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Cut or Burnt? – Categorizing morphological characteristics of heat-induced fractures and sharp force trauma

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Author declaration of interest

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ABSTRACT

Distinguishing trauma from heat-induced fractures is a challenge faced by forensic anthropologists and pathologists during medicolegal investigations in which fire has been used by the perpetrators to destroy evidence. This paper aims to validate the provided identification features to distinguish between fire induced alterations and sharp force trauma.

A total of 80 cremated adult individuals were used in this paper: 3 recently deceased embalmed cadavers from Cementerio Sur de Madrid for the sharp force trauma experiment in which 55 pre-burning injuries were inflicted using a machete and a serrated knife in different anatomical regions. And 77 cremated individuals from the Forensic Anthropology and Odontology Laboratory osteological collection. Five cremated long bones from this collection were selected, and 10 cuts were manually inflicted using a serrated knife to analyse post-burning trauma. Heat-induced changes and trauma morphologic characteristics were thus documented and analysed. The examination and documentation of morphological traits enabled the production of a heat-induced changes visual guide and a flow-chart. Two intraclass correlation tests were performed to validate the capacity of the observer to distinguish between fire related alterations and toolmarks.

The results obtained in the statistical analysis indicate that, even if the toolmarks are visible and recognizable upon macroscopic observation by the observers, some features, such as the *step* and the *transverse* fractures can be mistaken with inflicted trauma. The use of the proposed features coupled with careful anthropological examination is recommended and has been found functional for participants with no prior knowledge in the analysis of cremated remains.

Highlights

- The different macroscopical features between heat-induced changes and inflicted toolmarks were recognized (ICC= 0.945).
- Participants with no prior knowledge of analysis of cremated remains obtained a mean of 86% correct answers.
- *Step* fracture and the axial plane of a complete *transverse* fracture can be confused with pre-burning induced toolmarks.

Keywords

Cremation, heat induced fractures, pre-burning trauma, forensic anthropology, human cremated remains, cutting trauma, chopping trauma

1. Introduction

Fire can be considered a taphonomic agent that destroys and severely modifies osseous remains, providing certain limitations and challenges during the anthropological examination. In cases of burnt bodies, one of the main tasks of the forensic anthropologist is to distinguish whether the fractures present are caused by thermal alteration or trauma, because this distinction is fundamental to interpret the circumstances surrounding death and deposition. Burning is more commonplace as the funerary rite of cremation and as result from accidents, rather than as a result of violent deaths in homicide cases [1,2]. Nevertheless, due to the number of fire scenes in police and humanitarian investigations [3–5], it is becoming increasingly necessary to perform a comprehensive anthropological study to identify thermally induced fractures from other types of trauma.

In recent years, many studies have investigated the skeletal modifications caused by exposure to high temperatures, some using direct observation of complete individuals at a crematorium [6]. All of these experiments have sought to improve techniques for analysing cremated bone, focusing on their biological profile [7,8], mass [9–13], pre-combustion state [14–16], microscopic changes [17–20], and fire's temperature [21–24]. This advancement in methodology [1,25] has made it possible to refine protocols, so that they can be used in court in accordance with the recommendations following Daubert v. Merrell Dow Pharmaceuticals, Inc [26,27].

Physical and forensic anthropologists have studied heat-induced modifications for decades in both human and non-human bone [1,2,6,19,25,28-34]. One of the most widely accepted system of classification and definitions used by biological anthropologists is summarized in Symes *et al*. [32] who define the seven characteristic types of thermal fractures: *longitudinal, transverse, curvilinear, step, patina, splintering/delamination* and *burn line*. Even though the definitions are straight-forward and detailed, some descriptions are slightly difficult to apply when identifying deformed, fragmented, and broken burnt bone.

It has been demonstrated in previous studies that pre-cremation sharp force trauma is visible and identifiable after burning [35-46]. Experimental studies have been carried out in controlled environments using funeral pyres and muffle furnaces, in which non-human remains were used as proxy [35–37,39–45]. Pope and Smith [38] stated that toolmarks could not be replicated in calcined bone, as burning makes the bone brittle and the pressure of the inflicted trauma compacts it, making the post-burning trauma easily recognizable. While obvious and well-accepted, no studies have been done to test the accuracy of this fact.

Despite recent advancements in methodology, a simple protocol to distinguish heat-induced changes from trauma to facilitate the interpretation may be beneficial. This could be particularly helpful in cases where calcined remains are highly fragmented and warped [36,37]. Therefore, this paper is provides some comprehensible and simple visual guidelines and a flow-chart that strengthens the definitions described in Symes *et al.* [32]. Definitions for *warping* [30,34], and pre-burning and post-burning cut and chop trauma [47–50] were also added. The main objective is that both students and professionals may be able to properly differentiate between thermally induced changes and pre-burning trauma using the proposed features, and to analyse the difficulties that arise during the identification, to minimise and avoid future mistakes.

