Assessment of skeletal changes after post-mortem exposure to fire as an indicator of decomposition stage

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Abstract

Forensic anthropologists are tasked with interpreting the sequence of events from death to the discovery of a body. Burned bone often evokes questions as to the timing of burning events. The purpose of this study was to assess the progression of thermal damage on bones with advancement in decomposition. Twenty-five pigs in various stages of decomposition (fresh, early, advanced, early & late skeletonisation) were exposed to fire for 30 minutes. The scored heat-related features on bone included colour change (unaltered, charred, calcined), brown and heat borders, heat lines, delineation, greasy bone, joint shielding, predictable and minimal cracking, delamination and heat-induced fractures. Colour changes were scored according to a ranked percentage scale (0 – 3) and the remaining traits as absent or present (0/1). Kappa statistics was used to evaluate intra- and inter-observer error. Transition analysis was used to formulate probability mass functions [$P(X=j|i)$] to predict decomposition stage from the scored features of thermal destruction. Nine traits displayed potential to predict decomposition stage from burned remains. An increase in calcined and charred bone occurred synchronously with advancement of decomposition with subsequent decrease in unaltered surfaces. Greasy bone appeared more often in the early/fresh stages (fleshed bone). Heat borders, heat lines, delineation, joint shielding, predictable and minimal cracking are associated with advanced decomposition, when bone remains wet but lacks extensive soft tissue protection. Brown burn/borders, delamination and other heat-induced fractures are associated with early and late skeletonisation, showing that organic composition of bone and percentage of flesh present affect the manner in which it burns. No statistically significant difference was noted among observers for the majority of the traits, indicating that they can be scored reliably. Based on the data analysis, the pattern of heat-induced changes may assist in estimating decomposition stage from unknown, burned remains.

Key words: taphonomy, burned bone, patterned thermal destruction, transition analysis, heat-induced changes

1. Introduction

In the Highveld of South Africa, expansive and flat, open veldt, usually populated with tall grasses and low lying scrubs, can be seen throughout the countryside. The South African veldt, or bushveldt, offers shelter to destitute people and provides a hidden location for the disposal of bodies. The winter months (May to August) are often dry and cold, a situation that increases the risk of accidental veldt fires, also referred to as wild fires in the USA. Once the tall grasses and scrubs are burned, human remains are more easily, and always inadvertently, discovered. The question often addressed to the anthropologist is based on the state of the remains (degree of decomposition) at the time the fire occurred.

A fleshed human body burns in a predictable sequence on account of repositioning of the body's antagonistic muscles and tissue distortion. When exposed to fire, the body's antagonistic muscles pull into the pugilistic posture via flexion/contraction of the neck, torso upper and lower limbs. This change in position creates differential tissue shielding of skeletal elements [1-3]. For example, if exposed for the same duration, bone covered with minimal tissue (frontal bone, anterior mandible) will undergo faster and greater thermal alteration than bones covered with thickened tissues (head of femur) [4]. During decomposition, muscular contraction and soft tissue shielding are lost such that fleshed and decomposed remains will present with different burn patterns, or signatures. While the process of thermal alteration to a fully fleshed body has been studied under controlled conditions and are documented in detail [1,5,6], the effect of decomposition on normal burn patterns is not as well recognised. Because tissue and the tissue shielding contribute to the burn patterns, studies into the process of decomposition and burning may be useful in estimating the condition of the body prior to the burn event.

Many researchers agree that specific thermal characteristics exist among fleshed, wet and dry bone [7-12] with burn fracture characteristics being similar between wet/green and fleshed bone but not between wet and dry bone. Previous research focused on recording fracture patterns in accordance with the condition of bone (fleshed, wet or dry) [7-11] and changes in colour [13-19]. Certain features such as heat borders, heat lines and joint shielding are linked to burned fresh remains while others such as delamination, brown burning and some heat-induced fractures are linked to more dry bone (skeletonisation) [1,4,12]. Yet, the relationship between burn patterns and bone condition has not been empirically tested.

The purpose of this study was to utilise the core principles of transition analysis to evaluate standard features of thermal destruction in bone with five decomposition phases as a means to establish general burn characteristics in fleshed, wet and dry bone.

