shrinkage, fracture pattern, recrystallisation), there is still a lack of knowledge in cut mark analysis on burnt remains. This study provides information about heat alteration of cut marks and whether consistent features can be observed that allow direct interpretation of the implemented tools used.

In a controlled experiment, cut marks (n = 25) were inflicted on pig ribs (n = 7) with a kitchen knife and examined using micro-CT and digital microscopy. The methods were compared in terms of their efficacy in recording cut marks on native and heat-treated bones. Statistical analysis demonstrates that floor angles and the maximum slope height of cuts undergo significant alteration, whereas width, depth, floor radius, slope, and opening angle remain stable.

Micro-CT and digital microscopy are both suitable methods for cut mark analysis. However, significant differences in measurements were detected between both methods, as micro-CT is less accurate due to the lower resolution. Moreover, stabbing led to micro-fissures surrounding the cuts, which might also influence the alteration of cut marks.

1. Introduction

1.1. Cut mark analysis in archaeology and forensic science

The analysis of cut marks is instrumental for interpreting the manner, and potentially, the cause of sharp force trauma in forensics and archaeological contexts. Furthermore, it allows drawing conclusions about the implement used and can help to characterise the tool class, and in certain cases even the identification of specific, individual tools. This is helpful to match the weapon used with the wounds on the victim in crime investigations.

In archaeological human remains cut marks are usually related to acts of violence, sacrificial or otherwise mortuary behaviour, whilst animal remains show cut marks from butchering [1–7]. In forensic investigations, the analysis of cut marks is of major importance for crime investigation as, for example, stabbing is the most common method of homicide in Britain [8–10], where a knife was used for the assault in 53% of all murder cases [7]. The most common weapon in stabbing is a long, slender, and double-edged knife, such as common household knives [11,12]. As prime target for attacks, the chest is the most vulnerable body area [6,8].

Stabbing is a complicated sequence of different movements, which produces axial and non-axial forces and torques, that are difficult to reproduce in an experimental context [13,14]. This is the main reason why only little research has been conducted so far. Besides these forces, the shape and geometry and the sharpness of the knife blade tip, the velocity of the attack and resistance factors, such as clothing and bones have a crucial impact on the injury of the victim [13,15–19].

Once cut through the skin, no more force on the knife is required to penetrate deeper into soft tissue [20]. In general, a force of about 5–29 N [15,16] is necessary to spike human skin. However, these are just minimum values. Beside the stabbing forces, it is even more important to define the characteristics of cut marks. There are many features that can be measured to describe the form of cut marks. Generally speaking, sharp metal blades produce V-shaped kerfs and clear apices [21], whilst scrapping and slicing cuts create U-shaped pits [22].

Several case studies emphasize the importance of cut mark analysis and the examination of burnt remains [23,24]. In forensic settings, usually bone fragments and, sometimes, soft tissue will be encountered, but depending on experience and time, a body can be burnt completely so that only calcined bone fragments remain

* Corresponding author.
E-mail addresses: luk.wal@hotmail.com (L. Waltenberger), hschutkowski@bournemouth.ac.uk (H. Schutkowski).

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[24]. However, often the corpse is just deluged with petrol and inflamed, which only leads to charring of the outer surface.

1.2. Heat alteration of bones

When bone is burnt, various extrinsic (temperature, time, oxygen, humidity) and intrinsic factors (bone composition, soft tissue, pathological lesions, injuries, age) are responsible for fracturing, shrinkage, deformation and weight loss. In general, heat alteration leads to a removal of organic compounds and a reorganisation of inorganic material [25]. The impact of heat depends on the oxygen supply, the thickness of soft tissue and other protective materials [26,27]. Mayne Correia [28] summarised the effects of heat induced changes, which were later slightly revised by Thompson [29]. They observed four stages of transformation: first the bone dehydrates, which is followed by pyrolysis of organic compounds and inversion, which is the loss of carbonate. Finally the inorganic compounds start to fuse.

Dehydration leads to warping and cracking of the bone [30–34]. Between 600 °C and 800 °C the organic compound is completely burnt and the contraction of the bone structure increases [32,33]. In the literature the total amount of shrinking varies between 0.5 and 27% [25,31,35,36]. Accompanied by shrinkage and colour alteration, the carbonate concentration decreases from 6% in raw bones to approximately 1% in calcined bones [37,38].

Finally, it has to be considered that in reality it is quite difficult to completely burn a corpse: camp fires burn at 400 °C and rarely reach 700 °C [39]. House fires gain 700 °C, burning cars and crematoria around 1000 °C [24,31]. However, because of the thin layer of soft tissue of the chest and head, the rib cage and facial bones are revealed within 20 min, if the body is heated up to 650 °C [40]. Therefore a careful analysis of burnt ribs is important in many cases, because injuries may be destroyed quicker than on other body parts, which are covered by thicker layers of soft tissue. Usually a body is fully cremated in 3 h at a temperature between 670 °C and 810 °C in a cremation furnace [41].

