Title

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Through Fire and Flames: Post-burning survival and detection of dismemberment-related toolmarks

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Abstract:

During a homicide investigation in which fire has been used to reduce the size of the cadaver and conceal the evidence of injuries, the identification of perimortem trauma presents a challenge, in particular in cases when the perpetrator has dismembered the body followed by burning the remains. It is therefore important to understand the effects which heat causes on fresh bone. The aim of this paper is to perform a pilot study on the survival ratio of toolmarks in different anatomical regions associated with dismemberment, and a descriptive analysis of the variables that may potentially influence the post-burning survival and detection. To achieve this, three donated embalmed cadavers were used to simulate a case in which an attempted dismemberment and burning had occurred. 55 pre-burning injuries were manually induced: 30 using a machete to inflict chopping trauma, and 25 with a serrated bread knife to inflict sharp force trauma, on the thigh, knee, ankle, and wrist. The cadavers were cremated in a furnace at Madrid's Cementerio Sur and the burnt remains were analysed at the Laboratorio de Antropología Forense of the Universidad Complutense de Madrid. Not all pre-burning injuries inflicted were visible after the cremation process; only 13% were detected in this experiment. Toolmarks can be masked, modified, destroyed, or overlooked from the outset of the procedure due to several factors which influence the post-burning survival and detection of toolmarks and contribute to conceal the evidence of trauma. Additional research should be done to study further variables which affect the post-burning visibility of sharp force trauma.

Key words:

Cremated human remains, pre-burning trauma, sharp force trauma, dismemberment, forensic anthropology

Highlights:

- Three donated embalmed cadavers were used to simulate a case in which an attempted dismemberment and posterior burning had occurred.
- Only 13% of the injuries inflicted were visible after cremation.
- Toolmarks can be masked, modified, destroyed, or overlooked throughout the process due to intrinsic and extrinsic factors.
- Sharp implements can lead to different post-burning survival of toolmarks depending on how the trauma was inflicted.

1. Introduction:

One challenge often encountered in medicolegal cases is the differentiation between perimortem trauma and postmortem damage [1]. A perimortem injury is defined as one which occurred around the time of death while a post-mortem lesion is one which occurred after death [2, 3]. Regarding bone, forensic anthropologists make the distinction between fresh or wet bone versus dry bone [4]. In burnt human remains, the identification of perimortem trauma poses an added interpretive challenge, since fire is a highly destructive agent which burns the skin, shrinks tissue, destroys internal organs and dehydrate, warp and fragment the skeletal remains [5, 6]. Therefore, it is important to study the effects which fire has on perimortem trauma.

Fatal fires are more commonplace in accidents, wildfires, and suicides [7], and postmortem mutilation or dismemberment in armed conflict [8–10], or individual domestic cases [11–13]. However, there have been cases in which the offender attempted to incinerate the remains after dismembering the victim [14].

In recent decades, several experiments have been performed to analyse trauma in burnt bone [15–26]. These studies have focused on sharp force trauma induced with knives [16, 17, 20, 23, 26], saws [21, 24] and chopping weapons, such as machetes and cleavers [18, 19]. However, these have mostly been performed with non-human models, using bones rather than whole cadavers. Koch and Lambert [26] used six pig carcasses, which were subjected to blunt, sharp, and ballistic trauma. Their experiment showed that certain cuts were visible only on soft tissue, and the evidence of sharp force trauma was susceptible to being concealed after burning. Pope and Smith [20] used human models for their experiments: 40 non-embalmed heads, which were subjected to blunt, sharp and ballistic trauma before the burning process in an open pyre. The biomechanical properties of the cranium are different from those of other postcranial bones, and the results cannot be extrapolated to the whole body [27]. However, it was proven that sharp force trauma could easily be identified after burning on the bases of a number of observable morphological characteristics.

Despite the different methodologies, all of the authors agree that sharp force trauma can be detected and recognized by direct macroscopic observation after exposed to fire damage; some features are more clearly visible after burning, but others may be lost due to bone fragmentation [24]. Linear cuts and sharp edges are maintained [22], sharp force trauma induced with knives leaves a characteristic V-shape [19], sharp force trauma induced with saws leaves a square or U-shape in a cross-section [21, 24, 28], and chopping trauma forms a V or U-shaped cross-section, depending on the thickness of the blade [18, 29, 30]. It has also been proven that trauma morphology is distinguishable from thermal damage [15, 19].

However, experimental research analysing the behaviour and analysis of toolmarks when a whole cadaver is cremated is scarce [16, 26], and in human model, non-existent. Anthropological studies are often prone to error if the body has endured high temperatures, mechanical fracturing, agitation, and manipulation of the fire during the burning process, potentially reducing the skeletal remains to small broken pieces [5–7]. In their experimental study, Emanovsky et al. [16] concluded that fragmentation was the most influential variable in the survival and later visibility of sharp force trauma in bone, because the cut marks could be easily overlooked, and the identifying features destroyed during the anthropological analysis.

This paper presents the results of a pilot experiment on human cadavers to analyse the post-burning survival ratio of toolmarks associated with dismemberment in different anatomical regions. This study simulates an attempted dismemberment and subsequent burning, with the goal of exploring which variables in toolmark analysis can be affected by fire. It was hypothesised that not all trauma inflicted would be visible after burning, in accordance with Koch and Lambert [26] and Emanovsky et al. [16], due to extrinsic and intrinsic factors. For the analysis, all of the variables were examined from the beginning of the procedure to the anthropological examination; observations made during the postmortem examination and throughout the cremation process and the weight and completeness of the burnt remains, were correlated with the ratio of survival and detection of toolmarks, compared with to the total number of injuries inflicted, with the anatomical region and with the implement used.

2. Materials and Methods

2.1 Human Samples

Three embalmed adult male cadavers were used for the sharp force trauma experiment; they had been donated to the Laboratory of Forensic Anthropology and Odontology at Universidad Complutense de Madrid through the Funerary Services of the Autonomous Region of Madrid, Spain with prior authorization. The data obtained before the experiment is provided in Table 1; all cadavers were embalmed, covered with plastic shrouds, and buried inside a zinc coffin.

The cadavers used for the experiment were donated to the Cementerio Sur de Madrid by the families of the deceased. Due to the European Union's Data Protection Law (2018), not all antemortem data was available. Hence, the full data on individual 3, and the sex of individuals 1 and 2 were obtained. This experiment was carried out in accordance with the Code of Ethics of the World Medical Association (Declaration of Helsinki) and falls within the scope of the Mortuary Health Act of the Autonomous Region of Madrid (Decree 124/1997, of October 9, 1997) [31].