2. Materials and Methods

An experimental, descriptive approach was used to investigate the relationship between burn patterns and degree of decomposition. The sample comprised of 25 pigs (*Sus scrofa*). All pigs died of natural causes (Listeria, E. coli or Clostridium infections) and were obtained from commercial pig farmers in South Africa. Ethical approval for this study was obtained from the Main Ethics Committee at the Faculty of Health Sciences, University of Pretoria (134/2008)

The pigs were collected and placed less than 12 hours after death. None of the pigs were placed in refrigerated compartments. All pigs were left to decompose, until the necessary decomposition stage was reached. Pigs ranged in size from 50 to 100 kg. Decomposition was recorded for each pig prior to burning. The stages ranged from fresh (stage A), early (stage B), advanced (stage C) and skeletonisation (stage D). As stage D (skeletonisation) can present with adherent tissues as well as completely dry bone devoid of any tissue, the stage was subdivided into early skeletonisation (D) and late skeletonisation (E) so that burn pattern evaluations can be made on wet/greasy and dry bone.

The decomposition scoring procedures of Megyesi and colleagues [20], which are based on the original version of Galloway and co-authors [21], were applied separately to the head, thorax and limbs. The three regions of the body were considered separately, because they decompose at different rates. Total body scores (TBS) were calculated for each pig. The allotted point value was recorded for each of the three regions and added to reach the TBS, or overall stage of decomposition. By taking the minimum and maximum scores possible for each stage, the following groups, pertaining to TBS, were established. A score equal to 3 is in the fresh stage of decomposition. TBS scores between and including 4 to 16 are assigned to the early stage, TBS scores between and including 17 to 24, fall within the advanced stage of decomposition. A TBS score that fell in the 25 to 32 range was considered to be in early skeletonisation and any TBS over 32 was considered in the late skeletonisation stage.

A natural, outdoor veldt fire was replicated. In order to start and maintain the fire, surrounding flora was used in an open area with no accelerants. To prevent the risk of an uncontrollable fire, a 1500 mm x 1200 mm perforated and mobile steel frame was constructed to surround the pig carcasses during the burning process. Each pig was exposed to fire for 30 minutes. The time period was chosen because a fleshed human has been shown to display thermal alteration to bone as soon as 10 minutes after exposure and at 30 minutes the majority of bony elements are exposed enough to undergo thermal damage [5]. A timeframe extending beyond 30 minutes was not considered as many skeletal elements such as the cranium, small hand and foot bones, and ribs elements may be destroyed. Photographs were taken in situ before and after burning and then the remains were collected. In cases where some dried / burnt tissues were still adhering to the bone, the tissue was gently cleaned in order to assess the bones specifically.

Thirteen heat-related characteristics (unaltered bone, charred bone, calcined bone, brown burn/border, heat border, heat line, delineation, greasy bone, joint shielding, minimal cracking, predictable cracking, delamination and heat-induced fractures) based on descriptions found in the literature [1,6,12,13,22] were assessed. In Table 1, the definitions and associated figures (Figures 1 – 7) for these heat-related traits are provided. A ranking system was developed as a means to quantify the distribution of unaltered, charred and calcined changes on a single skeletal element (Table 2). One bone received three scores; a score for the amount of unaltered bone, the amount of charred bone and the amount of calcined bone; as the process is cumulative a score of 3 for all 3 categories is not possible. The remaining 10 heat-related features (brown burn/border, heat border, heat line, delineation, greasy bone, joint shielding, minimal and predictable cracking, delamination and heat-induced fractures) were scored using a binary system, present (1) or absent (0).

Statistical analysis of the data

Statistical analysis was done using the program R version 3.0.2 (VGAM library). Transition analysis is used with any trait/process that can be arranged into an invariant series of senescent stages. In this study, the process closely mimics that which is described in Boldsen et al. [23]. However, the statistical process described in Boldsen et al. [23] was used for estimating a continuous parameter (age) whereas in this study the method was applied to a discrete, ordinal classification system for the level of decomposition that exists in a bone element before being burnt.

