



The Effect of Burning on Saw Trauma Characteristics in Bone

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Abstract

Dismemberment and burning of a corpse are means recurrently used by criminals to facilitate the concealment of a homicide. Readily available dismemberment tools, such as saws, leave characteristic markings on bone that can be analysed by forensic tool mark analysts to estimate the class of weapon utilised in a case. As bone is vulnerable to morphological changes under high heat exposure, the burning process may alter and distort these marks, misleading the tool mark analysis. This study aimed to analyse and compare the characteristics of saw cut marks in bone before and after burning at various temperatures. Fifteen *Ovis aries* femora were used as an analogue for human long bones, and were traumatised with a hand saw, creating false start, incomplete, and complete cuts. Five femurs per temperature group were subjected to burning at 400 °C, 600 °C, and 800 °C for 30 minutes in a muffle furnace. Prevalence and metrics of saw cut mark characteristics were analysed pre- and post-incineration using visual inspection, stereomicroscopy, and silicon casting. Heat-induced alterations to saw mark characteristics included increases in kerf width and decreases in kerf depth, as well as visual enhancement of certain traits. The detection of exit chipping, regular striae, pull-out striae, and tooth hop striae improved post-incineration, even at high heat-intensities. These results indicate most saw mark traits persist after burning, but that forensic tool mark analysts must consider the vulnerability of heat-induced metric alterations to these traits in their analyses. Further research is necessary on the effect of burning duration to heat-induced saw mark alterations on bone burned at various temperatures.

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List of Abbreviations

ANOVA – Analysis of variance

BSML – Breakaway spur maximum length

BSMT – Breakaway spur maximum thickness

ICC – Intraclass correlation coefficient

MSD – Mean striae distance

POS – Pull-out striae

SEM – Scanning electron microscopy

TH – Tooth hop

TPI – Teeth per inch

CHAPTER 1: LITERATURE REVIEW

1.1. Background

Burning may be present in forensic cases of deceased individuals — such as the cause of accidental death by fire, or as a means to attempt to cover up physical evidence of homicide (Fantom et al., 2006). In the city of Cape Town, South Africa, between the years 2001 and 2004, the reported rate of burn mortalities was 7.9 per 100 000 persons per year, with 2.5% being homicide-related (Van Niekerk, Laubscher & Laflamme, 2009). A retrospective study on fire-related deaths in Salt River Mortuary in Cape Town, South Africa, reported 1370 deaths between the years 2006 and 2018, 10.4% of which were homicide-related, and 5.3% of which involved trauma (Davies, du Toit & Hlela, 2024). Dismemberment, which may either primarily be for the concealment and disposal of a body, or a result of a perpetrator's desire to mutilate, is sometimes done prior to the burning (Tümer et al., 2012; De Matteis et al., 2021). This is typically conducted with readily available tools, such as saws, which leave characteristic tool marks on the bones of the victim. The analysis of the characteristics of these cut marks may aid in the identification of the class of saw and/or matching of murder weapons, which may serve as vital evidence during criminal investigations (Saville et al., 2007; Symes et al., 2010). The act of burning following dismemberment can obscure or distort these characteristic marks, making the identification of the tool challenging (Tümer et al., 2012; Robbins et al., 2015). There has been limited previous research on the thermal alteration of saw cut marks on bone (Marciniak, 2009; Robbins et al., 2015; Vegh & Rando, 2019; Mata-Tutor et al., 2022), and as such, there is a lack of extensive literature examining whether or not the saw mark characteristics that are used to determine the class of weapon survive under fire treatment, and how they are altered by heat. Furthermore, there is a need to investigate if and how varying temperatures differentially affect these saw mark characteristics.

1.2. Introduction

To critically assess previous literature evaluating heat-induced alterations to saw cut marks in bone, a systematic review was conducted. This review begins with a summary of the relevant theory surrounding saw trauma and heat-induced alteration to bone, followed by the systematic review of the literature.

1.2.1. Dismemberment and burning crimes

The criminal act of dismemberment may be categorised as defensive, aggressive, or offensive (Petreca et al., 2020). Defensive dismemberment is done with the primary intent to facilitate disposal and concealment of the body and identity of the victim. In contrast, aggressive dismemberment is a rageful act accompanying the act of murder, while offensive dismemberment is carried out to fulfil sadistic desires of the perpetrator. In most dismemberment cases, the perpetrator's weapons of choice are easily available common household tools such as axes, kitchen knives, hacksaws and saws used for woodworking (Konopka et al., 2007). Regardless of the primary motive behind the dismemberment, the act serves to obscure the victim's identity, especially when accompanied by burning. Fire has been used post-dismemberment either to alter specific regions of the body, such as the hands and face that can aid in victim identification, or to completely obliterate the body and any associated evidence (Konopka et al., 2007; Sea & Beauregard, 2019; De Matteis et al., 2021). Other information that may be of key evidential importance can also be distorted or destroyed by post-dismemberment burning, such as the tool marks left behind on the victim by the weapon used.

1.2.2. Heat-induced alterations in bones

Fire exposure affects the morphology and structure of bone. When a body is burnt, dehydration and recrystallization of the bone tissue occurs along with the loss of organic matter, resulting in morphological changes that include colour change, shrinkage and warping of the bone (Thompson, 2005; Hutchinson, 2011; Robbins et al., 2015).

From lower to higher heat intensities, the colour of burnt bones can typically range from pale yellow to brown, to black, to grey, and then to white (Shipman, Foster & Schoeninger, 1984;

Thompson, 2005). Similar colour changes associated with heat have been observed in animal bones used as a proxy for human tissue. For example, sheep ribs were noted to change to black due to carbonisation at around 400 °C, grey due to partial calcination between 500 °C and 600 °C, and white at 700 °C due to the bones being fully calcined (Ellingham & Sandholzer, 2020).

There are four stages of heat-induced changes in bone, namely: dehydration, decomposition, inversion and fusion (Thompson, 2005; Robbins et al., 2015). Dehydration, occurs between 100 °C and 600 °C, resulting in fracturing and loss of bone mass. This is followed by decomposition between 300 °C and 800 °C, during which mechanical strength and mass is lost associated with increased bone porosity. Thereafter, inversion occurs between 500 °C and 1100 °C, in which the crystal size of bone mineral increases. Finally, fusion occurs at temperatures greater than 700 °C, in which mechanical strength and crystal size increase, bone dimensions decrease, and changes in porosity occur (Thompson, 2005; Robbins et al., 2015).

Fire burns at various intensities. Temperatures that are of forensic interest range between 400 °C to 1000 °C. Camp fires, house fires, informal settlement fires, and burning motor vehicles reach temperatures of 500 – 600 °C, 700 °C, 900 °C – 1000 °C and 1000 °C respectively (Shipman, Foster & Schoeninger, 1984; Fraser et al., 2003; Okamoto et al., 2013; Walls, Olivier & Eksteen, 2017). Bone undergoes dimensional changes when subjected to burning at forensically relevant temperatures, with expansion occurring at lower intensities and notable shrinkage at higher heat intensities (Thompson, 2005; Collini et al., 2015; Ellingham & Sandholzer, 2020). These heat-induced changes may alter the characteristics of sharp force trauma present on bone, which could lead to the inaccurate interpretation of these cut marks.

1.2.3. Saw marks on bone

Bones are well suited for tool mark analysis as they tend to retain the impressions of the tool used, allowing the class of weapon to be identified (Amadasi et al., 2019). Weapons used for dismemberment of a body leave behind marks on the bones of the victim that can be used as evidential clues in forensic investigations.

In cases where a saw is used to dismember a body, the impressions left behind by the saw on bone can be analysed to provide insight on the saw class used. Characteristics of the saw implement used, such as the size, width, shape and teeth set, as well as the perpetrator's sawing action has a direct effect on the nature of the tool mark present on the bone, thus allowing for inferences to be made about the characteristics of the saw used (Saville et al., 2007).

General morphologic features of saw cut marks on bone is that they are wider than the blade size of the saw, along with the presence of well-defined striations on the walls that are parallel to the floor of the cut (Amadasi et al., 2019). Kerf refers to the cut mark created by the saw, with kerf walls referring to the vertical sides of the cut, and kerf floors describing the horizontal face found in incomplete cuts, false starts or occasionally, in breakaway spurs (Saville et al., 2007; Symes et al., 2010).

The analysis of kerf width, walls and floors on sawed bone can inform the investigation on the saw's characteristics, such as teeth per inch (TPI), teeth set (alternating, wavy, or raker), and direction of sawing action (Symes et al., 2010). The minimum width of a kerf has direct relation to the width of the saw blade responsible (Symes et al., 2010).

The number of fine striations present on the kerf wall correlates with the number of teeth involved in a stroke, which is usually about two thirds of the total number of teeth present on the saw (Bonte, 1975). Breakaway spurs and notches are formed when the bone fractures at the terminal cut and can also be used to infer information on the force applied during the cut (Symes et al., 2010).

The tooth size of a saw blade is universally classified as the number of complete teeth present per inch (Symes et al., 2010). Tooth hop is the stria present across the face of the kerf wall that has a generally straight wavy pattern with breaks in between, caused by the successive movement of each tooth as it enters the kerf (Symes et al., 2010; Robbins et al., 2015). The measurement of the distance between two consecutive peaks or dips of each tooth hop wave is representative of the distance between each of the teeth on the saw's blade (Symes et al., 2010).

The analysis of other characteristics of saw cut marks including regular and pull-out striae, bone islands, tooth imprint, exit chipping, kerf flare and blade-drift, are all informative on the characteristics and class of saw used. However, in cases where burning follows

dismemberment, they may be vulnerable to distortion following the effects of fire (Marciniak, 2009; Hutchinson, 2011; Robbins et al., 2015).

1.2.4. Thermal alteration of cut marks on bone

Several studies have been conducted investigating the effect of burning on pre-existing trauma using either pig or sheep bones as animal analogues for human bones. Most research has focused on the alteration of sharp-force injury, and found that signature characteristics of cut marks are generally still observable after burning, but may be altered (Herrmann & Bennett, 1999; Kooi & Fairgrieve, 2013; Robbins et al., 2015; Macoveciuc et al., 2017).

As classic sharp force trauma cut marks are vulnerable to distortion following burning, understanding how this would affect signature saw mark characteristics is essential when assessing saw marks left behind in burning and dismemberment cases to identify the class of saw used. In order to understand the extent of previous literature evaluating heat-induced alterations in saw cut marks, a systematic review was conducted. The aim of the systematic review was to critically assess previous literature on the alteration of saw marks on bone due to burning.

1.3. Systematic review methods

A systematic search across four databases (PubMed, ScienceDirect, Scopus and Web of Science) was conducted using variations of the key words saw mark, saw cut, burn, fire, heat-induced alteration, and bone (Table 1). As only original research articles were included, search results from ScienceDirect, Scopus and Web of Science were filtered to include only research articles.

Articles were initially included based on their relevancy from screening the title and when necessary, reading the abstract. Thereafter, articles were included based on the following criteria: i) only English language articles were included, ii) only articles in which sharp force trauma was caused by a saw were included, iii) only peer reviewed original research articles were included. The reference list of every article selected was scanned and hand searched to identify any additional relevant articles. Seven articles in total were included based on the above-mentioned criteria. The following information was then extracted from each article

into an Excel document: the publishing journal, saw type used, specimen type/model, number of specimens, method of burning, burning temperatures (°C), burning duration, method of analysis, characteristics analysed, as well as key findings and conclusions.

Table 1: Number of articles returned and keywords searched across four databases (date of search 25/04/2023).

Database	Key words	No. results
PubMed	("saw mark*" OR "saw cut") AND (burn* OR fire OR "heat-induced alteration") AND bone*	6
ScienceDirect	("saw mark" OR "saw cut") AND (burn OR burning OR burnt OR fire OR "heat-induced alteration") AND bone	106
Scopus	("saw mark" OR "saw cut") AND (burn OR burning OR burnt OR fire OR "heat-induced alteration") AND bone)	68
Web of Science	("saw mark*" OR "saw cut*") AND ("burn*" OR "fire" OR "heat-induced alteration") AND bone*	13

1.4. Results

1.4.1. Literature search

A total of 193 search results across all four databases were returned, with only four meeting in the inclusion criteria. Three more articles were found by review reference lists, bringing the total number to seven. Four of the articles were published by the Journal of Forensic Sciences, with the remaining three published by International Journal of Legal Medicine, Archaeological and Environmental Forensic Science, and The American Journal of Forensic Medicine and Pathology. Three of the articles were conducted within the last 10 years with the remaining four having been published before. Two of the articles examined the effects of heat on saw trauma marks only, while the others included it in their study of sharp force trauma, sometimes along with blunt force, ballistic, and torsional trauma.

1.4.2. Specimen type and number

Most studies utilised animal analogues, with only one study utilising human tissue in their research. Six articles used pig (*Sus scrofa*) long bones or heads as an analogue for humans, whereas Pope & Smith (2004) utilised unembalmed donated cadaver heads (Table 2). Two of the articles (Marciniak, 2009; Robbins et al., 2015) utilised numerous saws in their experiment, while the other five focused on the marks created by just one or two types. Each experiment used approximately three to four specimens per saw with the exception of

Robbins et al. (2015) in which each saw cut two bones, one to be burned and one unburned control, as well as Pope & Smith (2004) in which six heads were treated with randomly distributed sharp force trauma. Two out of the seven articles inflicted trauma on de-fleshed bones, three used semi-fleshed bones, and two used fleshed specimens.

Table 2: Saw and specimen type used in research on the thermal alteration of saw marks on bone.

Article	Saw type	Specimen type/model	No. of specimen
(Herrmann & Bennett, 1999)	1 Stryker saw, 1 ripsaw	Semi-fleshed <i>Sus scrofa</i> femora	8 (4 Stryker, 4 ripsaw) + 8 controls
(Pope & Smith, 2004)	1 Stryker saw	Fleshed cadaver heads	6 + 10 controls
(Marciniak, 2009)	6 hand saws: a crosscut universal saw, a crosscut aggressive saw, a manual miter saw, a bow saw, a hacksaw, and a keyhole saw. 6 power saws: a table saw, a miter saw, a circular saw, a jigsaw, reciprocating saw, and a chainsaw.	Semi-fleshed <i>Sus scrofa</i> femora	36 + 12 controls
(Poppa et al., 2011)	1 unspecified saw	Fleshed <i>Sus scrofa</i> heads	3
(Robbins et al., 2015)	6 new saws: a hacksaw with 2 detached blades, a back saw, a PVC saw, a universal saw, a coarse cut carpenter saw and a drywall saw 5 used saws: 1 rip saw and 3 crosscut saws	Semi-fleshed <i>Sus scrofa</i> tibiae	12 + 12 controls
(Vegh & Rando, 2019)	2 saws: a wood saw and a hacksaw	De-fleshed <i>Sus scrofa</i> limbs	8 (4 wood saw, 4 hacksaw) + 4 controls
(Mata-Tutor et al., 2022)	1 hand saw with coarse serration and a 180-mm blade length	De-fleshed <i>Sus scrofa</i> femora and tibiae	4 (2 femora, 2 tibiae)

1.4.3. Burning methodology

Similarly, the methodology used to burn the bone samples varied between studies. The different burning methodologies used to subject traumatised bones to thermal damage included outdoor fires, electric furnaces, gas cookers, and a house fire, with outdoor fires being the most prevalent (Table 3). Only one of the seven studies examined the effects of multiple controlled temperatures on saw trauma on bone (Vegh & Rando, 2019). Duration of burning is an important factor to consider when analysing burned remains. However, two studies did not report the duration of burning experiments. Furthermore, in all studies returned, none examined the effect of burn duration. Burn duration was held constant, ranging from 20 – 247 minutes, with the exception of the study by Marciniak (2009), wherein the bones were removed from the fire if one or combination of specific conditions were met. These conditions include severe heat alterations to the bone, namely calcination, fragmentation, deformation, as well as if the temperature of the fire reached greater than 800 °C, or if the burn duration reached the maximum three hours. Of the studies that reported duration of burning, none exceeded a duration of five hours.

