**THE IDENTIFICATION OF PERIMORTEM TRAUMA ON BONES AFTER BURNING PROCESS: A SYSTEMATIC REVIEW**

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***Abstrak***

*Api yang kerap digunakan untuk menghancurkan barang bukti dalam kasus kejahatan tertentu, dapat membuat para ahli forensik dan antropolog forensik sulit dalam melakukan identifikasi penyebab kematian dan identitas korban. Meskipun jaringan lunak dapat terbakar habis selama proses pembakaran, namun bekas trauma pada tulang dapat bertahan sampai pada suhu dan durasi pembakaran tertentu. Deteksi trauma pada tulang setelah proses pembakaran penting dilakukan, karena dapat memberikan petunjuk tentang penyebab kematian yang sebenarnya. Oleh karena itu, penelitian ini dibuat dengan tujuan untuk mengetahui, apakah identifikasi trauma perimortem pada tulang setelah proses pembakaran dapat dilakukan dengan melakukan tinjauan sistematis dari penelitian-penelitian sebelumnya. Dari penelitian ini dapat diketahui bahwa tipe fraktur, tekstur, warna, bentuk, dan perubahan ukuran tulang dapat dijadikan acuan untuk membedakan antara trauma perimortem setelah proses pembakaran dan trauma posmortem akibat pembakaran.*

***Kata Kunci****: Antropologi forensik, proses pembakaran, perimortem, posmortem, trauma*.

**Abstract**

Fire is often employed to destroy evidence in criminal cases, posing the challenge for forensic experts and forensic anthropologists in determining the cause of death and the victim’s identity. Although soft tissue can be completely burned during the burning process, trauma on bone can persist up to a certain temperature and duration of burning. Detecting trauma on the bones after the burning process is crucial, as it can provide insights into the actual cause of death. Therefore, this study was conducted with the objective of assessing whether the identification of perimortem bone trauma after burning process is feasible through a systematic review of prior research. The finding of this investigation reveal that fracture type, texture, colour, shape, and alterations in bone dimensions can serve as indicators to differentiate between perimortem trauma occurring after the burning process and postmortem trauma resulting from burning.

**Keywords**:Anthropology forensic, burning process, perimortem, postmortem, trauma.

1. **INTRODUCTION**

In the field of forensic science, the terms “antemortem trauma”, “perimortem trauma”, and “postmortem trauma” are utilised to delineate the temporal occurrence of injuries that occurs to the human body. Antemortem trauma pertains to injuries that occur in the human body prior to death, while perimortem trauma encompasses injuries that occur in close proximity to or around the time of death, and postmortem trauma refers to injuries that manifest after death (Efe et al., 2021; Passalacqua and Fenton, 2012; Rundle, 2015). The perimortem period, as defined in forensic pathology, signifies the interval encompassing the process of death, caused by injury and/or fatal illness, whereas in the domain of forensic anthropology, the term “perimortem” relates to the duration during which a wet bone responds to external stress (Symes et al., 2012). This perimortem period ends when the bone desiccates. In essence, perimortem trauma is associated with an individual’s death due to the temporal proximity of trauma occurrences.

In several forensic cases, perpetrators resort to burning victim’s bodies to conceal identities, obliterate traces of trauma, and eliminate evidence. Fire and heat can indeed induce alterations in bone characteristics, such as changes in colour, density, texture, and size (Koch and Lambert, 2017). It is important to dispel the misconception that fire can destroy bodies, faces, fingerprints and other evidence. To effect complete destruction of a human body, it must be exposed to temperatures as high as 2500oC for a duration spanning 12 to 18 hours, akin to the conditions employed in the cremation process (Dirkmaat et al, 2012).

Perimortem trauma can be classified into three categories: blunt force trauma (BFT), sharp force trauma (SFT), and ballistic trauma (Efe et al., 2021; Symes et al, 2012). BFT is the most prevalent cause of death recorded in autopsy reports (Efe et al, 2021). This trauma arises not only from blunt-tipped objects, but also from vehicular accidents and falls from significant heights. In contrast, SFT can result from edged tools, such as kitchen knives or serrated knives, leading to stab and incision wounds (Symes et al., 2012). Meanwhile ballistic trauma, typically inflicted by bullets discharged from firearms, is characterised by the entry and exit trajectories of projectiles (Rundle, 2015).