2. Materials and Methods

2.1. Materials

The materials used in this paper were from two different data sets: 77 cremated adult individuals from the Forensic Anthropology and Odontology Laboratory osteological collection, and 3 recently deceased embalmed individuals from Cementerio Sur de Madrid.

A total of 77 cremated adult individuals, from the archaeological sites of *Checa*, *Alcubillas* and *Cerro de las Cabezas,* in Castilla-La Mancha, Spain (8^{th}-2^{nd} BC) belonging to the Forensic Anthropology and Odontology Laboratory osteological collection were first employed to examine heat-induced modifications in all anatomical regions. This first data set of archaeological material was chosen because the remains were not mechanically fractured prior or after the funerary rite of cremation and the bodies were burnt fleshed. This is known through documentation, written sources, and other historical and archaeological information for this period. [51].

Modern cremated remains of three recently deceased embalmed individuals donated to the Laboratory of Forensic Anthropology and Odontology through the Funerary Services of the Autonomous Region of Madrid, Spain with prior authorization from the families were used for the sharp force trauma experiment. All individuals were adult males. The specific age was unknown for two individuals -1 and 2- but through anthropological examination the age was estimated as old adult. The remaining individual's known age-at-death was 45 years.

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).

2.2. Pre-burning trauma

The tools selected to induce the pre-burning trauma were a kitchen machete to inflict chopping trauma, and a serrated knife to inflict cutting trauma [48]. These devices were chosen for being affordable objects frequently used in Spanish forensic casework where the victim was dismembered.

A total of 55 pre-burning injuries were manually inflicted in the Exploration Room from Cementerio Sur; 30 chops of varying sizes and depths with the machete on the left thigh and on the ilium crest of the three individuals, and 25 cuts perpendicular to the main axis with the serrated knife in the right tight and knee of the three individuals, on the left ankle of individuals 1 and 2, and on the left wrist of Individual 1. The cutting trauma in the articular regions was done by extending the foot or hand exposing its anterior part and slashing transversally five times. The cuts were of varying depths, as the purpose was to affect the bone but prevent amputation. The anatomical regions were selected to simulate an attempted dismemberment of the lower limb and hand through articular regions and through the separation of long bones diaphysis.

The anatomical regions, bones affected, and number of blows per area are summarized in Table 1.

Once the pre-burning trauma had been properly documented through photographs that evidenced the injuries and the exact location on the unburnt cadaver, the bodies were placed individually in a furnace at Madrid's Cementerio Sur for 85 minutes (±1.5 SD). The temperatures and duration of the burning process was monitored and documented every 5-15 minutes, further information of the exact temperature and duration is detailed in Table 2.

After the cremation process, the remains were collected in three separated bags labelled as Individual 1, Individual 2 and Individual 3, and transferred to the Forensic Anthropology and Odontology Laboratory, were the anthropological analysis for each individual was performed and the skeletal fragments sorted by anatomical region. The bone fragments containing toolmarks were separated and assessed based on the morphological traits described in Table 3.

2.3. Post-burning trauma

Five cremated long bones from the Forensic Anthropology and Odontology Laboratory osteological collection were selected: one femur, two radius, one humerus and one fibula from three adult individuals. Post-burning trauma was inflicted using only the serrated knife due to the fact that cremated bone is brittle and fragile, and chop marks would fragment it completely when the pressure of the trauma compacts it [38], whereas transversal cut marks in long bone diaphysis could prove more challenging during the identification. Thus, the previously selected five cremated long bones were subjected to 10 post-burning complete transversal cuts.

2.4. Features analysis

All heat induced modifications from a total of 80 individuals (3 recently deceased embalmed individuals from Cementerio Sur de Madrid and 77 cremated adult individuals from the Forensic Anthropology and Odontology Laboratory osteological collection) were documented following Symes *et al* definitions of 7 heat-induced fractures: *longitudinal, transverse, curvilinear, step, patina, splintering/delamination* and *burn line* [32] including *warping* [14].These were photographed and analysed both in macroscopic view and with a magnifying glass.

The examination and documentation of morphological features enabled the production of a thermally induced changes visual guide based on the descriptions detailed in Symes *et al*. [32] and expanded based on existing literature and the first author's (PM) observations during the anthropological analysis of the 80 individuals (Table 4) along with the traits detailed in Table 3. Identifiable features and macroscopic characteristics were selected to create the flow-chart (Graph 1). These guidelines were given to the participants prior to the validation tests.