Table 3: Burning methods used in research on the thermal alteration of saw marks on bone.

Article	Method of burning	Burning temperatures (°C)	Burning duration (mins)
(Marciniak, 2009)	outdoor fire	max of 800	max of 180
(Mata-Tutor et al., 2022)	electric furnace	max of 850	247
(Robbins et al., 2015)	outdoor fire	max of 710 and 720	180
(Vegh & Rando, 2019)	electric furnace	300, 600, 800, and 1000	20
(Herrmann & Bennett, 1999)	house fire	max of 700-850	150
(Pope & Smith, 2004)	outdoor fires	Ranged from 204-871	Unspecified
(Poppa et al., 2011)	gas cookers with iron grill	Unspecified	Unspecified

1.4.4. Method of analysis

All studies used either microscopy, scanning electron microscopy or both to analyse saw cut characteristics (Table 4). Four of the studies analysed changes in specific saw marks traits

related to the kerf floor and walls, such as those identified by Symes (1992), or the dimensions of the kerf itself due to heat exposure, whereas the remaining three articles focused only the visibility and detectability of the saw trauma post-burning. Mata-Tutor et al. (2022) uniquely, measured the optical surface roughness of the saw cut marks.

Table 4: Analysis methods and key findings of research on the thermal alteration of saw marks on bone.

Article	Method of analysis	Metric/non-metric analysis	Key findings
(Marciniak, 2009)	Macroscopy and microscopy	non-metric	Some of the saw types preserved saw mark class characteristics post-burning.
(Mata-Tutor et al., 2022)	Macroscopy, microscopy, and optical surface roughness measurement	metric and non-metric	Length of saw mark decreased post-burning, saw mark class characteristics still identifiable at high temperatures.
(Robbins et al., 2015)	Microscopy	non-metric	Heat alters saw mark characteristics but does not destroy them.
(Vegh & Rando, 2019)	Macroscopy and microscopy	metric	Length of saw mark decreased post-burning, saw mark class characteristics still identifiable between 300 -1000 °C.
(Herrmann & Bennett, 1999)	Radiography, macroscopy and microscopy	metric and non-metric	Saw trauma remained visible post-burning. Bone shrinkage occurred.
(Pope & Smith, 2004)	Microscopy and macroscopy	non-metric	Saw trauma remained visible post-burning and was clearly distinguishable from other sharp traumas.
(Poppa et al., 2011)	Microscopy	non-metric	Saw trauma remained visible post-burning.

1.4.5. Effect of burning on saw trauma

Marciniak (2009) dismembered *Sus scrofa* femora using six different types of hand saws and subjected them to burning using outdoor fires for a maximum of three hours. Induced cut marks included one complete bisection and one false start per bone. The bones were removed from the fire depending on whether they were partially calcined, if the temperature

exceeded 800 °C, or if there was significant cracking or deformation present. Saw mark characteristics were analysed, namely, kerf floor and kerf wall characteristics such as roughness and shape, as well as striae characteristics such as, regularity, depth and how fine the striae are on the cut marks were, before and after burning.

The results of the macroscopic and microscopic analyses conducted on the femora thereafter found that false starts were identifiable post-burning and the analysis of saw mark characteristics and identification of saw class was still possible. Saw mark characteristics were preserved by cremation to a certain extent, depending on saw used, bone position in the fire, temperature of the fire and atmospheric conditions. Striations caused by the aggressive, the universal crosscut, and the manual miter hand saws were difficult to recognise, especially in bone areas that were calcined. In other saw types such as bow saws, the striae were visible, allowing for the class of saw to be identified post-burning.

Mata-Tutor et al. (2022) cut four de-fleshed *Sus scrofa* long bones with an unspecified type of hand saw, creating 30 lesions per bone, comprising of five repeats of progressively increasing depths. Thereafter the bones were burned in an electric furnace for a total of just over four hours at a maximum temperature of 850 °C. The bones were placed in the furnace at 39 °C and heated until a maximum of 850 °C was attained. Burning continued at this temperature for 30 minutes. Following this, the bones were removed from the furnace after cooling overnight.

A 3D optical surface roughness meter device was used to generate the mean roughness depth (Rz) of the cuts to analyse the roughness of the lesions created by the saw. The maximum width, length and floor shape was determined for each cut before and after burning. It was found that the length of saw cut marks decreased post-incineration but there was no significant change in width. The roughness of the cuts significantly increased, indicating that the surface became more irregular and coarse. The U-shape of the saw kerf was preserved after thermal damage. The study found that thermal treatment distorts signature saw class characteristics, but that they were still identifiable even after burning at high heats for long durations.

Robbins et al. (2015) used old and new saws to cut *Sus scrofa* tibiae into distal, middle and proximal sections, as well as to create shallow and deep false starts. The traumatised bones

were then burned in an outdoor fire pit until they reached partial calcination, which took approximately three hours with a maximum temperature of 720 °C. The prevalence of nine saw mark characteristics were detected – namely breakaway spur, tooth hop, false start, exit chipping, tooth imprint, breakaway notch, pull out striae, kerf flare, and blade drift, before and after burning. The study found that fire did have an effect on the saw marks, but did not necessarily obliterate them. Kerf flare became more visible and the detectability of tooth hop became more prevalent post-burning. It was also demonstrated that the use of scanning electron microscopy to analyse the post heat treatment cut marks on bones enhanced the identification of their traits. The study found saw-tooth imprints on the burned samples to be observable using scanning electron microscopy (SEM), and not stereomicroscopy.

Vegh & Rando (2019) used a hacksaw and wood saw to traumatise four de-fleshed *Sus scrofa* long bones each. The traumatised bones were then burned along with uncut bones in an electric furnace at controlled temperatures (300 °C, 600 °C, 800 °C, 1000 °C). One uncut bone along with one cut bone per saw type were burned per temperature treatment for 20 minutes. Macroscopy and SEM were utilised to metrically analyse cut lengths and widths of saw marks on bone before and after burning. The maximum width and length of each cut was measured from scanning electron images for each bone. The study found that all saw cut marks were identifiable post-burning, but that their dimensions changed at higher temperatures. The lengths and widths of the lesions changed at 1000 °C with only the lengths shrinking consistently. Both the lengths and widths of the cuts decreased post-burning, with the exception of the wood saw in which an increase of the maximum width occurred.

Herrmann & Bennett (1999) bisected *Sus scrofa* femora, four with a ripsaw and four with a Stryker saw, which were then burned in a housefire during a training exercise with the Tennessee fire department. The estimated maximum temperature of the fire was between 700 – 850 °C and burned for approximately two hours and 30 minutes. Subsequent macroscopic and radiographic analyses found that the transverse and longitudinal cut marks made by the Stryker saw, as well as the kerf walls created by the ripsaw remained detectable and recognisable on the burnt femora. The study also reported the presence of bone shrinkage ranging from 6.8 – 17.7% post burning.

Pope & Smith (2004) traumatised six human heads with a variety of randomly distributed sharp instruments including a Stryker saw, followed by burning in open air fires which ranged

from 204 – 871 °C until either partial or full calcination. The trauma left by the saw were identifiable and distinguishable from the marks caused by the other sharp tools when analysed by macroscopic visual inspection and microscopy.

Poppa et al. (2011) similarly traumatised three fleshed *Sus scrofa* heads with a variety of sharp force implements which included the generation of lesions with an unspecified type of saw. The heads were placed on iron grills and burned with gas cookers, and were analysed at four different stages of burning (unburnt, carbonisation, darkening and shrivelling of soft tissue, and calcination of bones). Microscopic analysis of the post-burning trauma found that the irregular edges and general linear shape was still detectable after heat treatment, losing their distinctiveness at the mid-stages of carbonisation and became visible again in the latest stage of burning, when the soft tissue had burned away.

1.5. Discussion

Sharp tool weapons are often used to carry out homicidal acts, as well as in attempts to cover up the crime, such as saws used to dismember a corpse when getting rid of a body. The impressions left behind by sharp weapons tend to be retained on the bones of victims, allowing for the analysis of these tool marks to identify the type, and even class of weapon used (Amadasi et al., 2019).

Cut marks caused by a sharp tool, such as a smooth knife, tend to leave V-shaped kerf floors on bone. However, sharp tools with a serrated edge such as serrated knives or saws leave different characteristic floor profile shapes on bone, with serrated knife cuts having Y-shaped floors and saws marks having U-shaped floors (Norman et al., 2018). Serrated blades also differ from smooth edged blades in that they leave well-defined striations on the kerf walls, the characteristics of which can help in saw class identification (Vachirawongsakorn et al., 2022).

The burning of a body is a further method that can be deployed along with dismemberment, to obscure the evidence of homicide. Fire can damage bone to the extent that warping and fracturing occurs, as well as dimensional changes such as expansion at lower heat intensities and shrinkage occurring at higher intensities (Thompson, 2005; Hutchinson, 2011; Collini et al., 2015; Ellingham & Sandholzer, 2020). Sharp force trauma marks on bones may therefore

be vulnerable to obliteration or distortion following fire exposure. This review sought to assess the literature available on heat-induced alterations of saw marks on bone.

It is clear that a limited number of studies have been conducted examining the effects of burning on saw marks on bone, as only seven original research articles that met the inclusion criteria were obtained from a search across all four databases. The majority of studies utilised animal models as an analogue for human bones. While human specimens are the most accurate at predicting what would be seen in forensic cases, they are far less easily available as animal specimens obtained from butcheries or abattoirs.

All of the studies that used animal models used pig (*Sus scrofa*) bones, which have been proven to be an adequate proxy for human bones in previous literature (Symes et al., 2012). It should be also noted however, that sheep bones have also been used as acceptable an animal model analogue for human bones in forensic anthropological research (Thompson, 2005; Macoveciuc et al., 2017). Further research is necessary to compare pig and sheep bones as human tissue proxies, to determine if one is a more suitable analogue. A fairly low number of specimens were used per saw in each study, ranging from two to six. It is recommended that further studies done use an increased specimen sample size, to improve the robustness of results.

All seven studies found in this review illustrated that cut marks, and specifically saw marks, survive the burning process. Pope & Smith (2004) and Mata-Tutor et al. (2022) found that saw trauma was still easily distinguishable from the marks caused by other sharp tools post-burning. Herrmann & Bennett (1999) found that bone fracturing does not obliterate saw trauma characteristic marks. There was also however, a consensus that fire exposure alters saw trauma marks along with bone morphology.

It was found that signature characteristics of saw cut marks on bone persist after burning but are vulnerable to distortion, the extent of which is influenced by the heat intensity, heat exposure duration, and saw type (Marciniak, 2009; Robbins et al., 2015; Vegh & Rando, 2019; Mata-Tutor et al., 2022).

Mata-Tutor et al. (2022) and Vegh & Rando (2019) performed metric analyses on cut marks caused by sharp tools including saws. Both studies agreed that the length of cut marks caused by sharp tools decreases post-burning, with Mata-Tutor et al. (2022) noting that the lengths

of marks caused by saws shrank the most. Mata-Tutor et al. (2022) detected no change in width of cut marks caused by any of the sharp instruments including saws, whereas Vegh & Rando (2019) found that the widths of the sharp implements except for the saw decreased post-burning at 1000 °C. This discrepancy may be due to Mata-Tutor et al. (2022) only reaching a maximum burning temperature of 850 °C, and it could be possible that the cut mark widths would have decreased if allowed to burn at 1000 °C.

Vegh & Rando (2019) also detected an expansion in three marks produced by a wood saw at 1000 °C. This may be due to some of the bony projections at the edges or walls of the kerfs burning off at a high heat intensity. While discrepancies in metric analysis may be due to the employment of different methodologies, further research is necessary to determine if the degree of alteration affects tool mark identification. If thermal alteration effects are not taken into consideration, there is the potential for forensic anthropological analyses on saw cut marks on burned bones to result in inaccurate saw class identification.

The fire temperatures investigated were all at forensically relevant temperatures, simulating heat exposures similar to that of camp fires, house fires, informal settlement fires, and burning motor vehicles (Thompson, 2005; Collini et al., 2015; Ellingham & Sandholzer, 2020). Notably, only Vegh & Rando (2019) explored the effects of different heat intensities. Further research is needed at controlled temperatures to understand if varying temperatures of heat exposure differentially alter saw mark characteristics, and what those differences are.

Duration of heat exposure is an additional factor that was left unassessed by these studies, which may have a significant influence the degree of shrinkage in burnt bones, with longer burning time tending to increase shrinkage (Thompson, 2005).

The use of electric furnaces may be beneficial over open fire burning conditions in experiments that require the burning of bones. The majority of studies used outdoor fires or housefires to burn traumatised bones, having the advantage of being more realistic simulations of forensic case conditions than the studies that used electric furnaces. However, this has the added disadvantage of not allowing for the evaluation of different heat intensities at controlled temperatures and durations. Electric furnaces may also help minimise the loss of bone fragments.

The use of scanning electron microscopy (SEM) may improve the visualisation of saw trauma on burnt bones over visual inspection and stereomicroscopy. SEM enhanced the visualisation of saw mark traits post-burning as seen in Robbins et al. (2015), in which saw tooth imprints on the burned bone was only visible under scanning electron microscopy, and not stereomicroscopic inspection, as well as in Vegh & Rando (2019), where SEM enhanced the visualisation of the kerf floor as compared to macroscopic visualisation.

1.6. Conclusion

While these studies have examined the effects of burning on saw marks on bone, there is a clear lack of extensive literature on the topic. Furthermore, the metric heat-induced alterations of saw cut mark characteristics have not been thoroughly interrogated by the literature. This is of great forensic interest, as the analysis of thermally altered saw cut marks on bones could lead to the estimation of misleading characteristics of the saw implement used to dismember a victim, impeding the identification of the weapon used to commit the crime. There is a need for further studies investigating this topic, with emphasis on the need of researching how signature characteristics of saw marks burn at various controlled temperatures of forensic relevance, and at which temperatures these marks and their characteristics no longer persist.