These perimortem traumas imprint unique characteristics on bone structures. Nevertheless, the attributes defining each form of trauma can undergo modification when bones are subjected to the effects of burning (Koch and Lambert, 2017).

Identifying and distinguishing perimortem trauma subsequent to the burning process is feasible, albeit requiring specialised techniques and heightened attention (Dirkmaat et al., 2012; Keys and Ross, 2022; Koch and Lambert, 2017; Rundle, 2015; Symes, 2012). This is due to physical changes undergone by burned bone upon exposure to heat and flames, manifesting as dehydration and surface fractures, which can obscure or mimic the appearance of perimortem trauma (Dirkmaat et al., 2012; Symes, 2012).

Although the body of research in this field is relatively limited, studies investigating the identification of perimortem trauma on bones after exposure to fire have been conducted, predominantly utilising animal specimens for experimentation (Koch and Lambert, 2017; Passalacqua and Fenton, 2012). It is imperative to acknowledge that these findings may not precisely replicate real-world scenarios involving human victims. Furthermore, certain studies exclusively concentrate on cranial bones, while others focus solely on postcranial bones. To synthesise and evaluate the outcomes of numerous prior investigations, this study undertakes a systematic review. Consequently, the primary objective of this study is to ascertain the feasibility of identifying perimortem trauma on bones after exposure to fire. The study’s emphasis lies in distinguishing perimortem trauma from postmortem trauma resulting from burning process. Additionally, this research is intended to serve as a valuable resource to aid forensic experts and forensic anthropologists in their fieldwork, especially in arson-related cases, to elucidate the true cause of death of the victim.

**2. RESEARCH METHOD**

This research constitutes a systematic review utilising the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) method. Previous research relevant to the subject matter of this study was gathered from various research databases, including PubMed, Science Direct, and Google Scholar. When conducting the research, the following keywords were employed: “(((((perimortem trauma) OR (blunt force trauma)) OR (sharp force trauma)) OR (ballistic trauma)) AND (fire))”, “(perimortem trauma) AND (fire)”, “(blunt force trauma) AND (fire)”, “(sharp force trauma) AND (fire)”, “(ballistic trauma) AND (fire)”. Subsequently, several filters were applied, resulting in the selection of research published within the last decade, specifically from 2013 to 2023. This ten-year timeframe was chosen due to the limited availability of sources pertaining to the research topic. Furthermore, only primary research findings were included for further review.

**3. RESULTS**

A keyword search in each database yielded a total of 75 research titles. After removing 23 duplicates studies, 52 remained. From these, only 28 studies were selected. Due to limited access to certain research sources, secondary research, and less relevant studies were excluded, resulting in a final count of 17 research titles. Out of the 17 studies, 4 discussed multiple types of perimortem trauma simultaneously, 4 focused on blunt force trauma, 7 delved into injuries caused by sharp objects, and only 2 specifically addressed ballistic trauma following the burning process (see Figure 1).

Records removed before screening:

Duplicate records removed (n = 23)

Records identified from databases

(n = 75)

**Identification**

**Screening**

Reports sought for retrieval

(n = 52)

Reports not retrieved

(n = 24)

Reports excluded:

Restricted (n = 6)

Secondary research (n = 2)

Not related: (n = 3)

Reports assessed for eligibility

(n = 28)

Reports not retrieved

(n = )

**Included**

Studies included in review

(n = 17)

Reports excluded:

Reason 1 (n = )

Reason 2 (n = )

Reason 3 (n = )

etc.