2.5. Validation tests

Two interobserver error tests were performed with the software SPSS, version 25.0, using the intraclass correlation index statistic (ICC), two-way mixed with 95% confidence interval [52]. The first test was done using only heat-induced fractures (*longitudinal, transverse, curvilinear, step, patina,* and *splintering/delamination*), and the second by adding heat-induced changes (*burn line* and *warping)*, and induced trauma (*pre-burning trauma* and *post-burning trauma)*. The tests consisted in recognizing if the bone or bone fragment displayed in the picture presented a trauma or a heat related modification and identifying which was it using the visual guide and the flow-chart. 30 pictures were analysed in total, 15 for each test. The photographs were high quality and each one occupied one A4 page with the specific part of the bone to be classified highlighted using a red arrow or a red circle. The considered "correct result/answer" was decided between the authors (PM, MB, CV). Both tests were performed in three population types: A: professionals with prior experience of forensic anthropology (N=2), B: students with knowledge of anthropology, archaeology or anatomy (N=2), and C: participants with no prior knowledge (N=2). The tests were done in separated days.

The first test' aim was to analyse difficulties with the identification of heat-induced fractures, and if these complications could affect the ability to recognize them from trauma. The main objective of both tests was to evaluate the capacity of the observer to distinguish between fire related alterations and inflicted injuries, and if this identification process is comprehensible enough that participants of group B and group C with no prior knowledge in the analysis of burnt human remains can obtain successful results. Hence, validating the morphological features and characteristics proposed in this paper. Whether they were successful or not was determined using the following guide:

- <70% of correct answers was considered "poor"
- Between 70-80% was considered "acceptable"
- Between 80-90% including 80% was considered "good"
- >90% including 90% was considered "excellent"

3. Results

The intraclass correlation results and the participants answers are detailed in Table 5. Figures 1-4 illustrate the pictures chosen for both tests. Consideration must be taken that the size of the photographs has been reduced to fit the paper. Pictures are mentioned throughout the text as #Number ^{test}; Test 1 is labelled as α and Test 2 as β.

3.1. Test 1 – Heat-Induced Fractures

3.1.1. Group A

Professionals with prior experience of forensic anthropology obtained 73% correct answers each in the first test, four wrong answers out of 15 pictures, obtaining a "good" result. The most recurrent error was made in picture #4$^{\alpha}$ where the participants were required to recognize the fracture in a cranial fragment as *delamination,* but it was identified as a *patina* fracture.

3.1.2. Group B

The students with knowledge of anthropology or related sciences, such as anatomy or bio archaeology, scored a result of 100% (participant 3) and 93% (participant 4) correct answers, obtaining an "excellent" result. Participant 4 labelled as *step* the *delamination* fracture from picture #4$^{\alpha}$.

3.1.3. Group C

The observers with no prior knowledge of forensic anthropology, or related sciences, scored a result of 80% (participant 5) and 87% (participant 6) correct answers, obtaining a "good" result. In total, two pictures which exhibited a *step* fracture (#11$^{\alpha}$) and a *curved-transverse* fracture (#13$^{\alpha}$) were confused with a *transversal* fracture.

The first statistical analysis showed a positive result of 0.975. Group B and C had a higher rate of correct responses than Group A. The most frequent misclassification was found in picture #4$^{\alpha}$.

3.2. Test 2 – Heat-induced changes and inflicted trauma

3.2.1. Group A

Professionals with prior experience analysing trauma in skeletal remains scored a result of 80% (participant 1) and 93% (participant 2) correct answers in the second test, obtaining a “good” and an a “excellent” result. None of the mistakes committed were shared. It was noted that participant 1 left unanswered picture #11$^{\beta}$. The only mistake committed by participant 2 was in picture #3$^{\beta}$ were a cranium fragment exhibited *warping* and it was identified as *delamination.*

3.2.2. Group B

Students with knowledge of anthropology scored a result of 87% (participant 3) and 93% (participant 4) correct answers in the second test, obtaining a “good” and an a “excellent” result. None of the mistakes committed were common within the two participants. Participant 3 misidentified as *pre-burning trauma* picture #14$^{\beta}$ which depicted a *transverse* fracture, and it left unanswered picture #11$^{\beta}$. Participant 4 labelled as *step* the *curved-transverse* fracture shown in picture #12$^{\beta}$.

3.2.3. Group C

Observers with no prior knowledge of anthropology and trauma analysis in skeletal remains scored a result of 80% (participant 5) and 67% (participant 6) correct answers, obtaining a “good” and an a “poor” result. Great disparity was found between the participants. The most frequent mistakes were in picture #11$^{\beta}$ and picture #12$^{\beta}$. Picture #11$^{\beta}$, a *post-cremation* trauma fracture present in a radius diaphysis, was identified as a *pre-burning trauma* by the two observers. Picture #12$^{\beta}$ was labelled as *patina* and *step*.

The second statistical analysis showed positive result of 0.945. In this test, Group A obtained the highest score, but it is worth mentioning that participant 5 only committed three errors. The most recurrent misclassifications were found in pictures #10$^{\beta}$, #11$^{\beta}$, #12$^{\beta}$ and #14$^{\beta}$.