2.2 Methodology

According to Pope and Smith [20], experimental studies should be performed in outdoor settings using pyres so that the experiments are more reliable and similar to a forensic setting, and to ensure that the burning process can be monitored in full, as it has been the case in fields of forensic science [32]. While this is preferable, it is not feasible when using whole cadavers; this experiment was performed in its entirety at Madrid's Cementerio Sur facilities, because the Mortuary Health Act of the Autonomous Region of Madrid [31] does not allow the cadavers to be moved before the cremation process. Therefore, a radiological study and a later outdoor cremation were not viable. The furnace at Madrid's Cementerio Sur was used, with temperatures and heat-induced morphological changes recorded. The maximum temperature authorized was 800 ºC.

2.2.1 Sharp force trauma

The sharp force trauma experiment was performed in the Examination Room of Madrid's Cementerio Sur. The shrouds were removed using scissors to uncover the body and evaluate the anatomical regions. An external examination was conducted to describe the cadaveric preservation, ante- or perimortem trauma, and observable pathologies. Data was recorded using a worksheet and the individuals were photographed in detail. The workflow of the experiment is illustrated in Figure 1.

The tools selected to induce the pre-burning trauma were a machete to inflict chopping trauma, and a serrated bread knife to inflict cutting trauma [33]. The machete was 300 mm in length, with a maximum width of 45 mm, and blade thickness of 2 mm. The serrated knife was 370 mm in length, with a maximum width of 30 mm, and tooth length of 3 mm. The space between the teeth, or gullet, was 9 mm. These utensils were chosen because they are affordable household objects frequently used in forensic casework. An analysis of dismemberment and mutilation revealed that 46% of victims were dismembered using only knives [14].

In all, 55 pre-burning injuries were inflicted manually, Table 2 describes the anatomical regions and number of blows to each area. The machete and the serrated knife were both used on the thigh. The knee, hand, and feet were injured using only the serrated knife in order to simulate an attempted dismemberment through articular surfaces [34]. The ilium was injured only with the machete to simulate an attempted mutilation through the middle of the cadaver [30]. Due to the cadavers' state of decomposition, described in Table 3, the attempted dismemberment was not possible in all anatomical regions.

The injuries were inflicted to simulate a case of criminal dismemberment. Therefore, no particular attention was paid to the size or depth of the blow. A comparison between pre-burning toolmarks and post-burning toolmarks on bone fell beyond the scope of this paper due to the presence of surrounding soft tissue. Nonetheless, a scale was used to document the length of the inflicted entry wounds. 30 chops were manually inflicted on the left thigh with the machete, along the longitudinal axis of the leg, beginning from the proximal portion, and on the left ilium crest of all individuals. 25 perpendicular cuts were inflicted on the main axis using the serrated knife on the right thigh of individuals 1 and 2, on the ankle of individuals 1 (right) and 2 (left), and on the left wrist of individual 1. The sharp force trauma on the articular surfaces was inflicted by extending the ankle or wrist and slashing transversally five times in the dorsal part of the foot and hand. The wounds were of varying depths, as the objective was to affect the bone to cause a toolmark but prevent amputation [35].

Pre-burning trauma was recorded with drawings, charts and written notes, as well as photographs which showed the exact location of the injuries on the unburnt cadaver; the sharp force damage was inflicted on soft tissue and putrid wet matter, and the photographs depicted the entry injury on the area, along with a scale.

2.2.2 Burning process

Once the trauma had been inflicted and recorded, each individual was placed in a wooden coffin then inside the furnace at Madrid's Cementerio Sur. The cremation was monitored through a window at the head end of the furnace. The procedure was controlled and supervised with photographic evidence and the temperature fluctuation noted every 5-15 minutes. The bodies were manipulated by the crematorium technician at specific moments when skeletal remains had to be separated from remnants of organic matter. The burning process ended after 85 minutes (±1.5 SD), reaching a maximum temperature of 701 ºC (±37.5 SD), when all organic matter was completely consumed, and the skeletal remains displayed a white colour. Further information on the exact temperature throughout the process and its duration is illustrated in Figure 2. The skeletal remains were removed by the technician with a metal tool and were left to cool overnight.

2.2.3 Anthropological analysis

The remains were collected in three separate bags and taken to the Laboratorio de Antropología Forense, where the anthropological analysis was performed in accordance with the methodology proposed by Fairgrieve [36]. The skeletal remains were sorted individually by anatomical region and weighed in grams using an electronic scale, to calculate the completeness and analyse the overall preservation of each region.

Special attention was placed on to the reconstruction of fragments, in accordance with the recommendations of Grévin et al. [37]. The anatomical regions were reconstructed and the bone fragments containing toolmarks were separated, analysed and assessed based on the morphological traits described for burnt bone displaying sharp force trauma: V or U-shape [17–19, 23], uniform lines of varying depths, [20, 22] and visible sharp edges [26].

The bone fragments were examined by two authors (PM, CV) on separate occasions to validate the results and ensure that no toolmarks were lost or overlooked during the examination, and a post-burning survival study of sharp force trauma was performed. The "survival ratio" was thus calculated using the relationship between the injuries induced before the burning process and the toolmarks observed after. Compared to the sum of the toolmarks induced with one tool, either machete or serrated knife, to the anatomical region, and to the total of induced injuries.

$$\text{Survival ratio} = \frac{\text{N observed toolmarks}}{\text{N induced injuries}}$$

3. Results

3.1 Postmortem Observations

The cadaveric preservation was examined through a macroscopic analysis, and the anatomical examination of the donated individuals is described in Table 3. Two individuals (1 and 3) were autopsied before burial; the ribs and sternum were cut but the cranium was intact.

The layers of protective soft tissue on the thighs of individuals 1 and 2, and in the iliac crest of individual 1, made it difficult to leave an imprint on the bone with a single blow. By contrast, the cuts made in regions with less protection, such as the knee, hand, and feet, were easier to produce. Individual 3 was skeletonized with remnants of putrid wet matter accumulated in the distal part of the body. During the chopping of the left femur a “perimortem effect” was observed due to the embalming, which preserved the freshness of the bone, even when there was no surrounding soft tissue [38].

3.2 Cremation

The morphological changes observed and recorded during the burning process are described in Tables 4-6.