1.7. Aim and objectives

Aim: To analyse and compare the characteristics of saw cut marks in bone before and after burning at various temperatures.

Objectives:

- To inflict reproducible sharp force trauma using a saw on *Ovis aries* femora.
- To analyse the saw mark characteristics using macroscopy and stereomicroscopy.
- To assess role of temperature on the alteration of saw mark characteristics on bone.
- To analyse the prevalence and metric changes in saw trauma characteristics caused by burning.

CHAPTER 2: METHODS

This investigation is a continuation of research conducted by Chang (2023) and employed the same methodology, with alteration to duration of burning. To investigate changes in the characteristics of saw cut marks in bone before and after burning, an experimental study was conducted utilising sheep (*Ovis aries*) femora. Lamb long bones were chosen as a proxy for humans due to ease of access from local butcheries, as well as their similar macrostructure, microstructure, and density to human long bones (Schickert et al., 2020). Sheep bones have been used as an analogue for humans in previous forensic research (Thompson, 2005; Macoveciuc et al., 2017). Fifteen semi-fleshed juvenile sheep femora were purchased from a local butchery and stored in a refrigerator at -20 °C until testing began. Prior to experimentation, the femora were thawed at room temperature for 24 hours. This procedure caused no notable alterations to the bones, as earlier research found no significant effect of the freezing and thawing processes on the mechanical and histological structure of bones (Lander, Brits & Hosie, 2014; Torimitsu et al., 2014). For the purpose of preventing soft tissue from obscuring the saw cuts during analysis, any remaining flesh was removed using a scalpel, especially along the shafts.

2.1. Pre-trauma analysis

The mass of each femur was measured and standard dimensions such as length, anteroposterior midshaft diameter, and mediolateral midshaft diameter, were collected using digital vernier callipers. Femora were grouped to ensure no differences in mean midshaft thickness between test groups (400 °C, 600 °C, and 800 °C). This ensured robusticity of the bones was not a confounding factor. The colour and general condition of each bone was recorded.

2.2. Saw trauma

A crosscut hand saw with alternating teeth set and thirteen teeth per inch (TPI) was used (Figure 1) by one right-handed individual to make three cuts on each bone shaft. The three types of cuts comprised of a false start, an incomplete cut and a complete cut (Figure 2). A clamp and mitre block were used to stabilise the bone during the sawing process to ensure consistent perpendicular motion of the saw (Robbins et al., 2015).

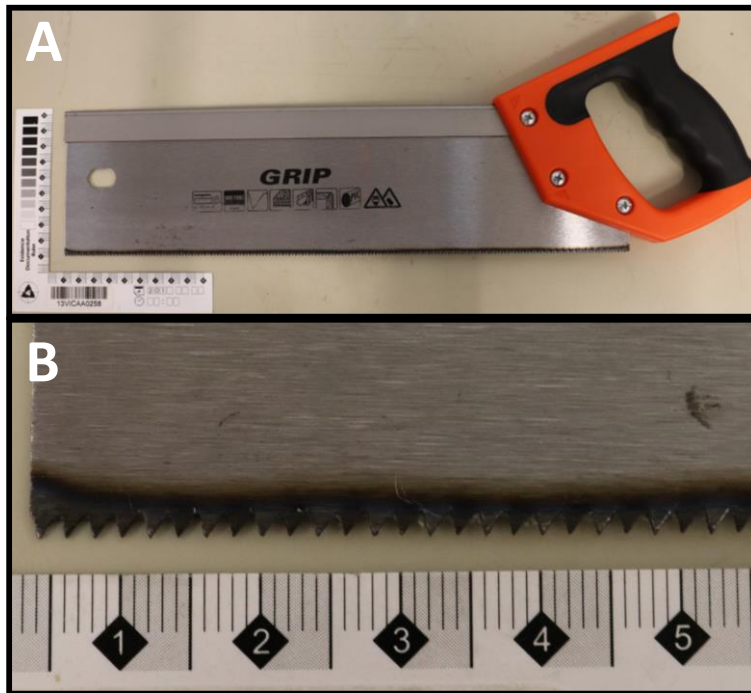


Figure 1: Crosscut aggressive hand saw with a teeth per inch (TPI) of 13.

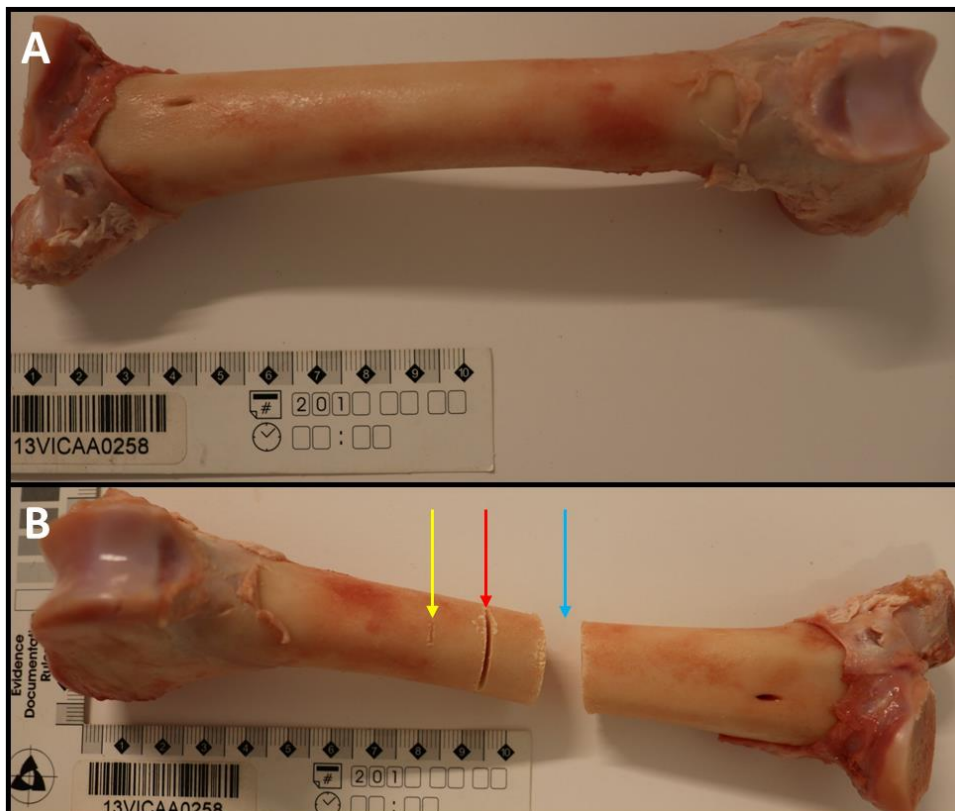


Figure 2: Three cut marks inflicted on a de-fleshed *Ovis aries* femur. A: Untraumatized. B: Traumatized bone; yellow arrow – false start, red arrow – incomplete cut, blue arrow – complete cut.

Following creation of the saw marks, all bones and saw marks were photographed under a stereomicroscope (Zeiss Discovery V20 stereomicroscope with an Axiocam 503 colour camera; Carl Zeiss (Pty) Ltd, Johannesburg, South Africa). Analysis of the casts, photographs and stereomicroscopy were done for all three cuts on each femur in order to identify the presence of common saw mark characteristics *viz.* breakaway spurs, breakaway notches, exit chipping, blade drift, bone islands, kerf flare, harmonics, tooth imprint, pull-out striae, and tooth hop. The number of tooth hop and pull-out striae present on complete cuts were counted and the kerf floor profile shape, kerf wall shape, and regularity of striae were recorded. Metric measurements such as the width and depth of kerfs, the maximum thickness and maximum length of breakaway spurs, as well as distances between striae were measured with digital callipers or on microscope images using ImageJ V. 1.54g (National Institute of Health, USA) software programme. Definitions and illustrations of these saw mark traits can be found in Appendix A.

2.3. Silicon casting

Casting of the lesions on the bones was done using the Body Double™ silicone casting set (AMT Composites, Cape Town, South Africa) in order to examine characteristics such as the patterns on the kerf walls and the shape of the kerf floor (Nogueira et al., 2016). Ease Release™ 200 was used to assist with removal of the dried cast from the bone. The silicon liquid was poured onto the bone kerfs and left to dry at room temperature for 24 hours.

2.4. Burning

Following the infliction of saw trauma, femora were individually burned in a muffle furnace (Labotec, (Pty) Ltd, Cape Town, South Africa) at one of three temperatures (400 °C, 600 °C and 800 °C). Each femur was placed one at a time into the furnace at the desired temperature, and allowed to burn for a total duration of 30 minutes. Thereafter, they were removed from the furnace and allowed to cool naturally. Five bones were used for each of the three different heat treatments.

The mass and colour of the burnt bones were recorded, as was done pre-incineration. Using colour changes present in burnt bones reported by Shipman, Foster & Schoeninger (1984) as a guide, the colour of each femur was visually assessed and recorded as either yellow-ish white, brown, black, grey, or white. The condition of each bone was visually assessed, with

the presence of longitudinal, straight transverse/step fractures, curved transverse, delamination, and patina heat-induced fractures recorded. Photography, stereomicroscopy and silicon casting was repeated for all the variables measured and identified.

2.5. Statistical analyses

All statistical analyses on the data collected was conducted using IBM SPSS V. 28 (IBM Corp.), with the level of significance set at $\alpha = 0.05$.

2.5.1 Pre-trauma analyses

A one-way ANOVA test was conducted across the three test groups to ensure that there was no significant difference in mean thickness between the temperature groups.

2.5.2. Intra-rater and inter-rater reliability

To assess reliability, a subset of the data ($n =$ five femora) was collected by the same individual, as well as by another rater before and after burning in order to evaluate intra-rater and inter-rater reliability. Rater reliability analyses were conducted by calculating Cohen's kappa coefficients for non-metric data and intraclass correlation coefficients (ICC) for metric data.

2.5.3. Significant heat-induced alteration of saw mark characteristics

Descriptive statistics were conducted on the data collected pre- and post-incineration. Shapiro-Wilk tests were done on metric variables, and if the standardised residuals followed a normal distribution, one-way repeated measures ANOVA tests were done to test the significant difference between the metric variables before and after burning. Wilcoxon signed-ranks tests were used as a non-parametric alternative for non-normal data. For variables in which significant differences before and after burning existed, paired sample t-tests were conducted for each temperature group. Similarly, McNemar's chi-squared tests were conducted on the non-metric variables, with further chi-squared tests performed for each temperature group if a significant difference existed for the overall variable before and after burning.

2.6. Ethics

An amendment was made to the ethical approval granted by the University of Cape Town's Animal Ethics Committee (AEC) to a larger joined project to include this study (AEC number: 022_015).

CHAPTER 3: RESULTS

The average robusticity of the specimens across each temperature group did not differ significantly (F-value = 0.915, p=0.915) as shown in Fig 3. The mean midshaft thickness of the specimens across each temperature group was 19.817 mm \pm 0.707 at 400 °C, 19.762 mm \pm 0.970 at 600 °C, and 19.620 mm \pm 0.5331 at 800 °C.

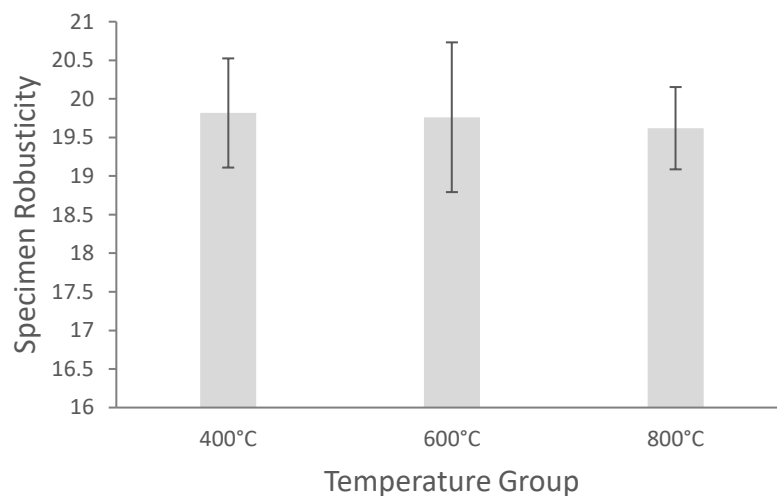


Figure 3: Specimen robusticity of *Ovis aries* femur bones assigned to different burning temperature groups before incineration.

Burning *Ovis aries* femora at various controlled temperatures resulted in morphological changes in colour, mass and condition (Table 5; Table 6; Fig 4). There was an overall decrease in mass of the femora post-incineration, with the mean mass decreasing as temperature increased. The femora pre-incineration were all a similar yellowish-white colour, which was altered upon burning. The femora burnt at 400 °C and 600 °C were charred black, whereas those subjected to the highest temperature turned ash grey. Calcination began to take place at 600 °C as white patches at the epiphyseal ends as well as along the shafts, and was more extensive at 800 °C, turning the ends of the femora mostly white.

Table 5: Heat-induced changes in mass and colour to *Ovis aries* femora burned at various temperatures.

Temperature group (°C)	Pre-incineration		Post incineration	
	Mass (g)	Colour	Mass (g)	Colour
400	158.02 ± 23.78	Yellowish-white	68.74 ± 13.88	Black
600	177.60 ± 24.10	Yellowish-white	61.8 ± 4.40	Black with white patches
800	158.46 ± 11.31	Yellowish-white	53.38 ± 2.50	Grey with white patches and white epiphyseal ends

The increasing temperature treatment also resulted in an increase in the brittle nature of the burnt bones, as well as heat induced fractures (Table 6). Longitudinal, step, and curved transverse fractures were present in all burning groups, and was most prevalent at 800 °C.