The following graph (Graph2) shows the percentage of correct answers obtained by the participants in each test.

4. Discussion

4.1. Thermally induced changes

These results further prove that thermal damage can be recognized, and the use of a visual guideline and flow-chart enables an easier and simplified process since the definitions are supplemented by photographs and short definitions. Heat-induced fractures are very recognizable in macroscopic view and the definition self-explanatory, but the difficulty increases when the bone is merely a small fragment or if it shows more than one thermal change. The importance of correctly recognizing heat induced fractures from each other is of forensic and bioanthropological importance, since fractured, warped, and calcined remains may be confused with trauma if they are not correctly identified as thermal changes.

Overall, the most significant errors found in Test 1 concern picture #4$^{\alpha}$ in which the participants were required to identify a *delamination* fracture in a cranial fragment. However, the bone fragment also presented a *patina* fracture on top and three participants labelled it as such. Both responses were correct, but the answer "*delamination*" was considered the only valid option because the red arrow was pointing towards that fracture. The other example (#6$^{\beta}$) had an "excellent" rate of correct responses (100%), ruling out the possibility that this fracture entails any complications in identification.

The *curved-transverse* fracture from image #12$^{\beta}$ in Test 2 was classified as *step* fracture by three participants. *Step* fracture is defined as "*an incomplete fracture that does not divide the bone […], irregular, transverse rupture lines […]"* (Full description can be found in Table 4 [32]) whereas *curved-transverse* as "*[…] concentric rings […] rounded edge."* [32]. Picture #12$^{\beta}$ illustrates a femur diaphysis fragment (4.5 cm) which shows a clear rounded edge, but also "irregular, transverse and somewhat curved" lines. While *step* fractures are indeed not completely straight, in this bone fragment is difficult to ascertain whether the fracture shown is clearly curved or only barely, and the distinction between both proves challenging.

However, the same bone fragment but before the cleaning process was used in Test 1 (#15$^{\alpha}$) and five out of six participants labelled as *curved-transverse.* It is possible that the cleaning of the fragment exposed hidden features and more heat-induced fractures, making more difficult the distinction. All other *curved-transverse* fractures were correctly classified in a ratio between 0 and 1 mistakes, discarding the possibility that the identification of this fracture is challenging.

It is interesting that *step* was used to label very different fractures: *delamination* fracture from picture #4$^{\alpha}$, *patina* fracture from pictures #6$^{\alpha}$, #9$^{\beta}$ and #15$^{\beta}$, and *curved-transverse* fracture from picture #12$^{\beta}$. *Patina* is defined as "*superficial mosaic-like pattern"* [32] and "*fine cracks on the exterior of the bone"* [28] (Full features provided in Graph 1), the definition is straight-forward and pictures depicting this fracture were correctly classified in a ratio between 0 and 2 mistakes, rejecting that *patina* classification entails complication.

Positive statistical results were achieved in the first test (ICC= 0.975), which demonstrates that the identification of heat-induced fractures is possible by using these well-known classification [35] and definitions [32] accompanied by images and a flow-chart. When the results are analysed by groups Group A had the lowest score of correct answers (73%). A possible explanation for this could be that those who specialize in skeletal remains, but not necessarily on cremated bone, trusted more their own knowledge about complete and incomplete fractures rather than the visual guide. On the contrary, Group B (100% and 93%) were familiar with skeletal remains, but not enough to trust their own judgment regarding cremated bones. Therefore, they may have used the proposed guidelines more frequently to clear any doubt that might have arisen during the test. Group C was the group most prone to error. Still, the participants achieved a "good" rate of correct responses (80% and 87%) and it can be further concluded that heat-induced fractures are recognizable even for individuals not familiar with the analysis of cremated remains.

4.2 Inflicted trauma

The statistical results obtained in the second test (ICC= 0.945) prove that heat-induced changes can be distinguished from cutting trauma. This concludes that the guidelines set in this paper can be used as a potential tool to aid the anthropological analysis of burned human remains. The ability of recognizing inflicted trauma in burnt bones using a blind test was demonstrated by previous authors [35,37] and these results expand and confirm their findings.

The most significant errors found in this test were regarding the sharp injuries in three pictures, wherein the participants classified as *pre-burning trauma* a *step* fracture in a femur diaphysis fragment (#10$^{\beta}$), a *post-burning trauma* fracture in a radius diaphysis fragment (#11$^{\beta}$), and a *transverse* fracture in a humerus diaphysis fragment (#14$^{\beta}$).