Topics:

Perimortem trauma (n = 4)

Blunt force trauma (n = 4)

Sharp force trauma (n = 7)

Ballistic trauma (n = 2)

**Figure 1.** Result of Preferred Items for Systematic Reviews and Meta-Analyses

**3.1 Perimortem Trauma**

BFT is the most extensively studied type of trauma when considering studies that encompass multiple perimortem traumas (Franceschetti et al., 2021; Friedlander, 2018; Koch and Lambert, 2017; Macoveciuc et al., 2017), followed by SFT (Friedlander, 2018; Koch and Lambert, 2017; Macoveciuc et al., 2017), with only two studies focusing on ballistic trauma (Franceschetti et al., 2021; Koch and Lambert, 2017). Out of four studies, two utilised *Sus scrofa* specimens for the limbs (Koch and Lambert, 2017; Macoveciuc et al., 2017), and ribs (Koch and Lambert, 2017), while the remaining two employed human samples, specifically focusing on cranial bones (Franceschetti et al., 2021; Friedlander, 2018) and the pelvis (Friedlander, 2018). Furthermore, each type of trauma discussed in this section will receive further examination in the following section, alongside an analysis of the thirteen studies categorised according to each type of trauma.

**3.2 Blunt Force Trauma**

BFT in several studies was induced using hammer, crowbar, and tire iron (Franceschetti et al., 2021; Keys and Ross, 2022; Koch and Lambert, 2017). Assistive devices were also employed to replicate similar trauma (Divya et al., 2022; Macoveciuc et al., 2017). Furthermore, in studies involving human bones, the specimens were obtained from cases of death caused by falls from heights and train accidents (Franceschetti et al., 2021), car accidents (Galtes and Scheirs, 2019), and injuries resulting from blows to the head and upper limbs (Bytheway et al., 2014). A significant portion of the research was conducted in enclosed spaces (Divya et al., 2022; Franceschetti et al., 2021; Friedlander, 2018; Galtes and Scheirs, 2019; Koch and Lambert, 2017; Macoveciuc et al., 2017). In the BFT experiments, the burning temperature ranged from 200oC to 1280oC, with the shortest burning duration being 6 minutes and the longest duration extending to approximately 7 hours and 5 minutes.

In research utilising *Sus scrofa* specimens (Keys and Ross, 2022; Koch and Lambert, 2017), limb bones affected by BFT displayed longitudinal fractures, classified as post-mortem trauma (Koch and Lambert, 2017). In the case of cranial bones, longitudinal fractures emerged after burning, often accompanied by transverse fractures radiating around the sutures (Keys and Ross, 2022). Longitudinal and transverse fractures in the perimortem trauma area were also observed in (Macoveciuc et al., 2017) using samples from sheep’s limbs. In addition to the appearance of new fractures after the burning process, postmortem fractures can be distinguished by their rougher texture compared to perimortem fractures.

In studies involving human bones, the shape of the fractures remained relatively unchanged after undergoing the burning process. To identify perimortem trauma, one can examine the fractures’ edges, which typically exhibit a round, yellow-brown colour and matte appearance on the fracture surface, in contrast to postmortem trauma, where the fracture edges tend to rough-textured and lighter in colour (Franceschetti et al., 2021). Similar findings were also reported in (Divya et al., 2022; Friedlander, 2018).

In (Friedlander, 2018), it was noted that fractures in the cranial bones are more resilient to heat compared to fractures in the pelvis, which are largely destroyed by fire. In (Divya et al., 2022), it was observed that bones affected by BFT become significantly more fragile after being subjected to burning, in contrast to bones that were not previously traumatised. The forms of postmortem fractures identified in both human and animal specimens’ bones exhibited similarities. Additionally, in that study, it was observed that the bones were bent and almost entirely calcified, indicating that they were still covered with soft tissue before the burning process.

Macroscopic detection of perimortem trauma is possible when the bone has not been completely consumed by fire. In a forensic case involving a victim found burning in a car (Galtes and Scheirs, 2019), several fractures in the lower limbs were observed, concealed by longitudinal fractures of the femur and comminuted fractures of the tibia and fibula, which are characteristic of trauma resulting from accidents.