A logistic regression generalised linear model was used since the data consists of ordinal variables. The model was used to find the most likely level of decomposition, which is the dependent variable. By using the information provided by the recorded post-fire damage, it is

Table 1. Definitions and abbreviations of the thirteen heat-related traits assessed

Heat-related trait	Abbreviation	Description
Unaltered bone	Una	Display no visual signs of thermal alteration (no colour change). Tissue present at this time of exposure protected the bone from damage (Figure 1)
Charred bone	Cha	Represents carbonized skeletal material and is black in colour (Figure 1)
Calcined bone	Cal	Is grey/white/blue/ash-brown coloured bone (Figure 1)
Brown burn	BB	Is brown discolouration due to heat exposure. Brown burn is located adjacent to a charred area and is not associated with a heat border (Figure 2)
Heat border	HB	Is an off-white/yellowish border located between charred and unaltered bone. The heat border has no direct contact with fire and represents chemical alteration of bone during heat exposure. Overlying albeit receding tissue protects this area (Figure 3)
Heat line	HL	Is a thin, whitish line directly adjacent to the heat border and represents the initial transition between unaltered and thermally altered bone (Figure 4)
Delineation	D1	Is present when a clear distinction is observed between unaltered bone, the heat line, heat border and charred area (Figure 3)
Greasy bone	Gr	Is a wet/oily surface and feel of the bone
Joint shielding	JS	Is when an area of joint articulation (eg., mandibular fossa and mandibular condyle) is protected from thermal alteration often by surrounding ligaments. The area around the joint displays signs of thermal alteration by the actual internal surfaces involved in the formation of the joint remain unaltered (Figure 4)
Predictable cracking	PC	Is when small, clear heat fractures are observed parallel to the heat border. These fractures are present at the transition area between the heat border and charred area (Figure 5)
Minimal cracking	MC	Is when a few random fracture lines are found within the heat-altered bone. These fractures are not associated with the mechanisms that create predictable fractures but result from direct exposure to heat/flame
Delamination	D2	Is the removal of the outer cortical layer of bone and subsequent exposure of the underlying spongy/cancellous bone (Figure 6)
Heat-induced fractures	HIF	Are scored as present if one or more heat fractures such as; transverse, longitudinal, step, patina or curved transverse are Observed (Figure 7)

Table 2 Ranking system guidelines for scoring the colour distribution on thermally altered bone

Score	Description
Zero (0)	The surface presents with either no unaltered, no charred or no calcined areas. A zero score is applied to either an unburned element of a uniformly burned element
One (1)	If less than a quarter (<25%) of the bone surface remains thermally unaltered then a 1 is scored for unaltered bone; if less than a quarter (<25%) of the bone surface displays charred or calcined bone then a score of 1 is given and can be considered minimal thermal alteration
Two (2)	If more than a quarter (>25%) but less than three quarters (<75%) of the bone surface remains unaltered a 2 is scored for unaltered bone; if charred or calcined bone is present on more than a quarter (>25%) but less than three quarters (<75%) of the bone surface then a 2 is scored for both charred and calcined and can be considered as moderate thermal alteration
Three (3)	If more than three quarters (>75%) of the bone surface remains unaltered then a 3 is assigned for unaltered bone; if more than three quarters (>75%) of the bone surface is charred or calcined then a 3 is scored for each and can be considered as extensive thermal alteration

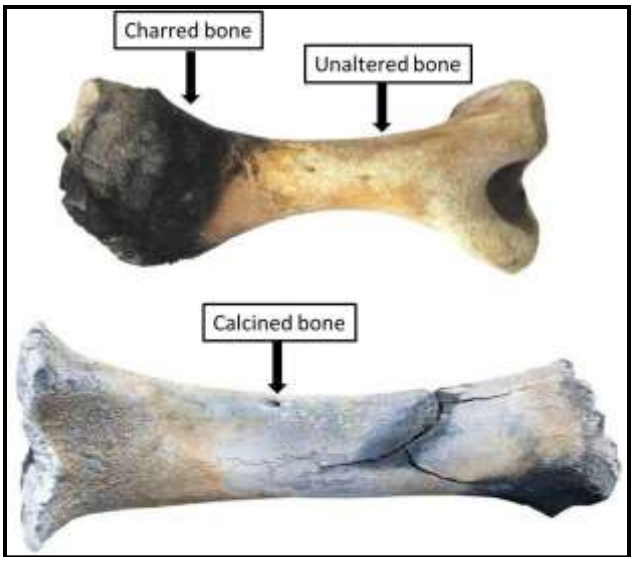

Figure 1 Charred proximal humerus of domesticated pig (blackened area) Calcined tibia of domesticated pig (*sus scrofa*)