The results show that *step* fractures can be confused with inflicted trauma as seen in image #10$^{\beta}$, where two participants from Group C did not recognize the heat-induced fracture and classified it as *pre-burning trauma.* In cases where the burned bone is a small fragment, some confusion can arise, as stated previously by de Gruchy and Rogers [37]; who indicate that success in the analysis depends on the size and condition of the burned remains. The bone is 3.75 cm, small-sized and fragmented. In such instances and in doubt, a more thorough analysis using magnifying glass to verify the following characteristics is recommended:

- Whether the fracture is transversal to the longitudinal axis of the bone, or it does not have a specific orientation
- Whether the fracture is slightly curved towards the middle of the bone or if it is completely straight (only applied in cut and chop marks, not punctures or incisions [47–50]).

In case of any additional confusion, it is recommended also to verify if the trauma has fracture lines that originate from the dissipation of force and to complement this with other peri-mortem features, which have been documented on fresh bone [53–56], and also on burnt bone [46]. However, these features vary depending on the condition and fragmentation of the remains and might not be visible in all occasions [36,37].

This outcome might be further explained by analysing the heat-induced fracture results. The *step* fracture has been proven problematic, it has been misclassified 4 times and confused with other fractures 6 times. There seem to be a lack of understanding from the participants of what a *step* fracture is and, therefore, was prone to error. The different definitions proposed and summarized by different authors [28,32,35] all agree that *step* or *straight transverse* is often associated with *longitudinal* fractures, are perpendicular to the main axis of the bone and fracture the shaft transversely. While Herrmann and Bennet [35] includes both *transverse* and *step* fractures in the same category of "straight transverse", Symes *et al.* [32] differentiate them by associating the second to *longitudinal* fractures. This fracture was clearly identifiable in well-preserved bones (#9$^{\alpha}$, #11$^{\alpha}$ and #13$^{\beta}$) with a ratio of 0 to 2 mistakes. However, the identification is challenging for broken and small remains were the *longitudinal* fracture cannot be seen due to the state of the fragment, and doubts and misclassifications arise. Due to this, it has been found in this experiment that the *step* fracture is susceptible to be mistaken with the inflicted trauma, and other types of heat-induced fractures can be confused with *step* in broken and fragmented remains.

There was also slight confusion during the identification of the *post-burning* fracture (#11$^{\beta}$). It was labelled as "unidentified" by two participants out of six, though, both observers from Group C categorized it correctly. The proposed definition *"irregular, splintered […]"* was difficult to apply in the given picture, since the texture could not be assessed, hence the "unidentified" but it was not confused with other burn damage or trauma. The morphological characteristics observed in this experiment were somewhat similar to post-mortem trauma in unburned bone, with brittle and splintered appearance [53,54] and no room for mistake with *pre-burning* complete transversal trauma which is *"straight, sharp and smooth […]"*. As stated by previous authors [32,38], it has been again proved that *post-burning trauma*, even the axial plane of the cut, cannot be confused and is recognizable in macroscopic view. However, further research needs to be done to provide with more morphological features which do not relay only in examining the texture.

The *transverse* heat-induced fracture from a humerus diaphysis presented in image #14$^{\beta}$ was misclassified by two observants: participant 3 as *pre-cremation trauma* and participant 6 as *post-burning trauma.* The image showed the axial plane of a complete *transverse* fracture. These results prove that well-preserved transversally fractured fragments could resemble the plane of the cut if it is somewhat flat. Cremated remains are fragile and brittle, and it is not unlikely that they may crumble into smaller pieces or splinter, masking main identification features, such as the texture and striation marks [37,39,42], and causing them to be missed. The heating and cooling of the bone causes structural failure during the burning process leading to thermal damage and, frequently, *transverse* fractures [18,19,32], whereas when the inflicted trauma on the diaphysis leads to a complete separation of bone, the fire effects all regions equally from the beginning of the process. And if the diaphysis is cut after burning, the interior of the bone has not been burnt at the same temperature as the exterior. This variation in the burning process leads to unique quantitative morphological features.

It is convenient to add that the same humerus from image #14$^{\beta}$ was also shown in image #1$^{\beta}$ but in a different orientation and, in this instance, it was classified as a *transverse* fracture by all observers, except participant 10 who categorized it as *post-burning fracture* as well. From these results, it is concluded that while the axial plane can cause doubts during identification, a detailed study of the morphological characteristics present on the plane surface using either a magnifying glass or a microscope should suffice to provide a proper identification.

Pre-burning trauma shown in other images (#4$^{\beta}$ and #7$^{\beta}$) was correctly identified by all observants, because they display these widely described morphological characteristics described for cut and chop marks in burnt bone: the V-shape [37,41,45], uniform linear cut [40] and sharp visible edges [44], as well as in literature regarding unburnt bone [47–50]. The results of this experiment further confirm that pre-cremation toolmarks made with machete and serrated knife are recognizable from heat-induced alterations even when the fragments are small-sized.