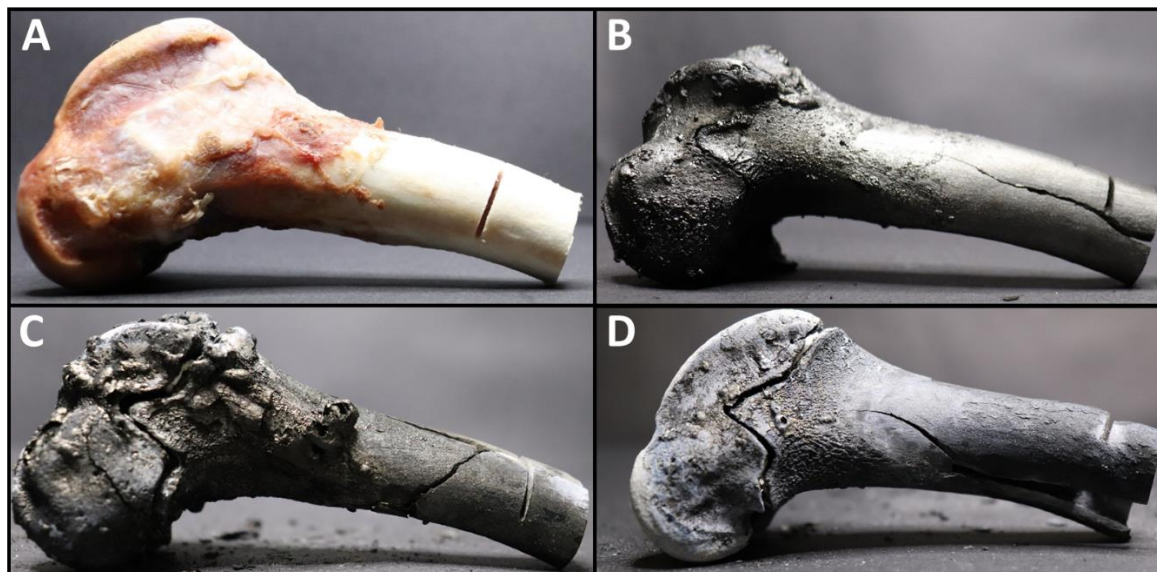


Figure 4: Heat-induced alteration of *Ovis aries* femur bones (distal ends) with saw trauma, burned at various temperatures for 30 minutes. A: Pre-incineration; B: 400 °C; C: 600 °C; D: 800 °C.

Longitudinal fractures appeared along the length of the shafts, very often intersecting the cut marks made pre-incineration. Straight transverse fractures often emerged from the margins of longitudinal fractures, in the form of step fractures. Curved transverse fractures also

appeared in the bone shaft region. Separation of epiphyseal ends began to take place 400 °C, and were completely separated at 600 °C and 800 °C. Delamination occurred minimally at 400 °C, and became more prevalent in bones burned at 600 °C and 800 °C. Patches of patina fracturing was present more commonly at 600 °C at the epiphyseal regions.

Table 6: Heat-induced fractures on *Ovis aries* femora burned at various temperatures.

Heat-induced fracture	Burning temperature (°C)		
	400	600	800
Longitudinal	15	44	70
Straight transverse/ step fractures	4	14	46
Curved transverse	8	8	42
Delamination	Slight	Present	Present
Patina	Small patches present on some bones	Small patches present on most bones	Small patches present on some bones

3.1. Saw trauma pre-incineration

3.1.1. Prevalence of saw mark traits pre-incineration

False starts and incomplete cuts

Blade drift, bone islands, and kerf flare were not detected in any of the cuts, pre-incineration. There was 100% agreement for both intra-rater reliability, and inter-rater reliability analysed for these traits (Table 7).

The shape of the walls of false starts and incomplete cuts were consistently categorised (100%) as straight, with none of the cuts appearing to have narrow and wide or necking shaped walls. There was 100% agreement for both intra-rater, and inter-rater reliability.

The profile shapes of incomplete cuts were classified in the majority as round in 68% of the kerfs, and square with round corners in 33.3% of the kerfs. No other profile shapes typical of sharp tools were detected (square, V-shaped, W-shaped or W-truncated). There was perfect statistically significant intra-rater agreement for the classification of kerf profile shape (Cohen’s kappa = 1, p=0.014). There was good inter-rater agreement with a Cohen’s kappa value of 0.667, but was not statistically significant (p=0.083).

Table 7: Prevalence and rater reliability of seven saw mark characteristics in false starts, incomplete and complete saw cuts on *Ovis aries* femora across three temperature groups pre-incineration.

Saw mark traits	Prevalence (%)				Inter-rater reliability		Inter-rater reliability	
	All	400 °C	600 °C	800 °C	Cohen's kappa	p	Cohen's kappa	p
Breakaway spur	53.3	60	50	50	1	<0.001*	1	<0.001*
Breakaway notch	46.7	40	50	50	1	<0.001*	1	<0.001*
Exit chipping	70.5	85.7	86.7	40	1	<0.001*	0.471	0.043*
Harmonics	93.3	90	90	100	1	<0.001*	1	<0.001*
Pull-out striae	13.3	10	10	20	1	<0.001*	1	<0.001*
Tooth hop	26.7	20	40	20	1	<0.001*	1	<0.001*
Striation regularity	83.3	80	100	70	1	<0.001*	0.625	0.02*

* represents a significant p-value.

Incomplete and complete cuts

Exit chipping was detected in 70.5 % of incomplete and complete saw cuts, and had perfect, statistically significant intra-rater reliability with a Cohen's kappa value of 1 ($p < 0.001$; Table 7). The inter-rater reliability calculated for exit chipping was moderate and statistically significant, with a Cohen's kappa value of 0.471 ($p = 0.043$).

Breakaway spurs, breakaway notches, harmonics, pull-out striae, and tooth hop were detected in complete saw cut marks (Table 7) with harmonics appearing most often (93.3%), and tooth hop the least (26.7%). Breakaway spurs were present in 53.3% of cuts and conversely, breakaway notches were present in 46.7% of complete cuts. In total, 14 pull-out striae (13.3%) and 13 tooth hop striae (26.6%) were identified in complete cuts. There was perfect, statistically significant intra- and inter-rater reliability for the above traits (Cohen's kappa = 1, $p < 0.001$). Tooth imprint was not detected in any of the cuts, pre-incineration, and had both intra- and inter-rater agreements of 100%.

Striae present were classified as having a regular pattern for 83.3% of the complete cuts, and had perfect, statistically significant intra-rater reliability (Cohen's kappa = 1, $p < 0.001$).

Striation regularity had good inter-rater reliability that was statistically significant (Cohen's kappa = 0.625, p=0.02).

3.1.2. Saw mark trait metrics pre-incineration

False starts and incomplete cuts

The average width of false start and incomplete cuts was 1.042 mm (Table 8). The kerf widths had good statistically significant intra-rater reliability (ICC = 0.949, p<0.001), but did not have statistically significant inter-rater reliability (p=0.229).

The mean kerf depth of the incomplete cuts on bone were 7.175 mm (Table 8). The measuring of kerf depth had good intra- and inter-rater reliabilities that were statistically significant (ICC = 0.183, p=0.015 and ICC = 0.979, <0.001 respectively).

Table 8: Metrics and rater reliability of five saw mark characteristics present on sawed *Ovis aries* femora pre-incineration. ICC: Intraclass correlation coefficient.

Saw mark traits	Intra-rater reliability			Inter-rater reliability	
	Mean	ICC	p	ICC	p
Kerf depth (mm)	7.175 ± 2.199	0.813	0.015*	0.979	<0.001*
Kerf width (mm)	1.042 ± 0.033	0.949	<0.001*	0.17	0.229
Breakaway spur maximum length (mm)	9.551 ± 1.9334	0.979	<0.001*	0.925	<0.001*
Breakaway spur maximum thickness (mm)	2.098 ± 0.700	0.96	<0.001*	0.543	0.076
Mean striae distance (µm)	159.817 ± 93.175	0.94	<0.001*	0.937	<0.001*

* represents a significant p-value.

Complete cuts

The average maximum length of the breakaway spurs formed on complete cuts was 9.551 mm (Table 8), and had good intra-rater reliability (ICC = 0.979, p<0.001) as well as good inter-rater reliability (ICC = 0.925, p<0.001). The mean breakaway spur maximum thickness measured was 2.098 mm. The measurement of this trait had good, statistically significant intra-rater reliability, whereas the inter-rater reliability was not statistically significant (p=0.076).

The mean striae distance was 159.817 μm and had a particularly high standard deviation ($\pm 93.175 \mu\text{m}$). Both the intra- and inter-rater reliabilities for this saw mark trait had good, statistically significant reliability.

3.2. Saw trauma post-incineration

3.2.1. Prevalence of saw mark traits post-incineration

False starts and incomplete cuts

The presence of blade drift, bone islands, and kerf flare were consistent with pre-incineration observations. These traits were not observed in false starts or incomplete cuts, with 100% intra- and inter-rater agreement.

Table 9: Prevalence and rater reliability of seven saw mark characteristics on sawed *Ovis aries* femora post-incineration.

Saw mark traits	Prevalence (%)				Intra-rater reliability		Inter-rater reliability	
	All	400 °C	600 °C	800 °C	Cohen's Kappa	p	Cohen's Kappa	p
Breakaway spur	53.3	60	50	50	1	<0.001*	0.471	0.098
Breakaway notch	40	40	40	40	1	<0.001*	0.524	0.098
Exit chipping	90	100	40	80	1	<0.001*	100 % agreement	
Harmonics	93.3	90	90	100	1	<0.001*	1	<0.001*
Pull-out striae	40	30	30	60	1	<0.001*	1	<0.001*
Tooth hop	60	60	60	60	1	<0.001*	0.676	0.013*
Striation regularity	100	100	100	100	100 % agreement		91.7% agreement	

* represents significant p-value.

The shape of the kerf walls for false starts and incomplete cuts were also consistent with that observed pre-incineration, and were all categorised as straight. There was 100% agreement for both intra-rater, and inter-rater reliability.

Sixty percent of kerf profile shapes of incomplete cuts were classified as round, with 40% classified as square with round corners. There was perfect statistically significant intra-rater

agreement, with a Cohen's kappa value of 1 ($p=0.014$). Inter-rater reliability showed poor agreement (50%) that was not statistically significant.

Incomplete and complete cuts

Exit chipping was detected in 90% of incomplete and complete cut marks, and had perfect intra-rater reliability (Cohen's kappa = 1, $p<0.001$) as well as 100% inter-rater agreement (Table 9). There was 100% prevalence at 400 °C, which reduced by more than half to 40% at 600 °C. Exit chipping observed then increased to 80% at 800 °C.

Consistent with pre-incineration observations, no tooth imprints were detected in complete cuts, with 100% intra- and inter-rater agreement.

Breakaway spurs, breakaway notches, harmonics, pull-out striae, and tooth hop were all detected post-burning (Table 9). Harmonics appeared the most often (93.3%), and pull-out striae and breakaway notches the least (40% each). Breakaway spur occurred in 53.3% of cuts. Both harmonics and pull-out striae (total number of 37) detected had perfect intra- and inter-rater agreement (Cohen's kappa = 1, $p<0.001$), whereas breakaway notches and spurs had perfect intra-rater agreements, but had inter-rater reliabilities that were not statistically significant ($p=0.098$).

A total 44 tooth hop were identified on 60% of complete cuts, with perfect intra-rater agreement, and good inter-rater agreement. In 100% of complete cuts, striae pattern was classified as regular, with 100% intra-rater agreement, and 91.7% inter-rater agreement.

3.2.2. Saw mark trait metrics post-incineration

False starts and incomplete cuts

Accurate measurements of the kerf widths of four cuts and kerf depths of three cut marks could not be taken due to severe heat-induced fracturing and were excluded. The average kerf width of false start and incomplete cuts was 1.207 mm (Table 10). The measuring of kerf width had excellent intra-rater reliability (ICC = 0.907, $p<0.001$) but did not have statistically significant inter-rater reliability ($p=0.218$).

The average kerf depth measured on incomplete cuts post-incineration was 5.182 mm (Table 10). The intra-rater reliability for the measuring of kerf depth post-incineration was excellent,

with an ICC of 0.954 ($p=0.005$), whereas the inter-rater reliability was not significant ($p=0.187$).

Complete cuts

The average maximum breakaway spur length on complete cuts was 6.951 mm (Table 10), and had excellent intra-rater reliability (ICC = 0.984, $p<0.001$), but statistically insignificant inter-rater reliability ($p=0.088$). The thickness of three breakaway spurs were excluded due to severe thermal damage affecting the accuracy of measurements. The average maximum thickness of breakaway spurs was 2.208 mm and had both excellent intra- and inter-rater reliabilities (ICC = 0.984, $p<0.001$ and ICC = 0.906, $p=0.049$ respectively).

The mean striae distance for complete cuts was 82.576 μm , with excellent intra- and inter-rater reliability (ICC = 1, $p<0.001$ and ICC = 0.935, $p<0.001$ respectively).

Table 10: Metrics and rater reliability of five saw mark characteristics present on sawed *Ovis aries* femora post-incineration. ICC: Intraclass correlation coefficient.

Saw mark traits	Intra-rater reliability			Inter-rater reliability	
	Mean	ICC	p	ICC	p
Kerf depth (mm)	5.182 ± 1.353	0.954	0.005*	0.503	0.187
Kerf width (mm)	1.207 ± 0.052	0.907	<0.001*	0.303	0.218
Breakaway spur maximum length (mm)	6.951 ± 3.053	0.984	<0.001*	0.952	0.088
Breakaway spur maximum thickness (mm)	2.208 ± 1.626	0.984	<0.001*	0.906	0.049*
Mean striae distance (μm)	82.576 ± 54.893	1	<0.001*	0.935	<0.001*

* represents a significant p-value.

3.3. Silicon casts

Kerf depth of incomplete cuts can be evaluated on silicon casts of the kerf, as well as for the evaluation of kerf profile shape (Fig 5). Casting was successful for cuts present on bones burnt at 400, 600, and 800 °C, but with increasing difficulty due to the brittle and fractured nature of the femora.

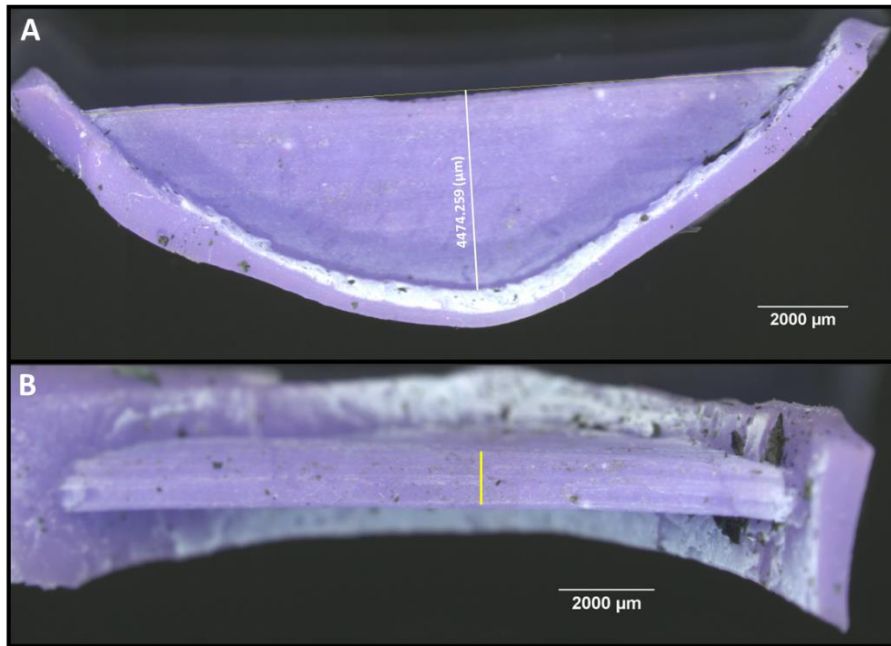


Figure 5: Silicon cast of an incomplete saw cut mark on *Ovis aries* femur burned at 800 °C. A: The depth of the kerf can be measured on the cast. B: The square with round corners shape of the kerf profile can be visualised on the silicon cast.