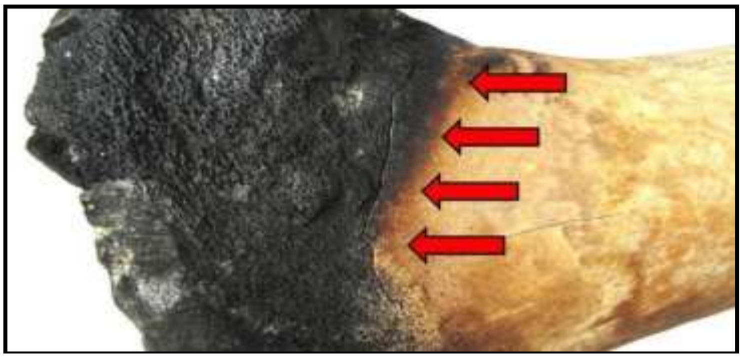

Figure 2 Brown burn adjacent to charred area

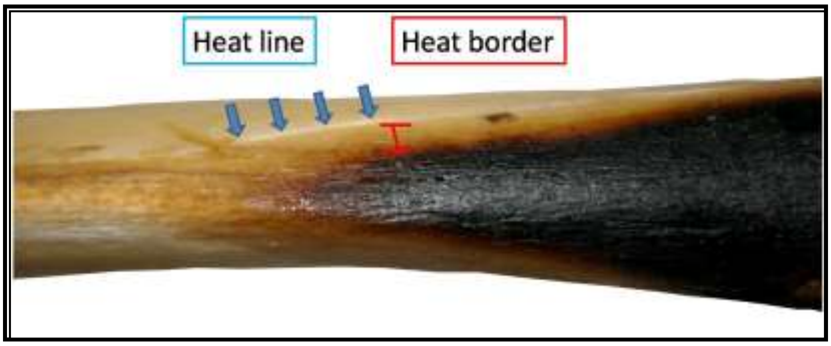

Figure 3 Heat line (blue arrows) adjacent to the heat border (red bracket)

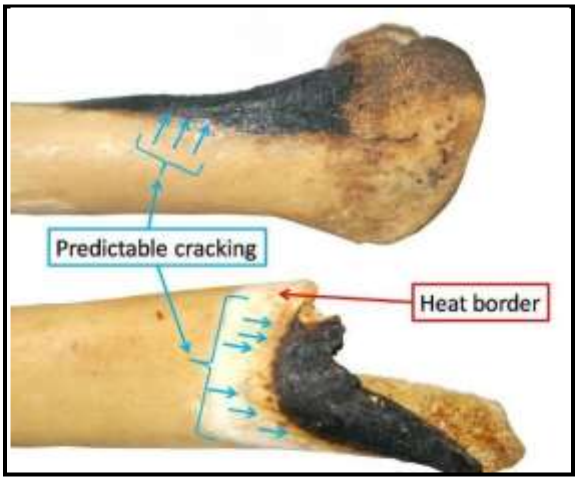

Figure 4 Predictable cracking along the transition area between charred bone and the heat border

Figure 5 Basal view of skull showing the unaltered mandibular fossa surrounded by charred bone (joint shielding)

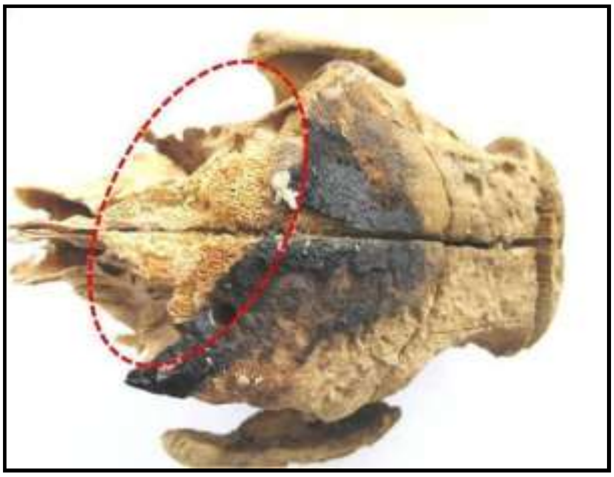

Figure 6 Delamination of the cranium with exposure of underlying cancellous bone

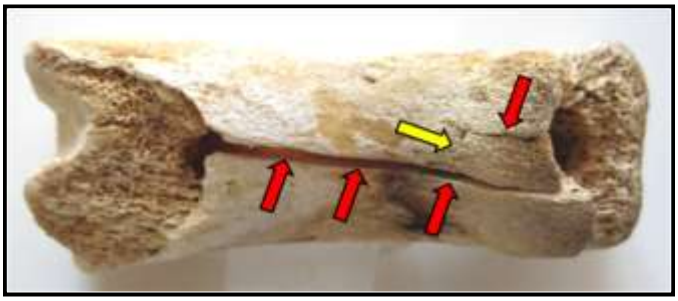

Figure 7 Longitudinal fractures (red arrows) and a step fracture (yellow arrow)

assumed that the post-fire damage is a function of the level of decomposition before the fire took place, indicating that levels of post-fire damage recorded are the independent variables in the study. The model is applied separately for each trait. The levels of post-fire damage then act as predictors of the level of decomposition before the fire.