Microscopic observations can also be made when the bones are almost entirely incinerated or when there is an unusual burning pattern, as exemplified in (Bytheway et al., 2014), where the victim’s body was only burned after undergoing the decomposition phase. Furthermore, non-invasive radiography can be employed to examine bone trauma patterns (Keys and Ross, 2022; Koch and Lambert, 2017). The use of additional tools to determine the curvature colour map (CCM) proves useful in distinguishing perimortem and postmortem trauma based on variations in colour gradients (Friedlander, 2018).

**3.3 Sharp Force Trauma**

Nearly all studies on SFT have utilised knives (Dennis, 2021; Friedlander, 2018; Koch and Lambert, 2017; Macoveciuc et al., 2017; Rosa et al., 2022; Tutor and Marquez-Grant et al., 2021; Tutor and Sanchez et al., 2021; Tutor et al., 2022; Waltenberger and Schutkowski, 2016). Some of these studies involved serrated knives (Tutor and Sanchez et al., 2021; Tutor et al., 2022), and bread knives (Tutor and Marquez-Grant et al., 2021; Tutor et al., 2022). Additionally, an artisanal knife was employed (Rosa et al., 2022). However, in (Robbins et al., 2014; Rosa et al., 2022; Tutor and Marquez-Grant et al., 2021; Tutor et al., 2022), trauma was induced using saws (Robbins et al., 2014; Tutor et al., 2022), axes (Rosa et al., 2022), and machetes (Tutor and Marquez-Grant et al., 2021).

All burning experiments were conducted within enclosed spaces, except for (Robbins et al., 2014). The burning temperatures ranged from 200oC to 1100oC, with the shortest burn duration lasting 6 minutes and longest duration extending to 7 hours and 5 minutes.

The burning process applied to *Sus scrofa* specimens did not substantially alter the form of trauma (Koch and Lambert, 2017; Robbins et al., 2014; Tutor and Marquez-Grant et al., 2021; Waltenberger and Schutkowski, 2016). Only the originally SFT edges became smoother after the burning process (Waltenberger and Schutkowski, 2016). Longitudinal fractures also became apparent on the bone surface following burning (Waltenberger and Schutkowski, 2016). Furthermore, the burning process led to a reduction in bone size (Tutor et al., 2022).

In studies involving saws, it was observed that newer saws exhibited traces of trauma that were easier to detect than older saws (Robbins et al., 2014). Apart form saws, the morphology of trauma resulting from serrated knives and bread knives could be distinguished from that caused by kitchen knives, even after the burning process had occurred (Tutor et al., 2022).

Lamb bones were also employed in the experiments. At the trauma site, superficial fractures, which did not penetrate the bone cortex, extended from larger longitudinal fractures after the bone was burned (Macoveciuc et al., 2017). Additionally, transverse fractures were detected, causing the bone to break in two in some areas. Rabbit bones were also utilised (Dennis, 2021). From this study, it was observed that bones with extensive SFT trauma exhibited faster colour changes than those with minimal trauma.

The morphological features of SFT on human bones can be identified during examination, with some features becoming more evident after burning process (Friedlander, 2018; Tutor and Marquez-Grant et al., 2021). Trauma resulting from a kitchen knife was considerably easier to detect than that from a serrated knife, which exhibited morphological changes after burning (Tutor and Marquez-Grant et al., 2021).

The detection of SFT after burning can be achieved not only macroscopically, but also microscopically. Micro-CT can be employed to ascertain whether SFT occurred before or after burning (Waltenberger and Schutkowski, 2016). Additionally, the use of SEM is preferable to the stereomicroscope, particularly in cases involving serrated-induced trauma (Robbins et al., 2014). The roughness of the trauma surface texture can also be assessed using an Optical Roughness-meter (Tutor et al., 2022). Utilising additional equipment to identify CCM through colour grading is also a viable approach (Friedlander, 2018). Moreover, the chemical elements present in the tools used to inflict trauma can be detected using XRF (Rosa et al., 2022). To determine whether SFT can be easily recognised with the naked eye after the burning process, a study in the form of a blind test was conducted on students with anthropological and non-anthropological scientific backgrounds (Tutor and Sanchez et al., 2021).