The results are as expected, Group A and Group B are participants familiar with the analysis of skeletal remains and "good" and "excellent" rate of responses was obtained. In Group C, there was more disparity between the participants. The findings obtained in this paper are consistent with the literature; induced toolmarks, pre and post burning, are recognizable using only macroscopic identifiable features. However, it is essential that more thorough analysis is undertaken to aid with the identification of fractures which can be prone to confusion, since heat-induced fractures were mistaken with inflicted injuries five times in Test 2, but not the other way around; the toolmarks evaluated in the present paper were recognized correctly by the participants. Therefore, special attention should be made to the correct classification of thermally induced changes.

5. Conclusions

The definitions and defining features were taken from the existing literature and expanded based on the first author's (PM) observations. It is advised to increase the sample size in further experiments to improve the descriptions and add more types of trauma. The degree of preservation of the body and unknown preexisting pathological conditions, such as osteoporosis, as well as the remnants of embalming liquid during the cremation process could have affected the results, and if these variables change, the results may be different. Further experimentation using partially burned and charred bones is encouraged to evaluate the proposed morphological features.

All morphological changes resulting from inflicted trauma as well as heat-induced fractures were well recognized, and the intraclass correlation tests were positive (ICC= 0.975 and 0.945). A majority of "excellent" scores were achieved, followed by a "good" score (Graph 2).

Nevertheless, complications do arise during the identification process. It was hinted that other types of heat-induced fractures can be mistaken with *step* fracture because either the description is insufficient, or the fragmented condition of the remains makes the identification challenging. The results show that *step* and the axial plane of a *transverse* heat-induced fracture could be problematic as they can be confused with inflicted trauma. Observants misclassified burn fractures with inflicted injuries in five cases, but not the other way round. Therefore, special attention is recommended when analysing heat-induced changes, particularly in small and fragmented remains, since these errors can be minimized and even avoided if the distinctive features are thoroughly examined.

Regarding trauma, results are consistent with the findings of other authors (see Table 3). The cuts and chop marks were visible and recognizable in macroscopic view after the burning process, even when the whole cadaver has been cremated. All the identifying features such as the characteristic V-shape and sharp edges were preserved. For pre-burning inflicted injuries no errors were found in their identification. It further proves that they are recognizable and easily identified, even for students and participants with no prior knowledge of analysing trauma in cremated remains. Moreover, complete transversal cuts made in a bone after the cremation process presented features which were easily identifiable, albeit prone to mistake if the texture cannot be assessed, such in cases of extreme fragmentation or when the assessment has to be done without manipulating the remains. Nonetheless, the results agree with previous authors' observations. This study concludes that good working knowledge of thermally induced changes is necessary in the forensic analysis of skeletal remains in which the use of a cutting device is suspected, because it was observed that participants which previous experience did not commit misclassifications in the three pictures which depicted trauma.

Thus, it has been demonstrated that the macroscopic differentiation is feasible using a simple visual guide and flow-chart, but it is still indispensable to be familiar with heat-induced taphonomic changes as to avoid potential mistakes. The outcome of this paper supports the conclusion that macroscopic differentiation between thermal damage and cut and chop marks is achievable, and that the visual guideline and flow-chart proposed are easy to understand and to use, even without having specific knowledge in forensic anthropology. The suggested features are functional for students and can be useful in research, confirmed by the fact that participants from Group B and C obtained a mean of 86% correct answers in both tests.

Using all tools available to aid the identification of the morphological characteristics is advisable when examining cremated human remains.

The validation of the identification of thermally induced changes and cutting and chopping trauma morphological features proposed in this paper yields positive results (ICC = >0.9). Additional research should be done in this area to add more identifying characteristics as well as an assessment of the post-burning survival and detection of sharp force trauma injuries, findings relevant to the forensic and the bioanthropological field.

6. Legends to Tables

Table 1: Pre-burning induced trauma (Number of blows per bone)

Table 2: Temperatures and duration of burning process

Table 3: Pre-burning cut and chop mark characteristics described in the literature

Table 4: Pictorial guideline (Descriptions based on Symes *et al.* 2015 (32))

Table 5: Participants answers in both tests

7. Legends to Figures

Graph 1: Flow-chart

Graph 2: Test results comparison for each participant

Figure 3 - Pictures from Test 1 (1α -7α). 1α: Transverse; 2α: Transverse; 3α: Longitudinal; 4α: Delamination; 5α: Patina; 6α: Patina; 7α: Curved-transverse.

Figure 4 - Pictures from Test 1 (8α -15α). 8α: Curved-transverse; 9α (red): Step; 10α (white): Longitudinal; 11α (red): Step; 12α (white): Longitudinal; 13α: Curved-transverse; 14α: Transverse; 15α: Curved-transverse.