The cadavers underwent the same pattern of thermal destruction. The coffin was destroyed in the first 9-17 minutes when cremation of the body began. The heat capacity of the wood increased the temperature during the initial minutes of the cremation process, but then the organic matter and embalming liquid functioned as fuel, reaching the maximum temperature of 649-735 ºC in 43-56 minutes. Full incineration of the organic matter was completed in 83-86 minutes (Figure 2).

All cadavers were monitored during the burning process to verify whether they still contained remnants of unburnt organic matter. During these observations, if necessary, the remains were manipulated by the technician with the metal tool, causing intentional fragmentation of the skeletal remains. As a result, individual 2 was reduced to small fragments (Figure 3 #2). Individuals 1 and 2 contained abundant amounts of organic matter and soft tissue and, therefore, a higher temperature and more aggressive manipulation were required to assure complete incineration of the skeletal remains. Thus, the bone fragments of individual 3 were larger (Figure 3 #3).

3.3 Anthropological analysis

The sharp force trauma to the three individuals placed in anatomical position and the weights of each region are detailed in Annex 4-5.

3.3.1 Individual 1

The cremated remains presented a whitish colour and weighed 2550 g including ashes and dust (Figure 3 #1).

The anthropological analysis revealed that the neurocranial remains were larger and sturdier (210 g) than the viscerocranial fragments (31 g), which were nearly destroyed and could not be identified, with the exception of the orbital region. A reddish colour was observed on the inner region of the cranial vault fragments. The skeletal remains from the thorax were identified but poorly preserved; the fragments presented a spongy appearance and were very deteriorated (85 g). No evidence of the autopsy was detected on the ribs or sternum. The scapular girdle was poorly preserved (42 g); only rigid regions such as the coracoids, acromion and spines could be identified and reconstructed. The limbs were well preserved (510 g).

The pelvic girdle was represented by six (90-20 mm) fragmented remains (24 g) from the most robust areas: the ischium, the sciatic notch, and the articular surface of the sacrum. The iliac crest was not located or identified, and as a result, the toolmarks inflicted upon the pelvis of individual 1 were not observed. No evidence of sharp force trauma was found in the os coxae fragments.

Both femora (132 g) and patellae (13 g) were well preserved after cremation. The patellae were intact, and no evidence of sharp force trauma was observed. The reconstruction of the right femur revealed two cut marks inflicted with the serrated knife in the distal portion of a diaphysis fragment which was 40 mm long and 12.5 mm wide. The first cut was 8 mm in length and 1.5 mm in width. It was fragmented and displayed a darker colour than the exterior of the diaphysis. A square U-shape could be observed (Figure 4 #1). The second cut was 21 mm in length and 2 mm in width and was located between the femur condyles just above the articulation joint with the patella. The cut displayed a wide V-shape (Figure 4 #3 and Figure 5). In both toolmarks a radiating fracture was observed.

The tarsal bones were fragmented and poorly preserved; only 9 out of 14 could be identified (21 g). On the right talus, three parallel cuts measuring 20, 8 and 21.7 mm in length and 2 mm in width were observed (Figure 4 #4 and Figure 6). These cuts were made with the serrated knife in the same direction: latero-medial, leaving three linear cuts with visible sharp edges. Two cuts left an incomplete toolmark and the third caused a complete fracture of the distal portion of the talus, which was detected during the anatomic reconstruction. No evidence of sharp force trauma was found on the calcaneus or tibiae. Only 3 out of 16 carpal bones were located intact and no evidence of trauma was observed, the rest of the fragments were unidentified.

The toolmarks observed in this individual (N= 5) were inflicted with the serrated bread knife.

3.3.2 Individual 2

The cremated remains presented a variety of hues and weighed 2967 g including ashes and dust (Figure 3 #2).

The neurocranial fragments were large, reaching a total weight of 219 g, in contrast with the viscerocranial remains, which were brittle and easily destroyed, with the exception of the orbital region (82 g). The mandible was reconstructed (39 g). The ribs of individual 2 were less fragmented than those of individuals 1 and 3, but the sternum could not be identified. The scapular girdle was poorly preserved (42 g), but the spine and acromion were recognized. The upper limb (157 g) was better preserved than the lower limb (144 g).

Few fragments from the os coxae were recovered; eight (50-10 mm) remains from the articular surface of the sacrum, and the acetabulum. Two small and brittle fragments from the iliac crest were recognized but no evidence of sharp force trauma was found on either of them.

The femora were comprised of just eight recognizable parts (80-40 mm), which broke down into smaller fragments than in individuals 1 and 2 (81 g). Only remains of the patellae were found (5 g) displaying no evidence of sharp force trauma. A cut mark was located along a fragment with a length of 80 mm and width of 20 mm. Due to fragmentation and delamination, it was not conclusive which instrument was used to imprint it, but due to the bone siding (probably right femur), it was estimated that the cut was inflicted with the serrated knife in the anteromedial part of the thigh. The cut was 8 mm in length and 3 mm in width. No radiating lines were observed (Figure 4 #2).

All tarsal bones were located and identified except the left talus (56 g). No evidence of sharp force trauma was observed because the talus was destroyed and broken down into small, unrecognizable fragments.

The toolmark located in this individual (N= 1) was inflicted with the serrated bread knife.

3.3.3 Individual 3

The cremated remains presented a whitish colour and weighed 3089 g including ashes and dust (Figure 3 #3)

There was excellent preservation of the cranial skeletal remains (321 g); all the cranium fragments were observed but reconstruction was not feasible due to the pronounced warping. The mandible was intact with a fracture in the right mandibular ramus (40 g). The vertebrae were less fragmented than in individuals 1 and 2 and the atlas and axis were found almost intact. No evidence of autopsy was detected on the ribs, and the sternum was unidentified. The scapular girdle was poorly preserved (55 g), but both glenoid fossae, a coracoid and an acromion were identified. The right clavicle was found intact with a fracture in the sternal end. The limbs were preserved in an excellent state and reconstruction of the epiphyses was feasible. The diaphyses, however, were warped and fragmented (1151 g).

The pelvic girdle was represented by ten (40-10 mm) brittle, fragmented remains with a spongy appearance (35 g). The inflicted sharp force trauma was not detected, because only two fragments of the iliac crest were located.

The skeletal remains of both femora were identified (219 g), as were the patellae (19 g). The reconstruction of the left femur diaphysis fragments revealed one chop mark inflicted with the machete on a small fragment, 31 mm long and 22.5 mm wide, in the anteromedial part of the femur. The chop was 12 mm in length and 2 mm in width, with a darker colour than observed on the exterior of the diaphysis, and there was no evidence of radiating fractures. (Figure 4 #5) The chop displayed a V-shape with sharp edges more clearly visible after the burning process (Figure 7).