3.4. Heat-Induced alteration to saw trauma

3.4.1. Heat-induced changes to prevalence of saw mark characteristics

No change in the prevalence of breakaway spurs or harmonics occurred post-burning, whereas there was an increase in prevalence of exit chipping, pull-out striae, and tooth hop (Fig 6). Striation regularity also had an increase post-incineration, with 100% of all complete cuts categorised as having regular striation patterning. This increase however, was not statistically significant ($p=0.063$).

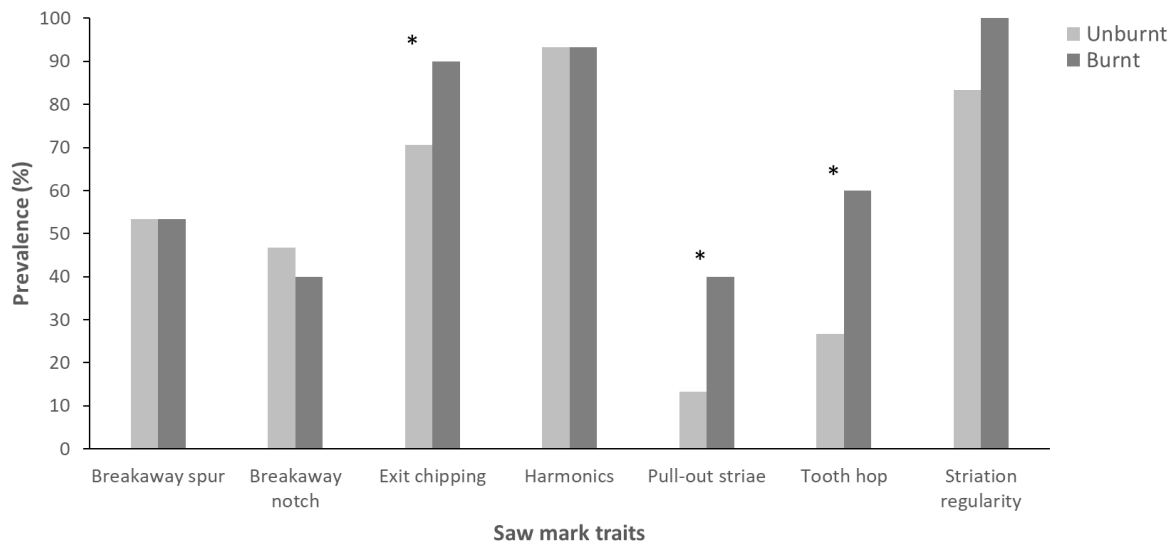


Figure 6: Change in prevalence of seven saw mark traits in traumatised *Ovis aries* femora before and after incineration. * represents a significant difference in presence of trait before and after incineration.

Exit chipping, pull-out striae and tooth hop had a significant difference before and after burning, with $p=0.012$, $p=0.021$, and $p=0.006$ respectively. Despite this, there was no significant difference for any of the traits when evaluated in their temperature level groups (Fig 7).

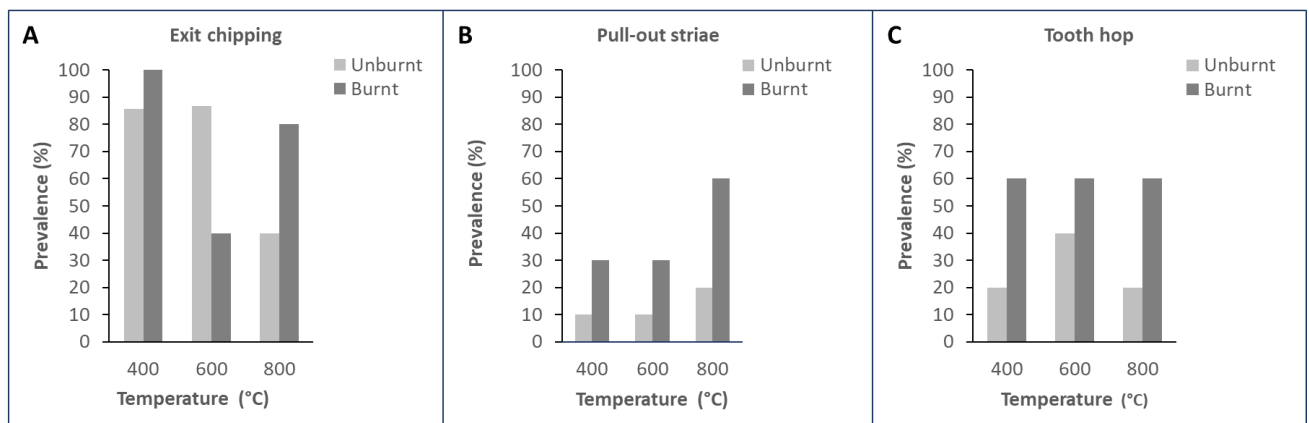


Figure 7: The prevalence of three significantly heat-altered saw mark traits on *Ovis aries* femora. There was no significant difference before and after burning at each temperature group level. A: Exit chipping; B: pull-out striae; C: tooth hop.

As seen in Figure 7A, there was no significant difference before and after burning for exit chipping at 400, 600 or 800 °C ($p=0.5$, $p=0.16$, and $p=0.07$, respectively). Similarly, as shown

in Figure 7B, no significant difference exists before and after burning for pull-out striae at 400, 600 or 800 °C ($p=0.5$, $p=0.5$, and $p=0.219$, respectively). Finally, as seen in Figure 7C, the detection of tooth hop had no significant difference at 400 °C ($p=0.125$), 600 °C ($p=0.625$), or 800 °C ($p=0.125$) before and after burning. The overall significant differences for these traits may be due to variation between temperatures rather than variation within a temperature group.

There was an improvement in the visibility of saw mark striae on the complete cuts post-incineration, as well as in the identification of tooth hop and pull-out striae (Fig 8). The only decrease in prevalence of saw mark traits post-burning occurred for breakaway notches.

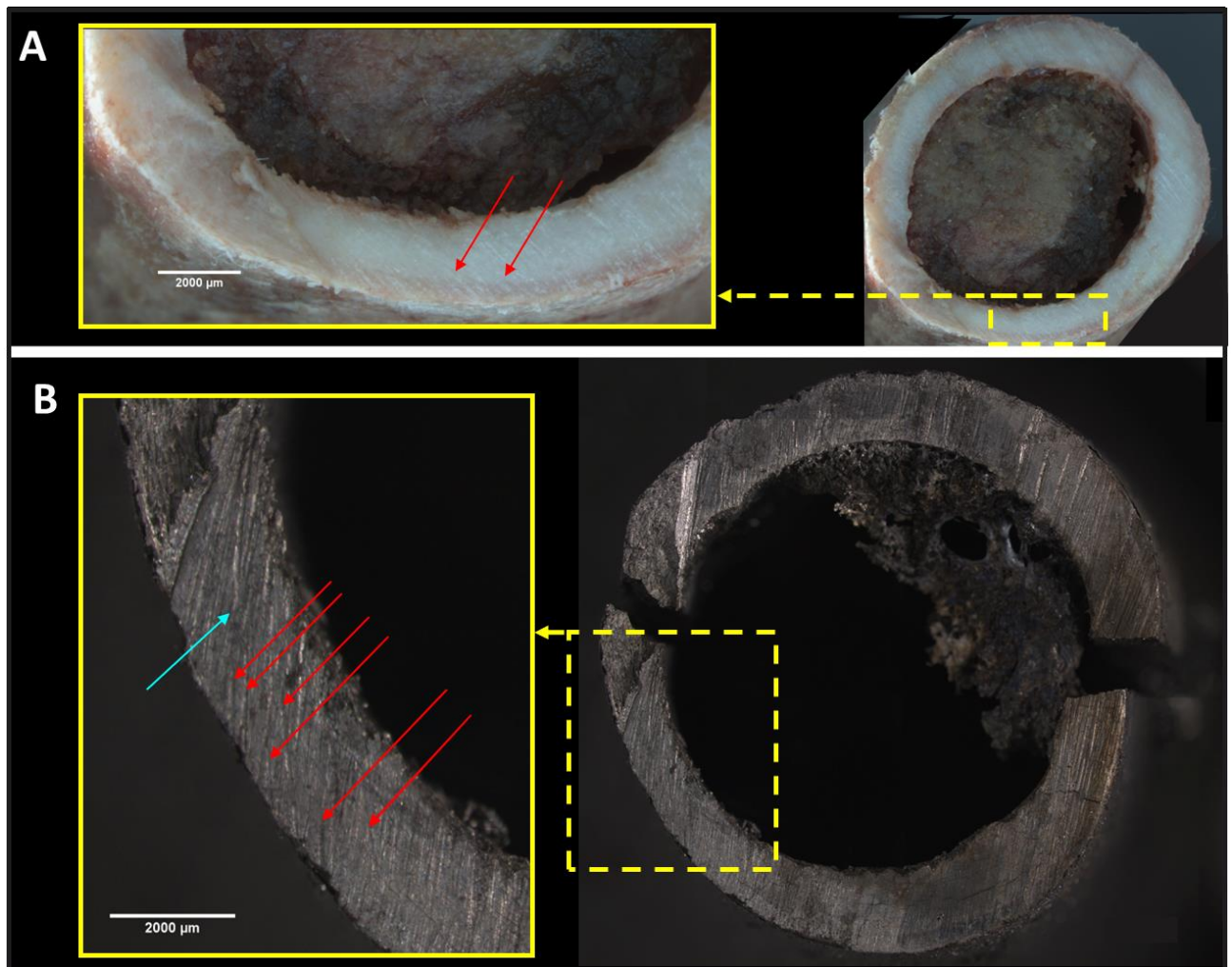


Figure 8: The detection of tooth hop and pull-out striae on a sawed *Ovis aries* femur before and after burning at 400 °C. A: Pre-incineration; B: post-incineration. Blue arrows – tooth hop; red arrows – pull-out striae.

3.4.2. Heat-induced changes to metrics of saw mark characteristics

There was a decrease in kerf depth, breakaway spur maximum length, and mean striation distance post-burning, whereas kerf width and breakaway spur maximum thickness both saw an increase (Table 11). There was also an increase in the number of tooth hop and pull-out striae measured post-incineration.

Table 11: Heat-induced alteration of saw mark metrics in *Ovis aries* femora. BSML: Breakaway spur maximum length; BSMT: breakaway spur maximum thickness; MSD: mean striation distance; TH: tooth hop; POS: pull-out striae. F: 1-way repeated measures ANOVAs, W: Wilcoxon signed-rank tests.

Saw mark traits	Unburnt	Burnt	Test statistic	p
Kerf depth (mm)	7.175 ± 2.199	5.182 ± 1.353	F = 9.614	0.01*
Kerf width (mm)	1.042 ± 0.033	1.207 ± 0.052	F = 9.401	0.005*
BSML (mm)	9.551 ± 1.934	6.951 ± 3.053	F = 3.95	0.094
BSMT (mm)	2.098 ± 0.700	2.208 ± 1.626	W = -0.445	0.656
MSD (µm)	159.817 ± 93.175	82.576 ± 54.893	W = -3.795	<0.001*
TH number	0.43 ± 0.858	1.47 ± 1.57	W = -3.022	0.003*
POS number	0.47 ± 1.106	1.23 ± 2.012	W = 2.046	0.041*

* represents a significant p-value.

Overall, a significant difference was observed between unburnt and burnt femora in terms of kerf depth, kerf width, mean striation distance, tooth hop number, and pull-out striae number. However, further investigation revealed that there were no significant differences between kerf depth or pull-out striae number of burnt and unburnt bone cuts within each of the three burn temperatures (Table 12).

Kerf width increased slightly for all three temperature groups post-incineration, with only the femora burned at 600 °C having a significant difference before and after burning. A substantial decrease in mean striation distances was observed in complete cuts after burning for each temperature, with only 400 °C and 600 °C groups having significant differences. The number of tooth hop observed after burning increased at every temperature level. However, a significant difference was only found at 400 °C.

Table 12: Saw mark metrics on *Ovis aries* femora before and after burning at three different temperature levels. MSD: Mean striation distance; TH: tooth hop; POS: pull-out striae. t: Paired t-tests, W: Wilcoxon signed-rank tests.

Saw mark traits	Temperature (°C)		Test		
	Unburnt	Burnt	statistic	p	
Kerf depth (mm)	400	7.965 ± 1.859	5.893 ± 0.788	t = 2.053	0.132
	600	5.748 ± 1.579	5.195 ± 2.123	t = 0.914	0.428
	800	7.813 ± 2.771	4.458 ± 0.458	t = 2.467	0.09
Kerf width (mm)	400	1.046 ± 0.192	1.182 ± 0.241	t = -1.794	0.106
	600	1.034 ± 0.193	1.356 ± 0.279	t = -2.976	0.018*
	800	1.044 ± 0.109	1.053 ± 0.197	t = -0.146	0.889
MSD (µm)	400	172.527 ± 118.259	56.872 ± 24.006	W = -2.803	0.005*
	600	166.797 ± 88.596	76.189 ± 22.846	W = -2.803	0.005*
	800	140.127 ± 73.994	114.668 ± 81.777	W = -0.764	0.445
TH number	400	0.4 ± 0.966	1.6 ± 1.838	W = -2.032	0.042*
	600	0.5 ± 0.707	1.3 ± 1.418	W = -1.461	0.144
	800	0.4 ± 0.966	1.5 ± 1.581	W = -1.725	0.084
POS number	400	0.6 ± 1.35	1.3 ± 2.83	W = -0.736	0.462
	600	0.1 ± 0.316	1 ± 1.7	W = -1.604	0.109
	800	0.7 ± 1.337	1.4 ± 1.43	W = -1.444	0.149

* represents a significant p-value.

CHAPTER 4: DISCUSSION

Following a homicide, attempts of concealment of the body usually follows in order to obscure any physical evidence of the committed crime, including the identity of the victim. Some methods of body concealment utilised in the past include submersions, burials, dissolvment in chemicals, dismemberments, and burning (De Matteis et al., 2021). Dismemberment and burning is sometimes used in conjunction, as seen in cases where perpetrators burn disarticulated or severed remains, sometimes on stove tops and other times with the ignition of buildings (Fanton et al., 2006; Konopka et al., 2007; Mata-Tutor et al., 2022). Dismemberment is most often aided with the use of commonly available household or hand tools, such as kitchen knives, hacksaws, axes, as well as hand saws used for woodworking (Konopka et al., 2007).