Figure 5 - Pictures from Test 2 (1β -7β). 1β: Transverse; 2β: Curved-transverse; 3β: Warping; 4β: Pre-burning trauma; 5β: Patina; 6β: Delamination; 7β: Pre-burning trauma.

Figure 6 - Pictures from Test 2 (8β -15β). 8β: Longitudinal; 9β: Patina; 10β: Step; 11β: Post-burning trauma; 12β: Curved-transverse; 13β: Step; 14β: Transverse; 15β: Patina.

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Table 1: Pre-burning induced trauma (Number of blows per bone)

Instrument	**Anatomical region**	**Affected Bone/s**	**Individual 1**	**Individual 2**	**Individual 3**
Machete	Pelvis	Os coxae	5	5	5
	Thigh	Femur	5	5	5
Serrated	Thigh and Knee	Femur	5	5	0
knife	Ankle	Talus	5	5	0

Wrist	Carpals	5	0	0

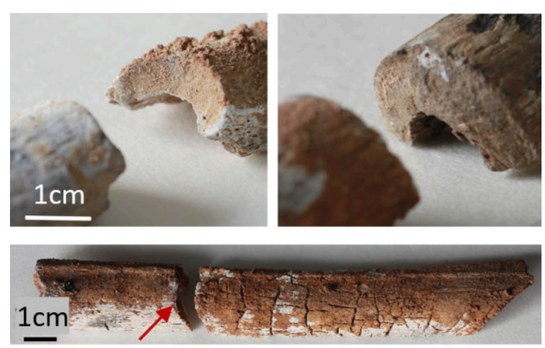
Table 2: Temperatures and duration of burning process

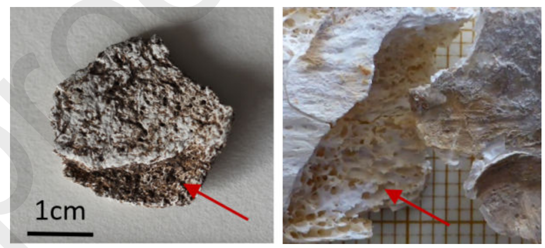
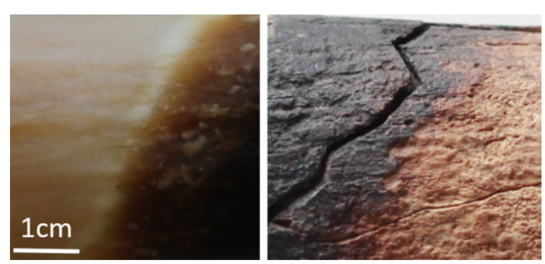
	Individual 1	Individual 2	Individual 3
Max (Cº)	735	720	649
Min (Cº)	363	336	196
Time (min)	85	83	86

Table 3: Pre-burning cut and chop mark characteristics described in the literature

Papers	Morphological features
Herrmann & Bennett (1999)	Sharp force incisions and edges are detectable. Heat-induced fractures spread through the deeper cuts.
De Grucky & Rogers (2002)	The sharp force cut marks produced by a knife create a characteristic V-shape.
Pope & Smith (2004)	Sharp force trauma may be detected in the form of uniform lines of varying depth.
Poppa *et al.* (2011)	The linear cut shape is maintained.
Kooi & Fairgrieve (2013)	Sharp force trauma after burning is characterized by a linear V-shaped cut.
Koch & Lambert (2017)	The sharp edges are preserved and visible.
Macoveciuc *et al.* (2017)	Sharp force trauma maintains the characteristic V-shape.

Table 4: Pictorial guideline (Descriptions based on Symes *et al.* 2015 (32))

	Type	Description	Examples
Heat-induced fractures	**1. Longitudinal** (32)	Fracture which follows the longest axis of the bone or is parallel to it. This occurs when the diaphysis is heated to the point that the proteins in the bone's matrix are denatured and the bone matrix shrinks. **Picture**: Humerus diaphysis	
	2. Step (32)	An incomplete fracture that does not divide the bone in two. These are irregular, transverse, rupture lines on the diaphysis which extend from the margin of the longitudinal fracture transversely across the bone shaft fracturing it at the intersection of another longitudinal fracture. **Pictures**: Long bones diaphysis: femur (L), radius (R)	
	3. Transverse (32)	Fractures perpendicular to the longitudinal axis of the bone which divide the haversian canals. These are common when the body goes into the pugilistic posture, because one area of the diaphysis is more exposed to the fire than the other, and the difference may lead to structural failure. **Picture**: Long bones diaphysis, femur (L), humerus (R), femur (down)	