**3.4 Ballistic Trauma**

Ballistic trauma in (Rundle, 2015) was caused by a 9 mm calibre firearm, and in (Rubio et al., 2020), it resulted from a .32 ACP pistol. The burning temperature used ranged from 600oC to 1500oC, with the shortest duration lasting 4 minutes and the longest extending to 7 hours. In the research conducted on *Sus scrofa* specimens, the assessment of whether ballistic trauma occurs during the perimortem period in the cortical bone requires consideration of the bone surface texture, colour patterns, and fracture walls (Rundle, 2015). Fracture extending from the central point to other regions can serve as an indicator of perimorterm trauma.

Research employing *Sus scrofa* ribs demonstrated the durability of the bones, allowing for the detection of perimortem trauma (Dirkmaat et al., 2012). In the vicinity of the trauma, bullet residue can still be identified. However, in samples from humans with perimortem ballistic trauma to the body, analysis cannot proceed, as burning at 1280oC for 90 minutes reduces most of the bone to ashes (Franceschetti et al., 2021).

The distance from which a bullet is fired relates to the presence of bullet residue on the body. In (Fais et al., 2012), where shooting experiments were conducted at distances of 5 cm, 15 cm, and 30 cm from the human lower limb, it was demonstrated that the closer the distance, the more residue remained in the entry wound. After the burning process, it becomes challenging to distinguish the shapes of the entry and exit wounds. Therefore, in this study, the use of Micro-CT is recommended as it capable of detecting bullet residue. Radiography can also be employed as a non-invasive method.

**4. DISCUSSION**

To identify trauma and determine the cause of death from human skeletal remains, various fracture types and characteristics are considered. However, bone fractures can undergo changes when exposed to heat, as is often the case in forensic scenarios. Criminals may resort to burning the body, complicating the identification process.

In the process of reconstructing such incidents, multiple experiments were conducted to assess whether perimortem trauma could still be identified after the burning process. Most burning experiments were conducted in enclosed spaces, reflecting the common occurrence of burn cases indoors, where temperatures typically reach around 900oC (Dirkmaat et al., 2012). Conducting experiments in closed room is preferable due to temperature stability and easier measurement during observations. In contrast, open-space burns are affected by factors like temperature, season, humidity, oxygen levels, and others, which can influence observation results.

After the burning process, postmortem fractures, in the form of fractures, can manifest and are sometimes mistaken for perimortem trauma. Thus, distinguishing when the trauma occurred is essential. Perimortem BFT is characterised by fractures radiating from the point of impact, resulting in bone fragments forming fractures around it (Symes et al., 2012). Common types of BFT fractures include transverse, oblique, butterfly, spiral, and comminuted fractures. The butterfly-type fracture is frequently observed in long bones. SFT exhibits cut forms, stab wounds, cuts, saws marks, and sign of mutilation (Rosa et al., 2022). Sharp objects with plain edges produce V-shaped wounds, while those with serrated edges result in U or W-shaped wounds. Ballistic trauma, on the other hand, is influenced by multiple factors, including bullet design, velocity, yaw, bone elasticity, and tissue density, impacting the size and shape of the bullet’s entry wound (Berryman et al., 2012). In cases of ballistic trauma to the cranial bones, keyhole-shaped fracture patterns are often observed.

The presence of a longitudinal fracture on the bone’s surface may suggest that the fracture is unrelated to the cause of the death. Longitudinal fractures are similar to those appearing postmortem after the burning process. Typically, a transverse fracture pattern accompanies a longitudinal fracture. Postmortem fractures tend to radiate around the trauma site, particularly in the cranial bone, where such fractures are common around sutures. This pattern is due to the concentration of heat during the burning process in the well-ventilated bone areas (Keys and Ross, 2022).