Saws leave characteristic trauma on human remains, and the retained markings on bone can be analysed by forensic specialists to infer information about the mutilating weapon (Symes, 1992; Saville et al., 2007). Tool mark analysis of these characteristics can be informative on the class of saw used. However, as bone morphology and metrics have been known to substantially change under burning conditions, the vulnerability of these saw mark traits to heat distortion may lead to inaccurate and misleading estimations (Shipman, Foster & Schoeninger, 1984; Mayne Correia, 1997; Thompson, 2005; Robbins et al., 2015).

Studies examining heat-induced alterations to sharp force injury on bone illustrated morphological changes to cut marks post-incineration (Herrmann & Bennett, 1999; Pope & Smith, 2004; Kooi & Fairgrieve, 2013; Macoveciuc et al., 2017). In addition to physical changes to cut mark characteristics, studies including trauma inflicted by cleavers, scalpels, smooth edged knives, and serrated knives demonstrated heat-induced metric distortions to sharp tool marks on bone (Hutchinson, 2011; Vegh & Rando, 2019; Mata-Tutor et al., 2022; Vachirawongsakorn et al., 2022).

As such, similar changes are expected in saw mark induced bone trauma exposed to the burning process. Despite the necessity for investigating heat-induced alterations of saw marks on bone, limited research has been conducted on the topic. The systematic search of the literature across four databases only found seven research articles in which thermal

alterations to saw mark trauma was examined (Herrmann & Bennett, 1999; Pope & Smith, 2004; Marciniak, 2009; Poppa et al., 2011; Robbins et al., 2015; Vegh & Rando, 2019; Mata-Tutor et al., 2022).

As such, an investigation was conducted on heat-induced alterations to saw mark trauma on bone. Fifteen semi-fleshed *Ovis aries* (sheep) femora were used as a proxy for human femora. Each femur was cut three times with a crosscut universal hand saw, creating false start, incomplete, and complete cuts on the de-fleshed shafts of each bone. The femora were divided into three different groups, corresponding to the three different burning temperatures to be investigated (400 °C, 600 °C, and 800 °C). The traumatised femora were burned for 30 minutes with an electric muffle furnace which allowed for controlled burning temperatures, enabling the comparison of heat-induced alterations of saw trauma on bones at different heat intensities. The three heat levels chosen were of a forensically relevant range, such as that seen in informal settlement fires, which are unfortunately prevalent in South Africa (Walls, Olivier & Eksteen, 2017). The analysis of bone saw marks before and after burning at various temperatures was achieved in this study, via a combination of visual inspection, microscopy, and silicon casting.

4.1. Saw trauma pre-incineration

The width of a kerf can be a useful measurement in the estimation of the class of weapon used, as seen in a study conducted by Mata-Tutor et al. (2022). The experiment compared cut marks on bones caused by a bread knife, a hand saw, a serrated knife, and a machete, and demonstrated that the saw generated the widest kerf. Furthermore, kerf width can inform class of saw used. Bailey et al. (2011) performed an investigation involving false starts on bovine bone created by five different types of powered and manual saws, and demonstrated that it is possible to use kerf widths to exclude different saw types when predicting the class of a saw used to traumatise a bone. Saville et al. (2007) in an experiment conducted on pig femur bones, described the kerf width of hand saws falling within a range of approximately 1 – 1.2 mm. The average width of false start and incomplete saw cut marks created by a hand saw on lamb femora pre-incineration in this study fell within that range (1.042 mm ± 0.033 mm). While the depth of the kerf created by a saw is dependent on the depth the individual

cut into the bone, it is a useful measure in this study to track the change in general bone metrics before and after burning.

The profile shape of kerfs can be classified as either concave or convex, and can contribute to estimating the saw class used to create the cut (Nogueira et al., 2016; Bernardi et al., 2020). Knives tend to leave concave V-shaped profiles, while serrated knives and saws often create profiles wider than the blade, with ripsaws typically producing concave profiles, while crosscut saws usually create convex profiles. Of the concave profiles, the cuts can either be round (U-shaped), square shaped, or square with round corners shaped. The kerfs created in this study had concave profiles and were classified as round in the majority, and minorly classified as square with round corners. This is in agreement with Mata-Tutor et al. (2022) wherein a hand saw created U-shaped kerf profiles.

All kerf wall edges on false start and incomplete cuts in this study were classified as straight pre-incineration. Symes (1992) described the shape of kerf wall edges and their relation to the teeth set of the saw blade used. Alternating narrow and wide edges were typical of alternating sets, straight walls typical of raker sets, and edges with necking in the middle region of the kerf walls typical of wavy sets. More recent literature on the subject has also identified that alternating sets can be responsible for straight edged kerfs (Nogueira et al., 2016; Norman et al., 2018; Bernardi et al., 2020). Norman et al. (2018) conducted a study on saw and knife trauma on human bone; and while in agreement with the literature and in contrast to the results in this study, identified alternating narrow and wide edges on kerfs produced by a bow saw with alternating teeth, also found straight edge shaped kerfs produced by a tenon saw and bow saw, both with alternating sets.

A breakaway spur, mirrored by a breakaway notch, is a fractured projection of bone on the terminal end of a cut, and as such, is informative on the direction of blade progress during the sawing action. Additionally, it can be used to infer information on the force applied during sawing, as a larger force applied during sawing will produce a larger spur (Symes et al., 2010). In this study, breakaway spurs and notches each occurred on approximately all complete cuts pre-incineration. This is intuitive, as every complete cut produced two cut wall surfaces, with most bones having a breakaway spur on one, and a complementary notch on the other. In agreement with this study, Robbins et al. (2015) described a 100% prevalence of breakaway spurs in cuts produced by a crosscut saw. The measurement of the maximum thickness and

maximum width of breakaway spurs was beneficial to downstream examination of dimensional bone trauma changes after burning.

A common characteristic of saws with alternating sets is the creation of blade drift as the teeth of the saw are bent in opposite directions, and so upon entrance to the kerf, the direction of the blade is altered (Symes et al., 2010). In agreement to this, Robbins et al. (2015) reported the presence of blade drift in more than half of unburnt saw cut marks on bone, including saws with alternating sets. In this study however, despite the use of an alternating set, no blade drift or bone islands were detected on false starts or incomplete cuts. Despite this, harmonics, which have been described as the “side view of blade drift” by Symes et al. (2010) was visible in most of the complete cuts created by the saw. This may be due to the teeth of the saw not alternating to a large enough degree to be visible on the false start and incomplete cuts, and needing to penetrate the bone deeper in order to show evidence of the blade changing direction.

Kerf flare, which is the flaring or widening of the kerf at saw’s handled-end of the cut, was another saw mark trait not present in false starts or incomplete cuts. It may be that the mitre block used during the sawing process steadied the sawing motion, preventing detectable flaring of the kerfs.

Tooth imprint is a residual imprinting of saw blade teeth on the kerf floor, due to an interruption in the sawing stroke. This was another trait absent in saw trauma analysed in this study. Robbins et al. (2015) were only able to detect tooth imprint on bone with the use of scanning electron microscopy (SEM) and not with stereomicroscopy. SEM analysis was beyond the scope of this current study; however, it is recommended for future studies interested in detecting tooth imprint on sawed bones.

Exit chipping is the chipping of small fragments of the bone produced by the blade’s teeth exiting the bone, and can be informative on the directionality of sawing action or side emphasised of the cutting stroke made by the individual (Symes, 1992; Symes et al., 2010). Exit chipping was detected in less than three quarters of incomplete and complete cut marks pre-incineration. In contrast, Robbins et al. (2015) had a prevalence of only 25% for saw trauma on *Sus scrofa* bone.

Linear scratches, or striae on the cut surface of the femora are formed by the blade's teeth during the cutting process, and can appear in regular or irregular patterning. Microscopy improved the visualisation of striae on the femur's complete cut surfaces, allowing for measurement of the distances between striae. The majority of cuts were classified as having regular striae arranged in a regular pattern of fine striae bordered by coarse striae, although the finer striae were often difficult to see. Pull-out striae indicate the withdrawal of the blade mid-stroke, and the distance between two consecutive striae is estimated to be the distances between two teeth on a saw with alternating set (Symes et al., 2010). Pull-out striae appeared infrequently in incomplete cuts (a total of only 14 in all 30 cuts), making measuring their distance obsolete. The distance between tooth hop can also enable estimation of distance between a blade's teeth was also infrequently seen in cuts pre-incineration (Symes et al., 2010). A similar low prevalence of both tooth hop and pull-out striae (less than 17%) was described by Robbins et al. (2015) in saw marks on bone pre-incineration. This may be indicative of the difficulty to detect these traits in unburnt bone.

4.2. Heat-induced changes to bone

Morphological changes in colour, mass and condition of the lamb femora took place under heat treatment. Bones burned at 400 °C decreased in mass as dehydration occurred, as well as completely blackened, signifying carbonisation of bone material. Fracturing of bone began to occur at this temperature as dehydration affected structural integrity, resulting in deformation. Femora burned at 600 °C underwent the decomposition stage of thermal alteration to bone, decreasing further in mass, and increased fragility as fractures became more frequent (Thompson, 2005). Patches of grey-white on the charred black bone indicated that the femora were starting to calcine. Femora burned at the highest temperature level decreased further in mass, and were mostly grey in colour, indicating partial calcination. They also had more regions of completely calcined whitening, in which the full pyrolysis of the bone's organic components occurred. Based on the literature, it is likely that inversion and fusion phases of thermal alteration began to place, in which bone mineral crystallisation, increased shrinkage, and bone fragility occurred (Mayne Correia, 1997; Thompson, 2005). The colour changes undergone by the femora in this study is nearly consistent with colour changes characterised by a study conducted by Ellingham & Sandholzer (2020) in which sheep ribs

burned at 400 °C turned black, 500-600 °C turned grey, and 700 °C turned white. The quicker burn stage colour changes can be explained by the longer burn duration of 45 minutes, as opposed to the 30-minute burn time of this experiment.

Femora burnt at 800 °C were the most brittle, and had the most heat-induced fractures. Most femora had at least one longitudinal fracture running along the shaft, increasing in number along with burnt temperature. These fractures along with step fractures often intercepted the pre-incineration saw trauma, affecting the analyses of these cuts. This is in agreement with previous studies on the burning of bones inflicted with sharp force trauma. Mata-Tutor et al., 2022 described heat-induced fractures transecting more than 80% of all sharp force trauma marks on pig long bones burned at a peak temperature of 850 °C for 247 minutes. Hutchinson (2011) found that areas where the sharp force trauma was inflicted on bone, were areas where most of the extensive thermally caused fractures were prevalent, due to their compromised structural integrity.

4.3. Heat-induced changes to saw trauma

4.3.1. Kerf width and depth

Previous literature has produced contradicting findings whether burning results in any metric alterations to the widths of various sharp force tool cuts. Studies investigating cut marks on *Sus scrofa* bones produced by hacksaws and knives demonstrated that kerf width decreases post-incineration (Vegh & Rando, 2019; Vachirawongsakorn, et al., 2022). Other research examining cut marks produced by tools such as knives, a machete and saw on pig bones found no significant alteration to kerf widths after burning (Waltenberger & Schutkowski, 2017; Mata-Tutor et al., 2022). However, Mata-Tutor et al. (2022) reported the exception of minimal shrinkage in kerf widths produced by a bread knife, and Waltenberger & Schutkowski (2017) explained that the variation of kerf width did increase, which may be a slight indication toward heat-induced alterations of this characteristic. This study found some significant heat-induced changes to kerf width metrics. It is possible that as opposed to the smooth-edged blades of non-serrated knives and machetes, the teeth of serrated blades inflict more trauma onto the bone surface, making them more vulnerable to heat-induced alteration. Tegtmeyer (2012) reported that kerfs on pig ribs produced by a serrated knife appeared to have more bone

damage, with rougher floors and walls than the smooth kerf walls and floors produced with a non-serrated knife.

The kerf widths of false start and complete cut marks had a small increase overall, as well as at each temperature level. This increase in width was statistically significant overall, as well as only for femora burnt at 600 °C. The width of four cut marks (one false start burnt at 600 °C, one incomplete cut burnt at 800 °C, and two false starts burnt at 800 °C) could not be measured accurately, due to interference from fracturing or obliteration of false starts at high temperatures, and so were excluded from these analyses. A related study was conducted by Chang (2023), in which a backsaw was used to traumatise lamb femora that were then burned at 400 °C, 600 °C, and 800 °C, in order investigate heat induced alterations on saw trauma, but wherein burning duration was set to 20 minutes instead of 30. Chang (2023) found increases in kerf width at all three temperatures. These increases were significant in false starts at 600 °C, as well as at 800 °C in incomplete cuts. Vegh & Rando (2019) also found slight increases in kerf width in saw cut marks on pig bones burned at 300 °C, 600 °C, and 1000 °C. This expansion may be due to bone warping under high heat conditions, the influence of fracturing, or the loss of some bone material, such as the burning away of small bony projections on kerf wall edges.

Overall, kerf depth significantly decreased after burning, but the difference pre- and post-incineration at the individual temperature levels were not statistically significant. The kerf depth of two bones, burned at 600 °C and 800 °C, could not be measured due to severe fracturing at incomplete cut marks. The fragmented bone shafts were pieced together but the warping of bone and smaller missing fragments did not allow reconstructions of the incomplete cuts where the depth could be accurately measured. A fragment of the bone burned at 400 °C was not recovered and the incomplete cut present on this fragment, as well as the other two from the two temperature groups were excluded from kerf depth analysis. While the kerf depth for any of the three burn groups did not have statistically significant change in this investigation, the overall decrease may be indicative of dimensional shrinkage of the bone in these traumatised areas. Chang (2023) found a statistically significant decrease in kerf depth at 800 °C.

4.3.2. Kerf wall and profile shape

Heat treatment had no effect on the shape of kerf walls, with all false start and incomplete cuts classified as straight before and after burning. This agrees with previous studies in which kerf wall shapes survive heat treatment (Marciniak, 2009; Mata-Tutor et al., 2022; Chang, 2023).

While the majority of incomplete cut kerf profiles were classified as round, there was a slight decrease in percentage of cuts classified as round, and a reciprocal increase in cuts categorised as square with round corners, proving that burning does impact kerf profile categorisation. Chang (2023) similarly found an increase in square with round corner classification and decrease in round profile shapes after burning. Vachirawongsakorn et al. (2022) described changes in the profile shape of kerfs created by serrated knives post-burning, that were not present in kerfs produced by non-serrated knives. Kooi & Fairgrieve (2013) reported that the V-shaped kerf profile decreased in prevalence in cuts produced by a smooth-edged knife post-burning, but more so in serrated knife kerfs. Serrated blades cause additional damage to kerf floor surfaces, which may make them more vulnerable to heat-induced alterations.