	4. **Patina** (32)	Superficial mosaic-like pattern which looks like fine fissures and cracks on the bone, usually appearing in flat area exposed to a great deal of heat. Correlated with the incineration of protective tissue and contraction of the cortical bone. Very frequent in areas of spongy bone. **Picture**: Femoral head (L), ulna diaphysis (R)	
	5. **Delamination and splintering** (32)	Separation from the layers of cortical bone on compact bone, separation from the inner and outer tables of the cranium or exposure of spongy bone at the epiphysis. Present in all anatomical regions, but especially frequent on the cranium and spongy bone. **Picture**: Cranial fragment (L), sternum (R)	
	6. **Curved-Transverse or thumbnail** (32)	The most common curvilinear fractures are shaped like concentric rings which tend to appear in areas where there are muscles that shrink during cremation. The fracture line breaks and gives rise to a diaphysis with a rounded edge. More frequent in fresh bone (14). **Picture**: Radial diaphysis, acetabulum (R)	
Heat-induced changes	**7.** **Burn line** (32)	Symes *et al.* (2015) describe this fracture as a line which divides the burned bone in direct contact with the fire, heat source or fuel, from another area that was not burnt. **Picture**: Radial diaphysis (L), acetabulum (R)	

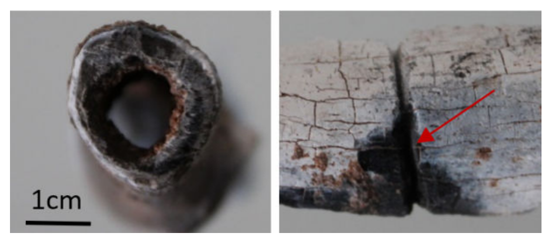
	8. Warping (14)	Severe, irregular change in the alignment of the bone which causes it to lose its usual shape, taking on a deformed appearance. More frequent but not limited to situations in which the cadaver was cremated fresh or with soft tissue (14). **Picture**: Radius	
Fractures induced by a sharp object	**9. Pre-burning induced trauma** (35-46)	Unlike the step fractures, cut marks are straight with sharp edges, they do not end at a longitudinal fracture, and there may be more than one cut in different directions, caused by false starts. It is linear, uniform and has a recognizable V-shaped morphology. The plane of the cut is straight (35-46). **Picture**: Tarsal bone, talus	
	10. Post-burning induced trauma (52, 53)	Cut marks induced after cremation have the same characteristics as post-mortem injuries; a very irregular, splintered cortical bone and, frequently, variation in colour on the interior of the diaphysis when compared with the exterior. **Picture**: Radial diaphysis (L), humerus diaphysis (R)	

Table 5: Participants answers in both tests

			Test 1				
N	**1**	**2**	**3**	**4**	**5**	**6**	**Result**
1	2	2	2	2	2	2	2
2	2	2	2	2	2	2	2
3	1	1	1	1	1	1	1
4	**5**	**5**	6	**4**	**5**	6	6
5	5	5	5	5	5	5	5
6	**2**	5	5	5	**4**	5	5
7	3	3	3	3	3	3	3
8	**2**	3	3	3	3	3	3
9	4	4	4	4	4	4	4
10	1	**2**	1	1	1	1	1
11	4	**6**	4	4	**2**	4	4
12	1	**2**	1	1	1	1	1
13	3	3	3	3	3	**2**	3
14	**3**	2	2	2	2	2	2
15	3	3	3	3	3	**6**	3
	73%	73%	100%	93%	80%	87%	
			84%				
			Test 2				
N	**1**	**2**	**3**	**4**	**5**	**6**	**Result**
1	2	2	2	2	2	**10**	2
2	3	3	3	3	3	3	3
3	8	**6**	8	8	8	8	8
4	9	9	9	9	9	9	9
5	5	5	5	5	5	5	5
6	6	6	6	6	6	6	6
7	9	9	9	9	9	9	9
8	1	1	1	1	1	1	1
9	5	5	5	5	5	**4**	5
10	4	4	4	4	**9**	**9**	4
11	**999**	10	**999**	10	10	10	10
12	**4**	3	3	**4**	**5**	**4**	3
13	4	4	4	4	4	4	4
14	2	2	**9**	2	2	**10**	2
15	**3**	5	5	5	**4**	5	5
	80%	93%	87%	93%	80%	67%	
			83%				

1: Longitudinal; **2**: Transverse; **3**: Curved; **4**: Step; **5**: Patina; **6**: Delamination/Splintering; **7**: Burn line; **8**: Warping; **9**: Pre-cremation trauma; **10**: Post-cremation trauma. **Group A**: Participants 1 and 2; **Group B**: Participants 3 and 4; **Group C**: Participants 5 and 6; Results: Correct answer; 999: Blank answer.

Highlights

- The different macroscopical features of heat-induced changes and inflicted toolmarks were recognized (ICC= 0.945).
- Participants with no prior knowledge of analysis of cremated remains obtained a mean of 86% correct answers.
- *Step* fracture and the axial plane of a complete *transverse* fracture can be confused with pre-burning induced toolmarks.