The toolmark located in this individual (N= 1) was inflicted with the machete.

3.3.4 Survival of anatomical regions

The completeness and survival of anatomical regions are described in Table 7. It can be observed that individual 1 was the lightest and individual 3 the heaviest. Individual 2 had the highest amount of ash and dust while individual 3 had the lowest. The limbs were the heaviest region in the identified skeletal remains.

A comparison of proportions in the three individuals is illustrated in Figure 8. The proportions of head, trunk, and unidentified were similar among all three individuals. However, the percentage of limb bone fragments from individual 3 was higher than in the other two, and the percentage of ashes and dust was lower.

3.4 Sharp force trauma survival

The post-burning survival ratio results are shown in Table 8, in which a comparison between the number of injuries inflicted before burning and the number of toolmarks observed after burning is provided. The total number of pre-burning induced injuries was 55, 30 with a machete and 25 with a serrated knife. The total number of toolmarks observed during the anthropological examination was 7. Therefore, toolmarks were observed at a rate of 13%.

Of the seven toolmarks observed, one was produced with the machete (1/30) and located on a femur diaphysis fragment from individual 3. The other six cut marks were inflicted with the serrated bread knife (6/25); three on the femur, and three on the right tarsus of individual 1. Figure 9 illustrates the survival of pre-burning sharp force trauma by anatomical region. It can be observed that no toolmarks were detected on the ilium (0/15) or on the carpal bones (0/5).

4. Discussion

This study analysed the post-burning survival and detection of sharp force trauma related to dismemberment in a burnt cadaver, and the extrinsic and intrinsic factors that contribute to the toolmark concealment. The results show that pre-burning trauma can be masked due to different variables which influence from the beginning of the experiment; only 7 toolmarks endured the procedure, of the 55 injuries inflicted on the unburnt cadaver (Figure 4). It is acknowledged that the three cadavers used to carry out the sharp force trauma experiment were embalmed, rather than fresh, which may have influenced the results and the toolmark survival ratio. In this experiment the use of a crematory furnace rather than an outdoor setting was sufficient, while also acknowledging the temperature and oxygen availability are limiting factors in forensic casework, and they fluctuate in an open pyre. Further research is recommended and needed to replicate this pilot experiment, increasing the number of individuals and pre-burning trauma induced with different implements, so as to compare the striation pattern that each object leave on bone, and their specific survival ratio.

During the mutilation and dismemberment of a cadaver, trauma may be concealed if the damage affects only the surrounding soft tissue, because injuries inflicted on regions containing protective tissue may be mitigated by that tissue [10, 34]. The results herein are concordant with the findings of Koch and Lambert [26], which indicated that fire could conceal wound entrance sites due to skin splintering and charring. In the event of complete incineration all damage done on soft alone tissue will be lost, as was observed in this experiment: four toolmarks out of 25 injuries induced on the thigh and knee were observed (Figure 4 (#1, #2, #3 and #5), Table 8).

Individuals 1 and 2 had remnants of soft tissue on the distal portion, and the injuries inflicted with the machete in areas containing layers of protective flesh were mostly mitigated by that tissue. This could be seen in the results, because only one of the three observed toolmarks on the femur diaphyses fragments was made with the machete. That fragment came from individual 3, which had wet putrid matter on the lower limb rather than compact soft tissue (Figure 7). On the contrary, trauma produced with the serrated knife presented less of a challenge during manipulation, and it was easier to affect the bone and potentially dismember the region. This was further observed on the articular surfaces, where the cartilage was not difficult to cut through, and three cut marks were detected on the right talus of individual 1 (Figure 6). The machete has been found inefficient for regions with abundant flesh, while the serrated bread knife was easier to use with minimal force, especially on articular surfaces, which explain the survival ratio of the injuries made to the femur (Figure 9).

Bonte [35] proved that chopping trauma could not result in full amputation of the limb unless it was held down on the opposite direction of the blow. According to Pachar Lucio [34], in criminal mutilation cases knives and sharp objects are in general used to slice the soft tissue and muscles, whereas saws and chopping weapons are employed afterwards to transect the bone, because they are considered the most efficient devices to do so [13, 39, 40]. The results obtained during the manipulation of the lower limb were consistent with both statements, as severing the leg without removing the surrounding soft tissue first have proved ineffective. With a machete, the complete separation of the femur through the thigh would not have been possible in this experiment. However, with the serrated bread knife the tissue could have been cut at the same time as the bone, shredding the surrounding muscle with a "to-and-fro motion" like a saw, cutting through by compression in the direction in which the blade is moving [30, 40], thus, allowing complete amputation. Even though the present experiment is a pilot study, the results seem to indicate that, due to the weapon type and the way in which the trauma was inflicted on the same anatomical region, two implements can have different post-burning toolmark survival ratios; only one observed toolmark was made with the machete. More research should be done in this topic to compare the post-burning survival ratio of different weapon types.

Cadavers cremated at high temperatures for an extended period of time generate calcined skeletal remains which are brittle and can easily fragment into pieces during collection, transport, and analysis [5–7, 36]. Therefore, toolmarks can be destroyed during the burning process if the remains are aggressively stirred, causing extreme fragmentation, or if the trauma is inflicted on less resilient anatomical regions.

The effect of manual fragmentation during cremation was seen in individual 2, which had the highest amount of ash and dust, whereas individual 3 had the lowest (Figure 8 and Table 7). The remains were highly fragmented and calcined, mixed with ashes from the coffin and broken burnt bone (Figure 3 #2). This was a result of the stirring at minutes 38 and 63 of cremation (Table 5), because remnants of organic matter were still present on the skeletal remains, and additional manipulation of the remains was necessary to assure the complete incineration of the body. During the burning process of individual 3, the stirring was less harsh (Table 6), and therefore, the remains were larger and better preserved (Figure 3 #3).

In the present experiment, the cremation of a cadaver with manual handling, the supine position of the body in the furnace may have influenced the destruction of anatomical regions until the remains were stirred. Glassman and Crow [41] stated that, if the body is placed on burning items or a combustible floor, the areas in contact with the fire will burn first. Considering that the stirring of the remains occurred after 67 and 75 minutes for individual 1 and 3, and after 38 minutes in individual 2, it can be assumed that the posterior side of the body was greatly affected from the beginning of the cremation, and susceptible destruction [27]. It was noted by Bohnert et al. [6] that as of 20 minutes after the beginning of cremation, the body became visible and started to fully burn, meaning approximately 47, 18 and 55 minutes of body destruction in a prostrate position in the present experiment. Preservation of the trunk (vertebral column, ribs, sternum, scapular and pelvic girdle) was poorer overall in individuals 1 and 3 than in individual 2, thus confirming the aforementioned conclusions (Table 7).