4.3.3. Breakaway spurs and notches

While burning did not change the prevalence of breakaway spurs in complete cuts, it did slightly decrease the prevalence of breakaway notches due to the loss of fragment of a bone burnt at 800 °C due to fracturing. However, this decrease in breakaway notch prevalence was not statistically significant. Furthermore, heat treatment created no significant change in breakaway spur thickness or length after burning. The thickness of breakaway spur for one bone at each temperature group was excluded, as an accurate measurement could not be taken due to fracturing. Chang (2023) found no change in prevalence of breakaway spurs, but described a significant decrease in mean breakaway spur thickness post-incineration, in bones burnt at 400 °C and 800 °C. While the prevalence of breakaway spurs is unaffected by heat treatment, the metrics of this saw mark feature may be vulnerable to heat-induced changes.

4.3.4. Exit chipping and harmonics

Burning had no effect on prevalence of harmonics on complete cuts, and did not enhance the detection of blade drift, which remained unobserved in all of the traumatised femora. The detection of exit chipping on the bones was improved by burning, as seen in the statistically

significant increase in prevalence after burning. This enhancement in prevalence of exit chipping has been seen in previous studies (Robbins et al., 2015; Chang, 2023). The identification of exit chipping increased at 400 °C and 800 °C, but decreased at 600 °C. Despite this, no statistically significant change was seen at the temperature group levels, before and after burning. While not statistically significant, this difference in exit chipping detectability at different temperature groups suggests that burning does improve the visualisation of this trait, but that it may be vulnerable to obliteration at higher temperatures. Chang (2023) noted the appearance of exit chipping after burning at 400 °C and 600 °C, as well as the obliteration of exit chipping at 600 °C and 800 °C.

4.3.5. Regular striae

While burning did not produce a statistically significant difference in the regularity of striae patterning on the traumatised femora, the saw striae marks became more defined and easier to visualise after burning. All cuts were classified as having regular striae patterning, as the coarse striae bordering fine striae pattern was clearer to identify in cuts after burning, across all temperature groups. At 800 °C, the high heat and increased brittle nature of the bone resulted in the obliteration of regions on both of one femur's complete cut surfaces, but striae analysis with stereomicroscopy could still be done on the surviving surface portions. One bone burned at 800 °C was so brittle and fractured that it fractured further in handling before stereomicroscopy of complete cuts could be done. Photographs of the cut surface still allowed analysis of striae, but at a much lower resolution. Marciniak (2009) found that universal crosscut hand saws leave a pattern of both fine and coarse striae on pig femora, the former of which became more pronounced on charred bones post-burning, but became less visible on bone beginning to calcine. While higher heat intensities did decrease striae visibility in this study, striae visualisation was not more difficult in whitened regions than in carbonised bone, possibly because they had not yet reached full calcination.

Burning resulted in an overall statistically significant decrease in striae distance. This can be explained by the improved visualisation of striae post-incineration, improving the accuracy of averaged striae distances, as seen in the substantially decreased standard deviation range. The mean striae distance of femora burned at 400 °C and 600 °C had statistically significantly decreased after burning. Subjecting femora to burning at 800 °C led to less accurate measurements of striation distances, due to increased fracturing and obliteration of regions

on the complete cuts. This can be seen in the increased post-incineration standard deviation. Chang (2023) found statistically significant decreases in mean striation distances after burning traumatised femora at 400 °C, 600 °C, and 800 °C. The decreased duration of burning may account for a more accurate measurement of mean striae distances at 800 °C, as the cuts were subjected to less thermal damage.

4.3.6. Pull-out striae and tooth hop

As burning increased the visibility of regular striae on cut surfaces, the overall identification of pull-out striae and tooth hop improved significantly after incineration. While there was an improvement in prevalence of pull-out striae from 20 to 60% for femora burned at 800 °C, there was no statistically significant improvement in pull-out striae identifiability or number at any of the heat levels investigated. All pull-out striae identified pre-incineration, survived the burning process. Femora subjected to burning at 400 °C, 600 °C, and 800 °C did not have a significantly improved prevalence of tooth hop before and after burning within their temperature groupings. Burning did improve the number of tooth hop identified overall, as well as at 400 °C. Bones burnt at 600 °C and 800 °C had an increased number of tooth hop identified after burning, but without any statistical significance. Despite this, one tooth hop marking present on a bone burned at 600 °C, and two burned at 800 °C, were not visible after burning. Chang (2023) saw a general improvement in pull-out striae prevalence post-burning, but also found a decrease in tooth hop identified at 600 °C and 800 °C. This may suggest that tooth hop is vulnerable to obliteration at higher burning temperatures. Robbins et al. (2015), described an increase in the prevalence of pull-out striae in saw marks on pig tibiae made by old saws, but a decrease in new saws post-incineration, as well as tooth hops increasing in prevalence with new saws and remaining the same for old saws post-burning. This suggests that the wear on the saw blade affects the survivorship of pull-out striae and tooth hops.

4.4. The effect of duration

As previously mentioned, Chang (2023) performed a similar study on heat-induced alterations on saw trauma, but burned femora for 20 minutes as compared to the 30-minute burning duration of this study. A longer burning duration resulted in a small difference in heat-induced colour changes, as small white patches of calcined bone were present in femora burnt at both the 600 and 800 °C temperature groups, whereas in Chang (2023), white patches only appeared at 800 °C. The increased burning time resulted in more fracturing in femora burnt

at 800 °C. This implies that the extended burning duration at high temperatures increases the brittle nature of the bone material as well as the presence of heat-induced fractures.

Of all the saw mark traits examined by the two studies, only the mean striae distance measured on bones burned at 800 °C was affected by duration. The longer burn time at this temperature lead to increased fragmentation and regions of obliteration on cut marks, resulting in less accurate measurement of average striation distance. This suggests that burn duration may influence the thermal alteration of certain saw mark characteristics, but may not have any effect on others. However, it should be noted that the difference in burn duration between these two studies is not extensive, and it is recommended that future studies investigate longer burning durations.

The shape of kerf floor profile in past experiments on sharp tool marks persists after burning even for longer durations than performed in this study, as seen in Mata-Tutor et al. (2022), where the U-shaped profiles of saw marks were preserved after burning for 247 minutes and in Macoveciuc et al. (2017), where the V-shaped profile of cut marks generated by a sharp force impactor was preserved after burning for 58 minutes at 820 °C. Despite this, this study as well as the one conducted by Chang (2023), show that saw kerf profile shape categorisation is vulnerable to changes after burning even at a shorter duration of 20 or 30 minutes. Similarly, Vachirawongsakorn et al. (2022) described changes to the shape of kerfs produced by a coarse serrated knife after burning for more than 30 minutes. A longer burning duration in this study may account for significant kerf width expansion occurring at lower burning temperatures that was only reported at 1000 °C for a duration of 20 minutes by Vegh & Rando (2019).

While this study found enhancement in the detection of general saw mark characteristics post-burning, traits such as exit chipping and pull-out striae may be vulnerable to thermal-induced obliteration with longer burning durations as seen in Robbins et al. (2015) where the prevalence of these two traits decreased post-incineration on saw marks on bones burned for 180 minutes.

Burn duration, like temperature, is a significant factor that has influence on the morphological and metric heat-induced alterations to saw marks on bone. There is a necessity for further

research that characterise the effect of burn duration on saw mark traits of traumatised bones burnt at various controlled temperatures.

4.5. Intra- and inter-rater reliability

Intra-rater and inter-rater reliability analyses were conducted on the counting of all prevalence traits analysed as well as the measurement of all metric traits examined in this study to ensure reliability and repeatability. There was perfect statistically significant intra-rater reliability for all prevalence traits both pre- and post-incineration. There was moderate to perfect inter-rater agreement for all prevalence traits pre-incineration, with only the good inter-rater agreement of the kerf profile shape not being statistically significant. Post-burning, the inter-rater agreement ranged from poor to perfect, with breakaway spurs and notches, as well as kerf profile shapes not having statistical significance. The low inter-rater agreement for kerf profile shape may indicate a difficulty in differentiating between round and square with round corner in saw marks.

There was good to excellent statistically significant intra-rater reliability for the measurement of metric saw mark traits both pre- and post-incineration. Inter-rater reliability was excellent for most traits pre-incineration, with the exception of kerf width and breakaway spur maximum thickness which were not statistically significant. This may be due to raters defining borders of maximum kerf width and breakaway spur thickness slightly differently. The inter-rater reliability for tooth hop number, breakaway spur maximum thickness, average striae distance, and pull-out striae number ranged from moderate to excellent and were all statistically significant post-incineration. Breakaway spur maximum length, kerf width and kerf depth did not have statistically significant inter-rater reliabilities post-incineration.

In general, this low inter-rater agreement may be due to sample size, as only a small subset of the data (n = five) was rated by other raters. Other contributing factors may be the training and experience of the raters in identifying saw mark traits, as well as the increased difficulty in accurate saw mark trait identification and measurement post-burning due to fracturing, fragment loss, and partial obliteration of cut marks. It is recommended that future studies use larger sample sizes when conducting inter-rater analyses.

4.6. Silicon casting of saw trauma

The utility of silicon-casting of saw trauma before and after burning was also investigated. Silicon casts were moulded onto the three cut types for each bone successfully pre-incineration, with only minor difficulty in getting the casting liquid to reach the kerf floor of incomplete cuts. The casts peeled-off with relevant ease on the pre-incinerated femora and were convenient for microscope analysis. Retrieval of the casts from the femora post-incineration became trickier as the bones, especially when burned at higher temperatures, were brittle and fractured. Patches of thin outer layers of the burnt femora sometimes stuck to the casts even with the use of a release agent, which may affect the analysis of false starts, especially if casting is done before all other analyses is completed on the bone. Although incomplete cut kerf depths were measured with the use of a dissecting teasing needle probe and digital callipers, a strong advantage of silicon casting would be to improve the accuracy and ease of measuring kerf depth, when casted properly. The casts were helpful with identifying the shape of the kerf walls as well as the shape of the kerf profiles, alongside visual analysis. In most casts, the impressions of some striae on the complete cuts and incomplete cuts could be seen, which may be an additional useful tool for striae analysis, alongside microscopy of the actual bone cut surface.

4.7. Limitations and recommendations

As this study is part of a larger study looking at the effect of burning on saw trauma, the sample size of cuts used in this investigation was relatively small, with only five lamb femora and three cuts created per bone (one false start, one incomplete cut and one complete cut with two cut surfaces) for each of the three burn groups. A larger sample size is recommended for future studies, in order improve the statistical value of the analyses conducted.

While juvenile *Ovis aries* femora were suitable analogues for humans, as human and lamb femora have similar densities as well as macro and micro-structure, experiments carried out on mature human bone may have differing results. Differences in cortical thickness, elasticity and mineralisation may affect fracture formation and bone shrinkage post-incineration (Waterhouse, 2013). Femora were de-fleshed especially on the bone shafts to enhance the analysis of saw mark traits pre-burning. In a forensic setting, dismemberments would be committed on fleshed bone, affecting the exposure of the saw cuts to heat trauma, which may influence heat-induced alterations.

While the effect of duration on heat-induced alterations to saw trauma on bone was discussed in this investigation, this experiment did not include multiple burn durations. Furthermore, only one hand saw was used. Various classes of saws create different saw trauma and may be differentially altered by heat exposure. It is recommended that further studies examine the effect of burn duration and saw type on heat-induced alterations to saw trauma on bone, at various temperatures. The effects of fire accelerants on heat-induced saw trauma alterations were also unexplored, and may be an interesting and forensically relevant avenue for future research. Finally, previous studies have found that SEM analysis enhances the detection and analysis of saw mark traits, such as the detection of tooth imprint, which was absent in this study (Herrmann & Bennett, 1999; Robbins et al., 2015; Vegh & Rando, 2019). While it was not within the scope of this study, it is recommended that any follow up studies done integrate the use of SEM in their saw mark analyses.

4.8. Conclusion

This study was a continuation of research conducted by Chang (2023), aimed to interrogate heat-induced alterations to saw trauma on bone burnt at various temperatures. Fifteen defleshed *Ovis aries* femora were traumatised with a hand saw, creating a false start, incomplete cut and complete cut on each bone shaft. These traumatised femora were evenly divided among three different temperature groups (400 °C, 600 °C and 800 °C) and burned inside a muffle furnace for 30 minutes. The visualisation and detection of several saw mark traits were enhanced post-incineration, specifically exit chipping, regular striae, pull-out striae, and tooth hop. This enhancement resulted in increased tooth hops and pull-out striae identification, as well as decreased mean distance measured between regular striae. A small number of tooth hops were obliterated on femora burned at 800 °C. Kerf width increased overall and at 600 °C significantly due to heat-induced bone expansion or warping. This study found that most saw mark traits persist even after burning even at high temperatures, allowing for tool mark analysis for weapon estimation. As the dimensions of saw mark characteristics were found to change under high heat conditions, forensic analyses on tool mark identification analyses on burnt bone may be inaccurate without taking to account these thermally-induced alterations. As this study found that various heat intensities alter saw trauma differently, it is important to consider the type of fire and temperature range that a body was exposed to before conducting tool mark estimation analyses.

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APPENDICES

Appendix A: Saw mark characteristics

Table A 1: Characteristics of saw cut marks in bone adapted from Symes et al. (2010).