It is also fairly simple to extend the generalised linear model to include multiple traits by multiplying the selected likelihoods of possible traits together. The model was used to compile likelihood functions, in order to identify the level of decomposition according to the scale used for classification and not as a direct function of time. Naturally, the stages of decomposition can be linked to time but are not explicitly defined as such in the dataset. The implementation of alternative models, such as the autoregressive integrated moving average model was not considered during the study because of the definitions used in the dataset, but could offer suitable alternatives in future studies.

Inter- and intraobserver errors were determined using intraclass correlation and kappa statistics to establish the repeatability of scoring the decomposition stage as well as determining the repeatability of scoring the various burn characteristics. Ten randomly selected pigs were then re-scored by observer 1 as well as an independent observer 2. While scoring, both observers were unaware of the actual TSD and stage of decomposition to prevent bias in scoring of the traits.

3. Results

The distribution of colour change or the presence/absence of heat-related traits on a skeletal element because of fire exposure across progressive decomposition are examples of single-trait analysis. Continuation ratio models for single trait analyses and the associated collective probabilities for the head and neck, the trunk and the limbs are shown in Tables 3, 4 and 5, respectively. The skeletal elements of the various regions were used in combination, e.g, the skull, mandible and cervical vertebrae for the head and neck region, but the three regions were assessed separately.

With the absence of burning on the head and neck, a 36 to 50% probability exists that the bones were in the first two stages of decomposition (Table 3). As the percentage of thermal alteration increased (more charred/calcined), the probability increased for the skeletal elements to be assigned to a later decomposition stage. As the likelihoods shift towards the later stages of decomposition an increase in the probability itself is observed; i.e., the more decomposed and burned the remains, the higher the predicting factor for decomposition stage as can be expected.

Minimal calcined bone indicated a 50% chance that the head and neck remains had progressed into advanced decomposition and beyond. Moderate calcined bone on the cranial surfaces indicated that the remains were beyond advanced decomposition with moderate to high probabilities (57 – 75%). Extensive calcination of the head and neck likely placed the remains in the final stage of decomposition prior to burning (75 – 99%). Minimal charred bone observed on the majority of the head and neck elements suggested that the remains were in advanced decomposition (50 – 99%). Increased amounts of charred bone (moderate – extensive) suggest a fair probability (50 – 58%) that the remains were in skeletonisation prior to burning. Grease on the cranial elements was noted in the fresh and early stages (28 – 33%). A heat border most often appeared in advanced decomposition (67-99%). Heat lines, delineation, joint shielding and predictable cracking were only observed on the cranium and only in the advanced stage of decomposition. Minimal cracking was only observed on the cranium and cervical vertebrae. If this trait was present, the remains were allocated to the advanced stage of decomposition (99%). A brown burn/border suggested that the head and neck elements were in the final stage of skeletonisation (99%). Delamination suggested that remains were in or had progressed beyond advanced decomposition prior to burning (44 – 50%) while the presence of other heat-related fractures indicated a state of skeletonisation (38 – 46%).

Table 3 Transition analysis results (probability mass functions) for the combined elements of the head and neck (cranium, mandible, cervical vertebrae)

Head and Neck		Stage of decomposition				
Score	Heat-related trait	A	B	C	D	E
0	Unaltered bone				28%	67%
	Charred bone	39 - 50%	39 - 50%			
	Calcined bone	36 - 42%	36 - 42%			
1	Unaltered bone				50 - 99%	50 - 60%
	Charred bone			50 - 99%		50%
	Calcined bone			50%	50%	50%
2	Unaltered bone	31%	31%	67%	99%	
	Charred bone				50 - 58%	50%
	Calcined bone				50 - 67%	75%
3	Unaltered bone	31 - 33%	31 - 33%	33%		
	Charred bone				50 - 58%	50%
	Calcined bone					75 - 99%
Present	Greasy bone	28 - 33%	28 - 33%			
	Heat border			67 - 99%		
	Heat line			99%		
	Delineation			99%		
	Joint shielding			99%		
	Predictable cracking			99%		
	Minimal cracking			99%		
	Delamination			44 - 50%		50%
	Brown burn/border			67%	50%	99%
	Heat-induced fractures				38 - 45%	38 - 46%
Condition of bone		Fleshed bone		Wet bone		Dry bone