Regardless, the os coxae was destroyed and reduced to a few brittle, fragmented bones with a spongy appearance in all three individuals and, as such, the chop marks were not visible on any. The trauma may not have affected the bone in individual 1 due to the protective tissue, but in individuals 2 and 3, in which the chop marks were assessed and confirmed, the concealment of trauma was a result of fragmentation and destruction of the pelvic girdle, either during cremation, transport or anthropological analysis. It must be taken into consideration that, besides manual fragmentation and body position, intrinsic variables of the individual can also influence resistance to fire damage. Bone pathologies such as osteoporosis, menopause, old age, and other intrapersonal factors are known to have an impact on bone sturdiness or the lack thereof [5].

In this experiment, all of the remains were collected from the furnace, an activity closely monitored by the technician, but in a forensic scenario the evidence of trauma can be lost if not all the skeletal remains are recovered from the scene [16, 24]. The fragmentation and destruction of brittle anatomical regions affected the post-burning survival. Bone fragments were vulnerable to breakage throughout recollection, transport, and analysis, as occurred with to the pelvic girdle in all individuals (Annex 5). Fragmentation was found to be the most influential variable in the post-burning visibility of trauma, and this pilot study confirmed and further expanded upon the findings of Emanovksy et al. [16]. Of the seven induced toolmarks that survived the experiment, three were found in small, broken bone remains.

Once detected, toolmarks were visible in macroscopic view and could not be mistaken for heat induced fractures [15, 19] (Figure 4 and Figure 10). The morphological characteristics of the chop and cut marks were recognizable during the anthropological examination and some features were more clearly visible after the burning process, as Robbins et al. [24] and Macoveciuc et al. [17] stated. Heat fracture lines penetrated the superficial radiating lines which originate from the impact point and were magnified by the thermal action. One example of this was observed in the femur epiphysis cut mark of individual 1, in which a radiating line was detected (Figure 4 #3), and in the femur diaphysis fragment of individual 3, in which a dark colour was observed inside the chop, darker than the exterior of the bone, enhancing the shape (Figure 4 #5).

The trauma inflicted with the machete was easy to recognize, presenting a V-shape and linear sharp edges. On the contrary, the serrated bread knife produced different morphological characteristics. One mark clearly displayed a square U-shape typical of saw marks (Figure 4 #1) [21, 24, 28], while another had a wide V-shape (Figure 4 #3), both marks were induced on the same bone from individual 1. These results fit in with the conclusion reached by Amadasi et al. [39]: knives may produce ambiguous features and unusual patterns depending on how the trauma was inflicted. Therefore, it can be further concluded that sharp force trauma is identifiable even when the whole cadaver has been incinerated and subjected to stirring and manual fragmentation, but caution must be taken when analysing the toolmark features to identify the implement used.

Detecting toolmarks during anatomical reconstruction requires a good working knowledge of the anatomy of cremated remains and forensic examination, because identifying fragments is a crucial step in anthropological analysis to avoid overlooking pre-burning trauma [37]. In the event of a complete fracture, reconstruction of the bone may result in the detection of a toolmark, as occurred with the right talus of individual 1 (Figure 6, arrow). This is also applicable to intact bone, but it is critical for cremated remains. Burnt bones undergo notable warping and severe fragmentation, and the recognition of bone features and later assembling may not be obvious at first [5–7, 36, 37]. The anthropological analysis proved challenging when the identifying features were masked due to fragmentation and heat-induced modifications, as observed during the examination of individual 2. The identification was complicated, because morphological features from sharp force trauma were masked by the extreme fragmentation and delamination (Figure 4 #2). Therefore, it is essential to be familiar with heat-induced taphonomic changes and anatomy in order to distinguish fire damage and trauma.

As for the dismemberment through articular regions, just one cut was observed after the burning process in the knee region of individual 1 (Figure 5). The preservation of the distal portion of the femur diaphysis and condyles contributed to the survival of this trauma, as opposed to individual 2, in which the epiphysis were badly preserved and the fragmentation and destruction masked the evidence of trauma inflicted in this region (Annex 5). The obtained outcome can be explained due to the aggressive stirring that took place during the cremation of individual 2.

The sharp force trauma inflicted on the feet of individuals 1 and 2 was evidenced only in the right talus of individual 1. The talus was not fragmented and could be reconstructed, contributing to the post-burning visibility and survival of the cut marks (Figure 6). No evidence of sharp force trauma was found in the left talus of individual 2. The evidence was masked, because the talus had been fragmented up into small pieces and fragments of broken bone which were mixed in with the remains which were unidentified, smaller than 2 mm, spongy and unrecognizable, and could also be explained by the stirring during the cremation.

The trauma induced on the left hand of individual 1 produced inconclusive results but was in concordance with the post-burning survival ratio of the other regions. No evidence of sharp force trauma was detected on the carpal bones, which were poorly conserved (Annex 5). The cutting was induced by extending the wrist and slashing transversally, and it is possible that only the carpal tunnel and the cartilaginous area were severed, and any evidence of trauma was lost during the incineration of the soft tissue. Another possibility is that the toolmarks were concealed due to fragmentation and destruction of the carpal bones.

This pilot experiment stresses the importance of locating and identifying morphological features to recognise skeletal fragments, because they provide valuable information about the events prior to the burning process, such as differentiating trauma to vital regions—ribs or cervical vertebrae [42, 43]—from mutilation trauma—toolmarks frequently seen on articular surfaces [8, 13, 34] like the ones inflicted in this study—.It is important to take this information into account when analysing sharp force trauma in a forensic context [40].

Of the 55 pre-burning injuries induced during the postmortem examination, 7 toolmarks were observed after the procedure had been completed. As stated, multiple inter- and intrapersonal variables before, during and after the burning process influenced the post-burning survival and detection of sharp force trauma in a complete cadaver. Therefore, the presence of a trained forensic anthropologist is advisable from the very beginning of the forensic investigation.