Heat fractures can be longitudinal, transverse, delaminated or reticulated. Transverse fractures usually occur due to the shrinkage of soft tissue [42]. Other fracture types present as small, reticulated cracks of the outer bone surface and delamination, a separation of different bone layers is often observed between cortical and spongy bone [43].

1.3. Innovations of cut mark analysis

Whilst many studies have focused on stabbing, cut mark analysis and heat induced bone alteration, only little research has been conducted on cut marks of burnt remains [43–45]. Frequently, only the presence or absence of cut mark structures was determined [46]. Other researchers suggested, that cut and saw marks on burnt remains can be identified and a determination of the type of tool is possible, although fire can alter and modify peri-mortem trauma [47–50].

Pope and Smith [44] observed the alteration of soft tissue around cut marks and noted that as the soft tissue is damaged above cut marks, the skin tends to split and form a bulge. This leads to shrinkage of the soft tissue lesion; the underlying bone is exposed and will be altered by the heat sooner and quicker as the bone is no longer protected by soft tissue.

Various methods have been used to analyse cut marks. Initially, light microscopy and SEM were employed [7,29,33,51–64], while recent years seen more sophisticated 3D-methods, like computer tomography (CT) [65–67]. However, Bello and Soligo [68] and Thompson and Chudek [69] point out that SEM is a destructive method and only provides 2-dimensional images.

In comparison to micro-CT, 3D-microscopy is an efficient method in terms of implementation, speed and costs, which renders it an ideal tool for cut mark analysis [21,68]. Even complex structures, such as micro-striations can be evaluated and measurements of cross sectional profiles allow a careful evaluation and have led to the application of 3D digital imaging techniques in various studies [61,68,70,71].

1.4. Pigs as a model for humans in forensic science

For various reasons, research on trauma and decomposition cannot be done with human cadavers in the UK. Often, pigs are often chosen as human analogues in forensic experimental studies [45,64,65,72,75–79]. Pig skin has similar mechanical characteristics to human skin, but it is thicker and contains more collagen, which makes it more flexible [15,16,80–84]. However, the mineral density is much less in pig bones than in humans [84,85]. As pigs used are still juvenile and a 40 kg pig has the same bone mineral density as an 8–10 year old child [86].

The aim of this study is to provide a novel approach to analyse heat alteration of cut marks by identifying how cut marks on bone are affected by high temperatures.

The following hypotheses will be tested:

- Cut marks are shrinking upon heating as previous research revealed shrinkage of bone due to a loss of organic material.
- Digital microscopy and micro-CT are both suitable methods to analyse cut marks and deliver similar results.
- There are correlations between fissures beneath the cut mark floor and the cut mark depth.

2. Material & methods

For this study, a rack of pig ribs, covered with soft tissue from a nine month old pig (Sus scrofa domesticus), were obtained from a butcher. Due to the juvenile stage, which is supported by the visibility of non-fused epiphyses, the bones contain a higher amount of organic material and are less mineralised as compared to adult pigs [87]. The sample included the 2nd to the 11th rib, cut off close to the sternal rib end but not containing any rib cartilage. The rib sample measured approximately 29 cm in length and 8 cm in width. The soft tissue above the ribs had a thickness of 43 mm. The rack was divided into three parts, each containing three ribs, and subjected to the experiment.

In order to achieve maximal reproducibility for the experimental setup, different interfering variables had to be excluded beforehand or at least minimized. A well-known factor difficult to copy in an experimental setup is stabbing, as: the literature suggests different forces, movements and differences between single human offenders [15,88,89]. Therefore a simple gadget was built, which works similar to a guillotine to create equal cut marks on the ribs (Fig. 1). Three cooking knives (Ikea, model Vörda) with a total length of 340 mm, a blade length of 207 mm and a weight of 147 g, respectively, were used for the experiment. The knife's spine is 190 mm long and the blade's height measures 48 mm in maximum. The knife's blade is straight on its first third next to the handle and non-serrated. The second third is slightly curved and its last third is strongly curved upwards. The knife's spine is not straight and is slightly curved towards the edge. The knife-edge has a total angle of 14° with a floor radius of 12 μm. Additionally, weights of 1 kg, each, were attached to either side of the blade to create more realistic forces. Thereby, the overall weight of the falling sliding carriage, including the knife was 2404 g, which is equal to a force of 24 N respectively.

Knives were replaced for the cutting of every rib sample (containing three ribs) after 11 cut marks to minimize variation of