Apart from fracture shape, the texture of the trauma-affected area undergoes changes following the burning process. The edges and walls of trauma become smoother, while postmortem trauma’s edges and walls feel rough to the touch. This change results from bone dehydration after death, exacerbated by the burning process.

Bone colour also changes after exposure to fire. The colour of burnt bones initially turns yellow, progressing to reddish and purplish hues with higher temperatures and longer durations, ultimately becoming black, grey, and finally white (Dirkmaat et al., 2012). Within 30 minutes of burning, yellow bones register temperatures of approximately 200oC, turning black at 400oC, grey at 600oC, and white when reaching 800oC (Rubio et al., 2020). Bones that have experiences significant trauma tend to discolour more rapidly.

Bone size can also change due to exposure to fire. Bone length decreases, including the length of SFT on the bone, though there is no change in the trauma’s depth. This can create the illusion of the trauma scar enlarging in size. Additionally, bones that bend after burning may indicate that they were covered with soft tissue before being burned.

In cases of SFT, fire offers a slight advantage, as bone trauma becomes more visible when the overlying soft tissue is completely consumed, facilitating identification. In contrast, identifying the entry and exit points of bullets in ballistic trauma becomes challenging after the bone has burned.

Microscopic methods, such as Micro-CT, SEM, and Optical Roughness-Meter, can be employed when macroscopic detection is challenging. Radiography is a non-invasive option, especially useful when substantial soft tissue remains. XRF can identify chemical elements from tools left around the trauma-affected bone area. The use of software featuring CCM (curvature colour map) aids in distinguishing perimortem and postmortem trauma through colour gradations, although it may be less effective in distinguishing between BFT and SFT.

Most research has been conducted on test animals rather than humans’ bone, with animal differences observed between the two comparisons. Notably, test animals are typically young, and differences in soft tissue thickness and anatomical shapes between animal and humans may affect study outcomes. Moreover, burning bones from children and adults yields different results, with child victims burning more rapidly due to less soft tissue.

Forensic investigations into the true cause of death are often challenging, particularly when the victim’s body is extensively burned, and access to sophisticated identification equipment is limited. Therefore, forensic experts and anthropologists must possess an in-depth understanding of this subject to enable identification, even on a macroscopic basis. A test conducted in (Tutor and Sanchez et al., 2021) gauged the proficiency of anthropology and non-anthropology students in identifying perimortem trauma to bones after the burning process solely based on literature and detailed descriptions, yielding highly satisfactory results. Increasing the available literature on this topic could significantly aid investigations in real forensic cases.

**5. CONCLUSIONS AND SUGGESTIONS**

Perimortem trauma, which occurs around the time of death, can serve as a crucial reference for determining a person’s cause of death. However, such trauma can be obscured by burning the victim’s body, a scenario frequently encountered in various forensic cases. Nonetheless, this does not imply that the identification of perimortem trauma is an impossible task. This study demonstrates that identifying perimortem trauma on bone after the burning process is feasible. Factors such as temperature, duration, burning location, and the extent of soft tissue covering play a role in determining bone resistance.

To differentiate perimortem trauma form postmortem trauma and achieve successful identification, it is essential to consider fracture type, texture, colour, shape, and changes in bone size. These characteristics can be observed through macroscopic and microscopic examinations, as well as by analysing the chemical elements present in the site of the trauma.

This research primarily focusses on the macroscopic identification of perimortem and postmortem trauma resulting from burning, as this method offers rapid and precise applicability in field investigations. While laboratory-based identification methods are not extensively covered in this study, the mentioned techniques can be further developed, and other methods with potentially greater accuracy may also be employed. The availability of abundant literature on related topics is expected to facilitate the progress of investigations into similar cases.

Additionally, research on the identification of ballistic trauma after the burning process is relatively scarce compared to other trauma types. This limitation highlights the scarcity of information concerning this specific type of trauma within the context of this study. Therefore, we look forward to future research that will delve deeper into the subject of perimortem ballistic trauma on bones after the burning process. This is especially important considering the high occurrence of fire-arm related homicides, and such research could greatly simplify the investigative process.

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