5. Conclusions

No experiments using whole cadavers to study dismemberment-related toolmarks after burning have been conducted in Europe before. Therefore, this pilot study is pioneer in the forensic anthropology field. The experiment described herein entailed a descriptive analysis of the simulation of a forensic case in which an attempted dismemberment and burning occurred, using three embalmed cadavers. It was hypothesised that not all of the injuries inflicted on the unburnt cadaver would be visible, in accordance with previous authors, due to extrinsic and intrinsic factors, and that initial hypothesis was proven true with the results obtained. However, it was also strongly suggested that toolmarks induced by two different sharp implements may have distinct post-burning survival outcomes due to the weapon type and the way in which the trauma was inflicted. These results open up a new line of research about the survival ratio of toolmarks produced with different types of weapons after being exposed to fire damage.

The ability to distinguish sharp force trauma from heat induced fractures within a forensic context involving criminal mutilation presents a challenge in the medicolegal field, and the analysis and examination of variables which influence the concealment of trauma is essential for understanding the post-burning survival of toolmarks. This study has demonstrated that, although sharp force trauma is indeed recognizable, not all evidence of it endures the cremation process. Inflicted pre-burning injuries may not be visible after the burning process; only 7 toolmarks were detected in this experiment (13%). Toolmarks can be masked, modified, destroyed, or overlooked from the very beginning of the experiment due to multiple factors such as presence of protective layers of soft tissue during the mutilation of the cadaver, the intentional fragmentation of skeletal remains during or after cremation, and major thermal alteration. All these variables influence the post-burning survival and detection of toolmarks and contribute to conceal the evidence of trauma.

The identification of bone fragments is crucial during anthropological analysis, because in the event of a complete fracture, the reconstruction can result in the detection of a toolmark and thus providing valuable information about the events prior to the burning. Additional research should be done on this topic to study more variables that affect the post-burning visibility of sharp force trauma in a burnt cadaver and gain a further understanding of the behaviour and survival of toolmarks made with different implements.

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8. Supplementary material

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Annex 2 – Individual 2 during the burning process at 38 minutes

Annex 3 – Individual 3 during the burning process at 75 minutes

Annex 4 – Sharp force trauma from individuals 1, 2 and 3 all shown in anatomical position. Red arrow points at the observed toolmarks; Green arrow points at the position of the undetected toolmarks.

Annex 5 – Weight of anatomical regions (g)

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Figures 1 and 2

Figure 1 – Workflow at Madrid's Cementerio Sur

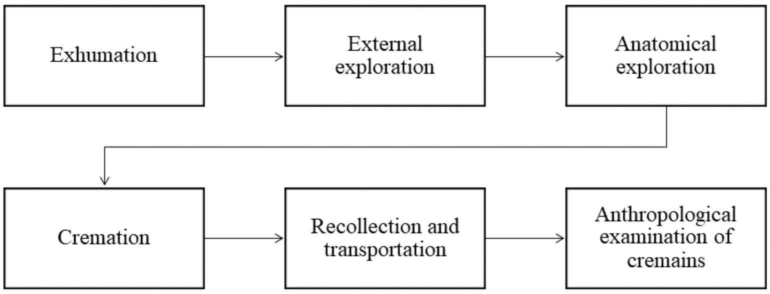


Figure 2 – Temperature and duration of the burning process

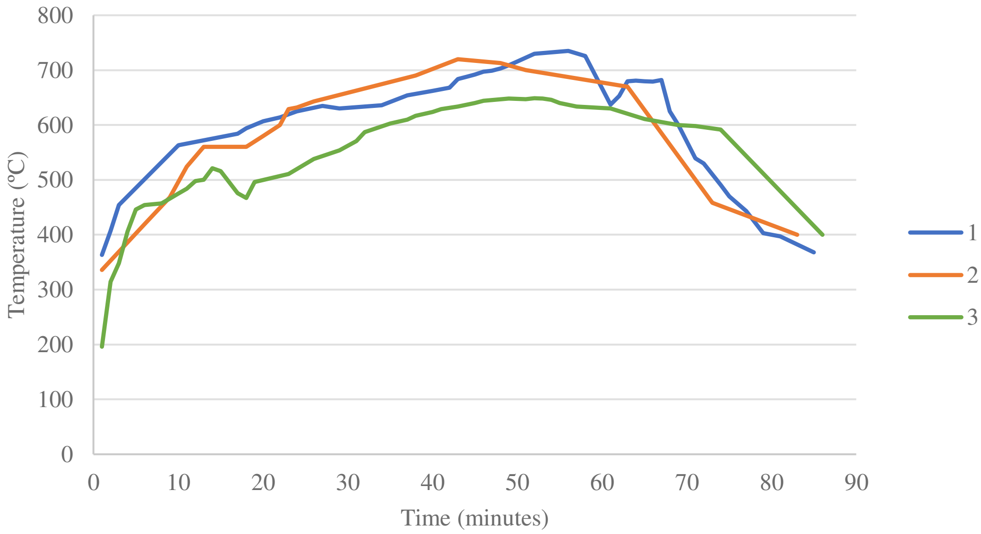


Figure 3 – 1: Individual 1 after the burning process; 2: Individual 2 after the burning process; 3: Individual 3 after the burning process.