Saw mark traits	Description	Identified/measured in cut type
Kerf width (mm)	Maximum width of the cut at the middle of the cut.	False start, incomplete
Kerf depth (mm)	Depth of the cut.	Incomplete
Breakaway spur	Projection of bone that forms at the terminal end of a cut.	Complete
Breakaway spur max thickness (mm)	Maximum thickness of breakaway spur measured with callipers.	Complete
Breakaway spur max length (mm)	Maximum length of the breakaway spur measured with callipers.	Complete
Breakaway notch	Mirror image notch formed on the other side of the cut bone.	Complete
Exit chipping	Chipping of bone present at the end or side of the cutting stroke.	Incomplete and complete.
Blade drift	A pattern caused by the drifting of the teeth of the saw across the kerf floor, when there is a change in the blade's direction when every tooth enters the bone.	False starts and incomplete
Bone islands	When material is left in the midline of the kerf due to blade drift.	False starts and incomplete
Kerf flare	Flaring that occurs on the kerf floor on one end, indicating the handle end of the blade.	False starts and incomplete
Harmonics	Peaks and valleys present on cross sections of bone caused by directional change of saw blade.	Complete
Tooth imprint	Residual imprint of the saw tooth points on the kerf floor.	Complete
Regular striae	Linear scratches with a regular pattern.	Complete
Mean striae distance (µm)	Average of distances between a maximum of 15 regular striae identified.	Complete
Pull-out striae	Perpendicular striae on kerf surface, caused by the saw being withdrawn mid-stroke.	Complete
Tooth hop	Stria present across the face of the kerf wall that has a generally straight wavy pattern with breaks in between, caused by the successive movement of each tooth as it enters the kerf.	Complete
Kerf wall shape	Shape of vertical sides of the cut; either narrow & wide, straight, or necking.	False starts and incomplete
Kerf Profile Shape	Profile shape of horizontal face of the cut; either round, square, square with round corners, V-shaped, W-shaped, W-truncated shaped.	Incomplete

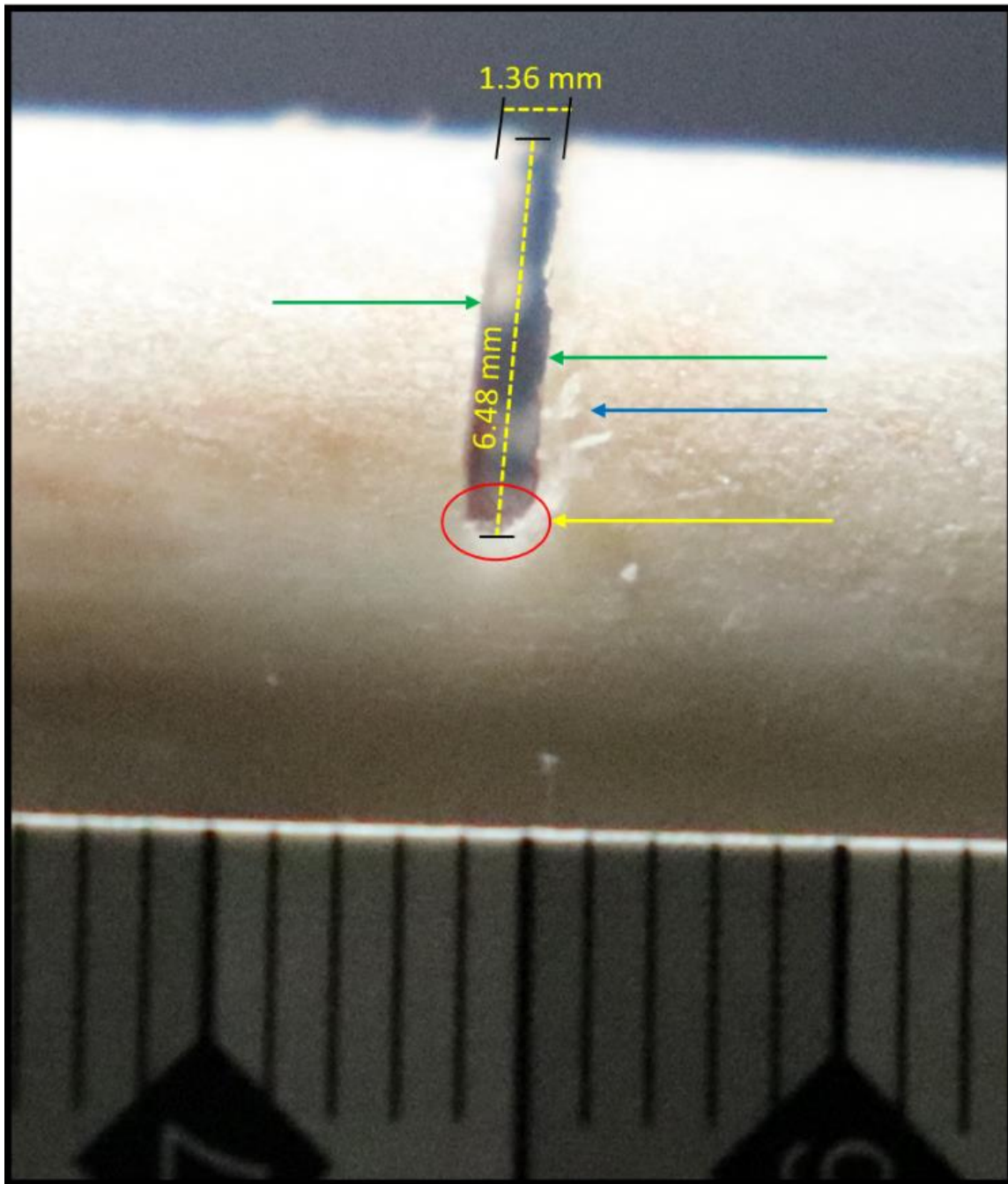


Figure A 1: An incomplete saw cut mark on an *Ovis aries* femur. The measured kerf width = 1.36 mm and kerf depth = 6.48 mm. Green arrows – shape of kerf walls (straight); blue arrow – exit chipping; yellow arrow – kerf profile shape (round).

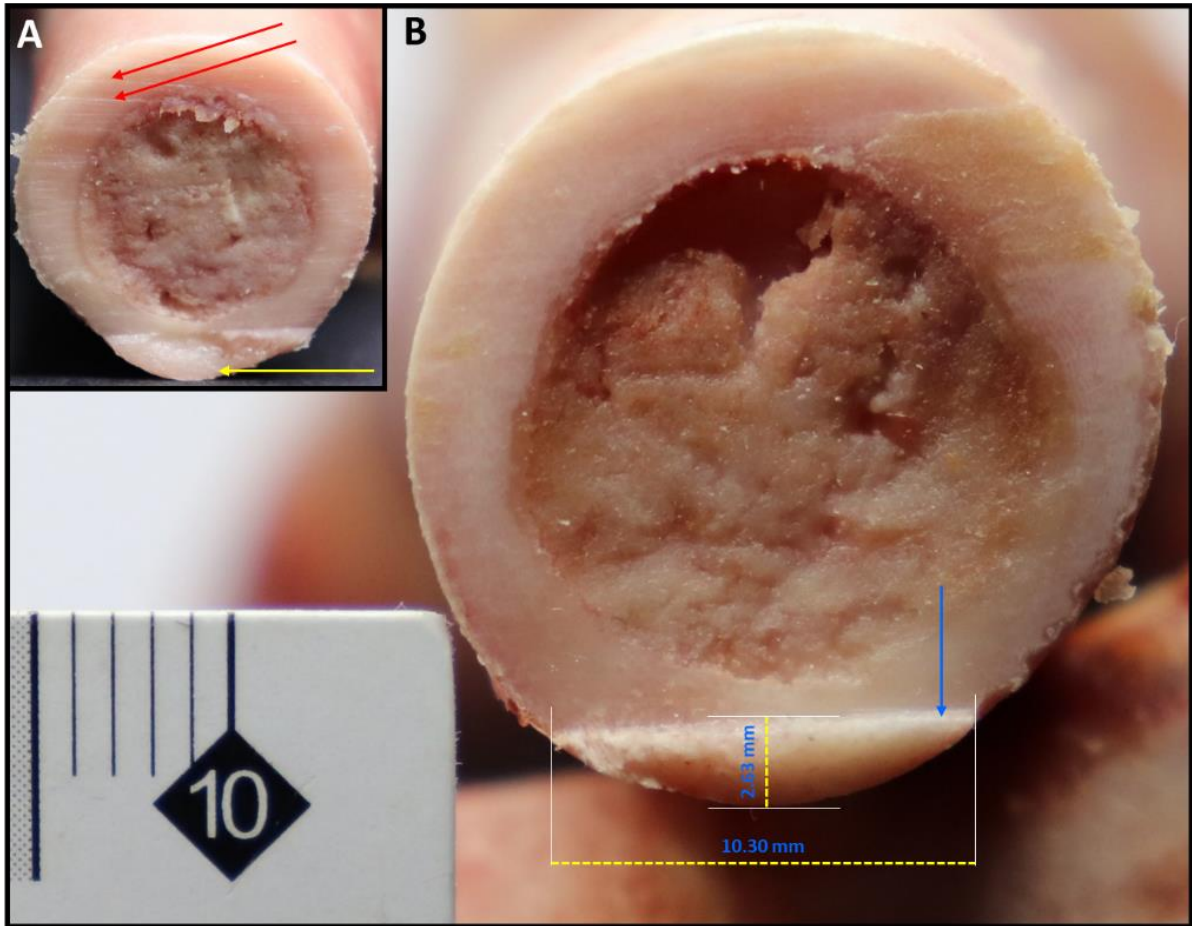


Figure A 2: Complete cut surface of *Ovis aries* femur traumatised by a hand saw. A: Cut surface of proximal end of femur; red arrows – harmonics; yellow arrow – breakaway notch. B: Cut surface of distal end of femur; blue arrow – breakaway spur; breakaway spur maximum thickness = 2.63 mm; breakaway spur maximum length = 10.30 mm.

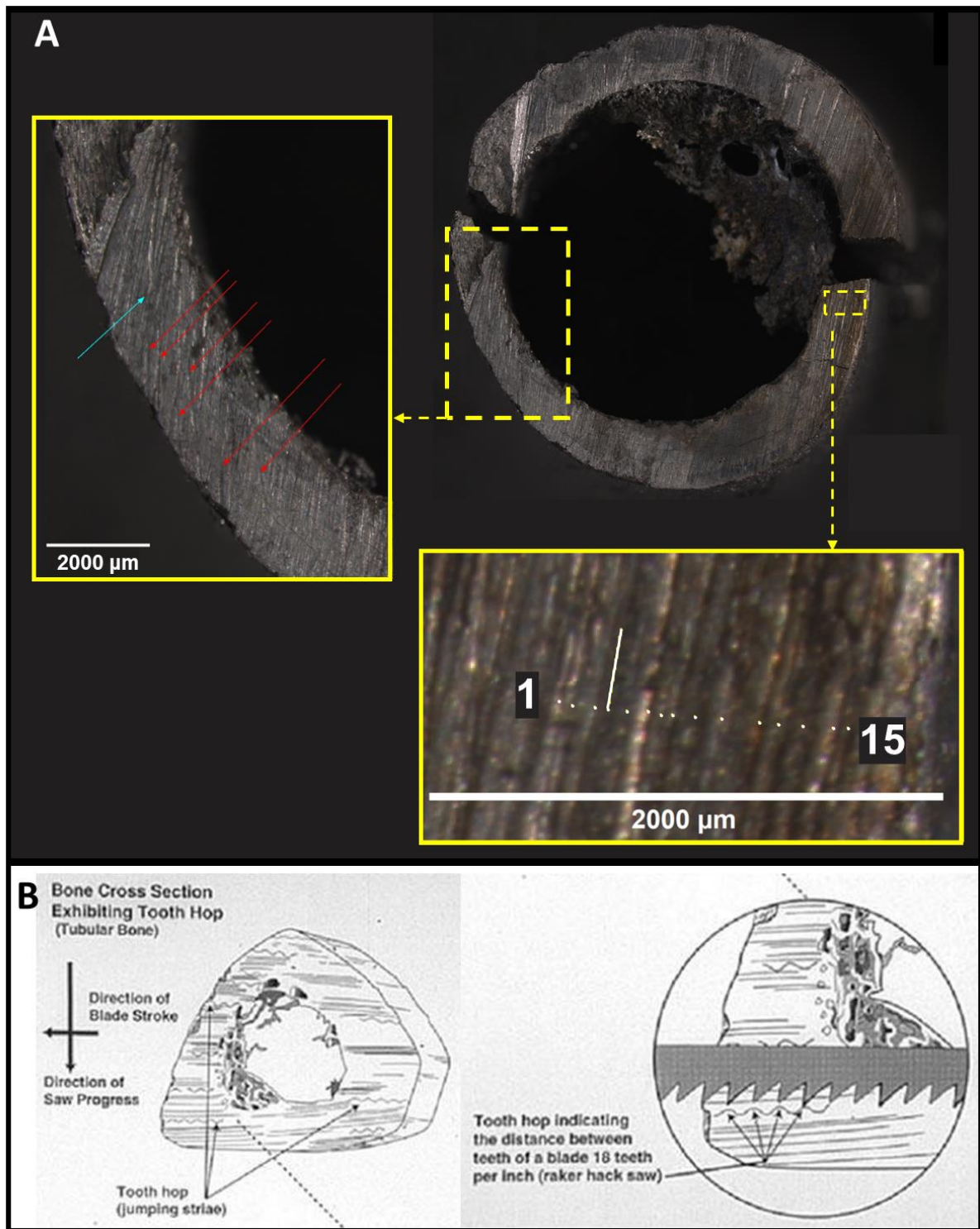


Figure A 3: Saw mark striae in bone. A: Saw mark striae present on distal end complete cut of an *Ovis aries* femur burnt at 400 °C; blue arrow – tooth hop; red arrows – pull-out striae; white dots – 15 regular striae used to calculate average striae distance on cut = 81.291 μm . B: Tooth hop on bone adapted from (Symes et al., 2010).

Appendix B: Ethics letter



UNIVERSITY OF CAPE TOWN
Faculty of Health Sciences
Animal Ethics Committee



Room E53 Old Main Building
Groote Schuur Hospital
Observatory 7925

Website: www.health.uct.ac.za/fhs/research/animalethics/forms

06 June 2023

FHS AEC REF NO: 022_015

Mr Calvin Mole

Division of Forensic Medicine and Toxicology
Department of Pathology
Faculty of Health Sciences
University of Cape Town

Dear Mr Calvin Mole

PROTOCOL TITLE: The Effect of Burning on Pre-incineration Trauma in Bone

Thank you for submitting your amendment to the Faculty of Health Sciences (FHS) Animal Ethics Committee (AEC) for review

I am pleased to inform you that the FHS AEC has **authorised** the following amendments to the above-mentioned study:

- Addition of student to the project: Zaineta Maherene Maharaj

1. A Form for amendment is also available via Submittable at: universityofcapetown.submittable.com/submit/72588/fhs005-application-for-amendments-to-a-previously-authorized-study-by-fhs-aec.
2. Annual progress report submitted to the ethics office is a requirement for on-going authorisation of studies.
3. Notification of study closure is a requirement.
4. Ethics authorisation letter and copy of the application form to be submitted to the Animal Unit when commencing the study for release of animals.
5. The principal investigator (PI) must ensure that:
 - 5.1 all study participants perform within the confines of the procedures and experimental design of the protocol as authorised, or as amended
 - 5.2 all study participants comply with all applicable national legislation, UCT policies, FHS policies and standard operating procedures (SOPs) and national standards (SANS 10386: 2008 or later version)
 - 5.3 all study participants are registered with or have been authorised by the South African

H Goqweni

AEC 022_015

Veterinary Council (SAVC) to perform the procedures on animals or will be performing the procedures under the direct and continuous supervision of SAVC-registered veterinary professionals or SAVC-registered para-veterinary professionals

5.4 DAFF Sec.20 permit approval have been obtained

5.5 immediately alert the FHS AEC to any event involving the welfare of the animals which has occurred during the course of the study, as well as the actions that were taken to respond to these events

5.6 alert the FHS AEC to any new or unexpected ethical issues that arose during the course of the study, and how these issues were addressed.

5.7 ensure that relevant institutional approvals, for example, Faculty or Institutional Biosafety Committee are valid for the full duration of the study

6. If the principal investigator or any study participant is in any way uncertain how to respond to any of these obligations or deal with any of the issues referred to above, they must consult with FHS AEC.

7. All animals found dead must be reported to the RAF on the appropriate form:
<http://www.health.uct.ac.za/fhs/research/animalethics/forms>

8. All animals found in distress must be reported to the RAF and AEC on the appropriate form.

Please quote the REC. REF 022_015 in all your correspondence

Yours sincerely

Signed by candidate

PROF G. LOUW
CHAIR, FHS AEC