Figure 4 – Observed pre-burning sharp force trauma

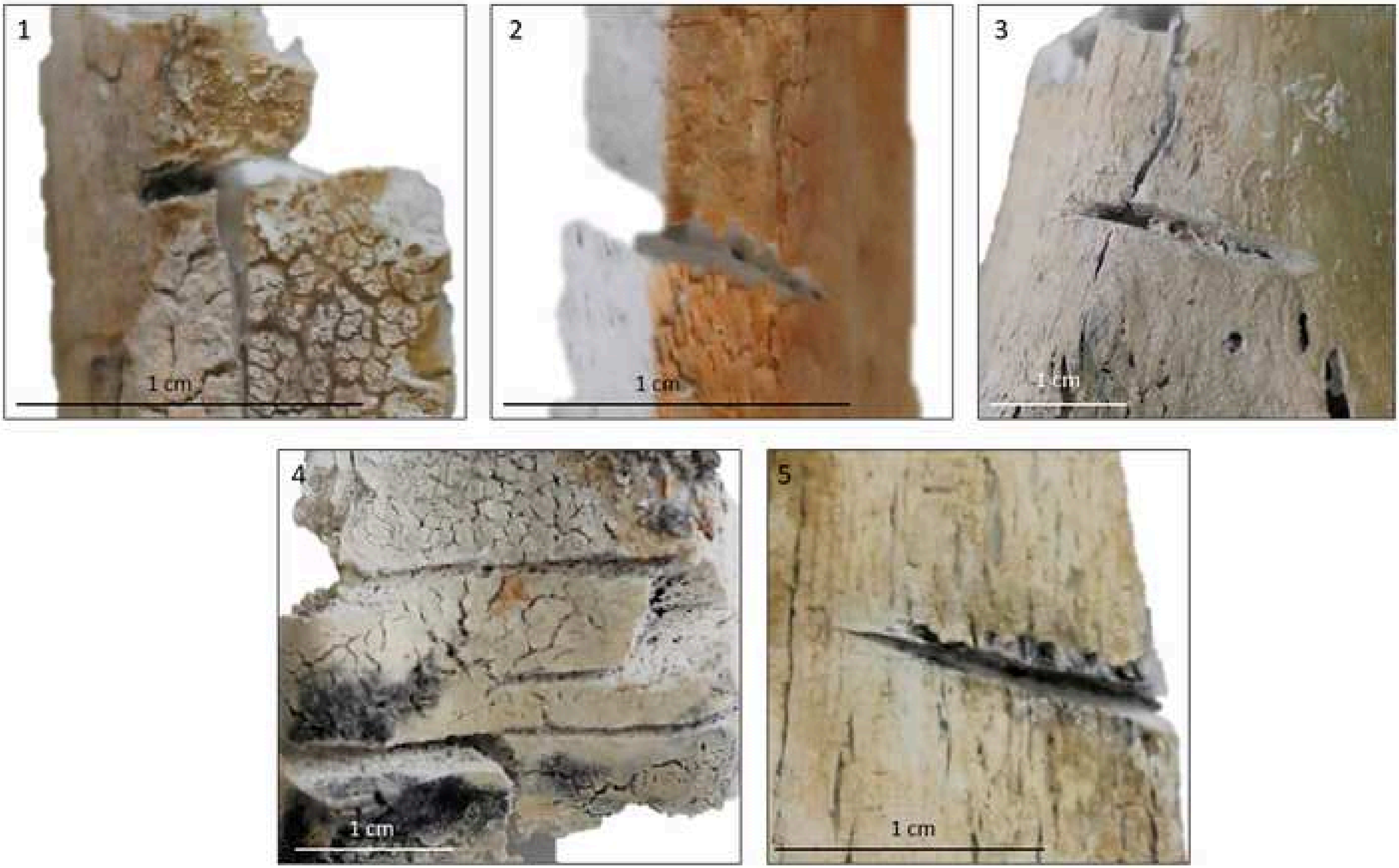


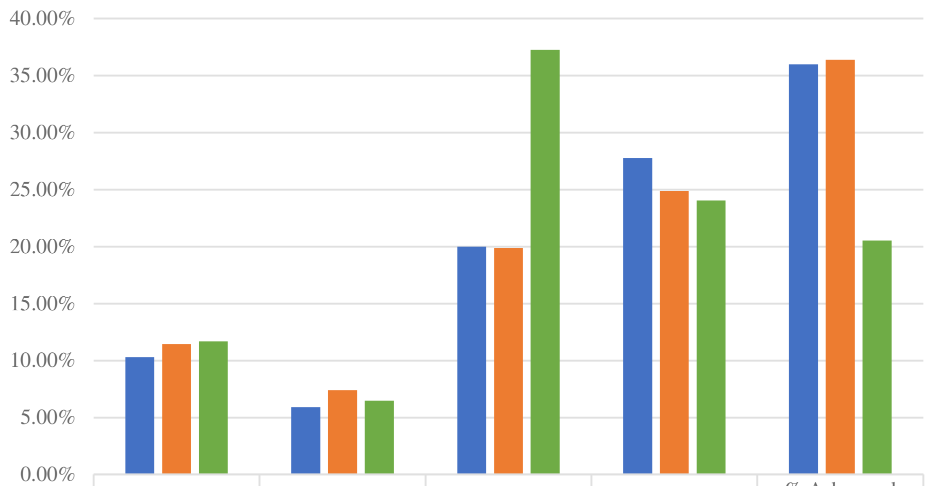
Figure 5 – Trauma inflicted with serrated knife before (left) and after cremation (right), on right knee of individual 1. The arrow points to a radiating line

Figure 6 – Trauma inflicted with serrated knife before (left) and after cremation (right), on right foot of individual 1. The arrow points to a complete cut mark

Figure 7 – Trauma inflicted with machete before (left) and after cremation (right) on the left femur of individual 3

Figures 8 and 9

Figure 8 – Completeness and survival of regions comparison **(Graph)**



	% Head	% Trunk	% Limbs	% No ID	% Ashes and dust
1	10.31%	5.92%	20.00%	27.76%	36.00%
2	11.46%	7.41%	19.85%	24.87%	36.40%
3	11.69%	6.47%	37.26%	24.05%	20.52%

Head: Cranium + Mandible; Trunk: Vertebral column + Ribs + Sternum + Girdles; Limbs: Upper + Lower + Hand + Feet; No ID: Spongy + Small (≤ 2mm) + Unidentified.

Figure 9 – Post-burning survival of pre-burning sharp force trauma by anatomical region **(Graph)**

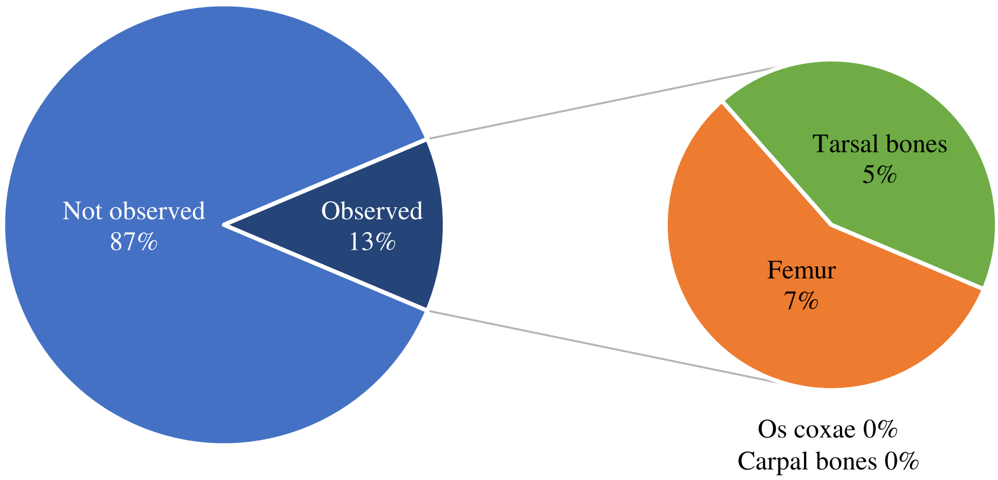


Figure 10 – Heat-induced fractures found during the anthropological analysis

Table 1 – Population data obtained during the exhumation

Code	Sex	Age	Cause of death	Preservation techniques	Coffin	Covering
1 (N50)	♂	60-80	Cardiorespiratory failure	Embalmed	Zinc	Plastic shroud
2 (N91)	♂	60-80	Cardiorespiratory failure	Embalmed	Zinc	Plastic shroud
3 (N92)	♂	45	Cardiorespiratory failure	Embalmed	Zinc	Plastic shroud

Table 2 – Induced sharp force trauma (Number of blows)

Tool	Anatomical region	Affected Bone/s	1	2	3
Machete	Thigh (L)	Femur	5	5	5
	Pelvis (L)	Os coxae	5	5	5
Serrated knife	Thigh & knee (R)	Femur & Patella	5	5	0
	Ankle (R & L) *	Tarsals	5	5	0
	Wrist (L)	Carpals	5	0	0

R. Right; L: Left; *: Right ankle in individual 1 and left ankle in individual 2.

Table 3 – Anatomical exploration

Code	Cadaveric preservation				Trauma or pathologies
	Pelvis	Thigh & Knee	Ankle	Wrist	
1	Saponification	Saponification	Saponification	Saponification	Autopsy – Ribs and sternum
2	Skeletonization with wet putrid matter	Saponification	Saponification	Skeletonization with wet putrid matter	Not observed
3	Skeletonization with wet putrid matter	Skeletonization with wet putrid matter	Skeletonization with wet putrid matter	Skeletonization with wet putrid matter	Autopsy – Ribs and sternum

Table 4 – Observations made during the burning process (Individual 1)

Min	ºC	Process	Observations
1	363	Start of the burning process	The furnace still conserves residual heat from previous processes.
17	584	The coffin lid is destroyed	The fire engulfs the body.
35	634	The state of the body is monitored	The top and walls of the coffin are destroyed, and the cadaver is on fire.
50	716	Temperature rise	The fat and organic matter function as natural fuel.
56	735	Maximum temperature achieved	Soft tissue and embalming liquid function as fuel.
61	637	The state of the body is observed	Remnants of organic matter are still present (Annex 1).
67	682	Management of the remains with the metal picker	Intentional fragmentation of the skeletal remains.
77	443	The state of the remains is observed	The organic matter is consumed.
85	363	End of burning process	The skeletal remains are fragmented and calcined, but most can be recognized and identified (Figure 3 #1).

Table 5 – Observations made during the burning process (Individual 2)

Min	ºC	Process	Observations
1	336	Start of the burning process	The furnace still conserves residual heat from previous processes.
6	419	Temperature rise	The calorific capacity of the coffin increases the temperature.
9	468	The coffin lid is destroyed	The fire engulfs the body.
11	524	Temperature rise	Further wood and fat combustion increase the temperature.
38	690	The state of the body is monitored, and the remains stirred	Remnants of organic matter are still present (Annex 2).
43	720	Maximum temperature achieved	Soft tissue and embalming liquid function as fuel.
48	713	Temperature drop	The consumption of organic matter decreases the temperature.
63	670	The state of the cadaver is observed, and the remains stirred	The organic matter is consumed. Intentional fragmentation of the skeletal remains.
83	400	End of burning process	The skeletal remains are highly fragmented and calcined, mixed with ashes from wood and bone, but there are fragments can be recognized and identified (Figure 3 #2).

Table 6 – Observations made during the burning process (Individual 3)

Min	ºC	Process	Observations
1	196	Start of the burning process	The furnace is heating up.
6	454	Temperature stabilizes and starts to rise	The calorific capacity of the coffin increases the temperature.
11	484	The coffin lid is destroyed	The fire engulfs the body.
15	521	Temperature rises	Wood and organic matter combustion increase the temperature.
38	617	Cranium is consumed	The neurocranium is intact.
52	649	Maximum temperature achieved	Putrid matter and embalming liquid function as fuel.
65	611	The state of the cadaver is monitored	Remnants of organic matter are still present.
75	592	The state of the cadaver is monitored, and the remains stirred	The organic matter is completely consumed. The cranium fragments after the stirring (Annex 3).
86	400	End of burning process	The skeletal remains are less fragmented, and better preserved than 1 and 2. Identification is feasible (Figure 3 #3).

Table 7 – Completeness and survival of regions (g)

Code	Head	Trunk	Limbs	No ID	Ashes and dust	Total skeletal remains	Total
1	263	151	510	708	918	932	2550
2	340	220	589	738	1080	1167	2967
3	361	200	1151	743	634	1735	3089

Head: Cranium + Mandible; Trunk: Vertebral column + Ribs + Sternum + Girdles; Limbs: Upper + Lower + Hand + Feet; No ID: Spongy + Small (≤ 2mm) + Unidentified.

Table 8 – Induced injuries vs observed toolmarks

Tool	Bone	SFT	1	2	3	SUM	I	T	SUMT
Machete	**Femur**	**Induced**	5	5	5	15	0.03	0.02	0.13
		Observed	0	0	**1**	1			
	Os coxae	**Induced**	5	5	5	15		0	
		Observed	0	0	0	0			
Serrated knife	**Femur**	**Induced**	5	5	0	10	0.24	0.05	
		Observed	**2**	**1**	0	3			
	Tarsals*	**Induced**	5	5	0	10		0.05	
		Observed	**3**	0	0	3			
	Carpals	**Induced**	5	0	0	5		0	
		Observed	0	0	0	0			

Induced: Pre-burning induced injuries; Observed: Post-burning observed toolmarks; *: All observed toolmarks were on the talus; I: Ratio of observed toolmarks regarding to the implement; T: Ratio of observed toolmarks regarding to the total; SUMT: Sum ratio of observed toolmarks regarding to the total of inflicted injuries (N=55).

Annex 1 – Individual 1 during the burning process at 35 minutes

Annex 2 – Individual 2 during the burning process at 38 minutes

Click here to access/download
Supplementary Material
Annex 2.jpg

Annex 3 – Individual 3 during the burning process at 75 minutes

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Supplementary Material

Annex 3.jpg

Annex 4 – Sharp force trauma from individuals 1, 2 and 3 all shown in anatomical position. Red arrow points at the observed

Annex 5 – Weight of anatomical regions (g)