The absence of thermal alteration on elements of the trunk, suggests (with 27 – 39% likelihood) that the remains were in the first three stages of decomposition (Table 4). Minimal calcined bone observed on the trunk indicated (67 – 99%) late skeletonisation. Minimal charred bone placed the remains in advanced or early skeletonisation (50 – 99%). With increased amounts of calcined or charred bone (moderate – extensive) the remains were most likely in a state of skeletonisation (50 – 99%). Grease on the trunk was observed in the fresh and early stages (26 – 39%). Predictable cracking was only noted on rib and scapular elements and only in the advanced stage of decomposition (99%). Heat borders were only observed on scapular elements in the advanced or early skeletonisation stages (50%). Brown burn/borders observed on the ribs, os coxae and lumbar vertebrae placed the remains in early skeletonisation (99%). However, if a brown burn/border was observed on the scapula this suggested that the remains were anywhere between advanced decomposition and late skeletonisation (33%). Minimal cracking was observed on the scapular elements in early skeletonisation (99%). Delamination or the presence of other heat-related fractures suggested the trunk elements were in a state of skeletonisation (39 – 63%).

Table 4 Transition analysis results (probability mass functions) for the combined elements of the trunk (ribs, scapula, os coxa, thoracic & lumbar vertebrae)

Trunk		Stage of decomposition				
Score	Heat-related trait	A	B	C	D	E
0	Unaltered bone				99%	99%
	Charred bone	31 - 39%	31 - 39%	31%		
	Calcined bone	27 - 33%	27 - 33%	27 - 33%		
1	Unaltered bone					80 - 99%
	Charred bone			50 - 67%	50 - 99%	
	Calcined bone					67 - 99%
2	Unaltered bone				99%	67 - 99%
	Charred bone				50 - 99%	50 - 60%
	Calcined bone				50 - 99%	50 - 67%
3	Unaltered bone	24 - 29%	24 - 29%	24 - 29%	24%	
	Charred bone					67 - 99%
	Calcined bone				50 - 99%	50 - 99%
Present	Greasy bone	26 - 28%	26 - 28%			
	Heat border			50%	50%	
	Predictable cracking			99%		
	Minimal cracking				99%	
	Delamination				39%	39 - 56%
	Brown burn/border			33%	33 - 99%	33 - 99%
	Heat-induced fractures				42%	42 - 63%
Condition of bone		Fleshed bone		Wet bone		Dry bone

With the absence of thermal alteration on the extremities, a 24 to 42% probability exists that the bones were in the first three stages of decomposition (Table 5). Minimal or moderate calcined bone indicated that the extremities were in a state of skeletonisation (50 – 99%). Minimal or moderate amounts of charred bone suggested that the remains were likely in or beyond advanced decomposition (33 – 99%). Extensive calcined bone or charred bone placed the remains in early or late skeletonisation (50 – 99%) prior to burning. Grease on the extremities was observed in fresh, early or advanced decomposition (28 – 31%). Heat borders showed a 50 to 99% chance that the remains were in advanced decomposition. Heat lines and delineation suggested that the remains were in early or advanced decomposition (50 – 99%). Predictable cracking allocated the remains to the advanced stage of decomposition (50 – 99%). Brown burn/borders on majority of the extremities associated the remains with late skeletonisation (60 – 99%). However, if brown burn/borders were observed on the ulna alone, it placed the remains in early or late skeletonisation (50%). Delamination or the presence of any other heat-induced fracture suggested that the extremities were in or had progressed beyond the advanced stage of decomposition (31 – 75%).

Table 5 Transition analysis results (probability mass functions) for the combined elements of the limbs (humerus, ulna, radius, metacarpals, femur, tibia, fibula, metatarsals)

Limbs		Stage of decomposition				
Score	Heat-related trait	A	B	C	D	E
0	Unaltered bone				50%	50 - 99%
	Charred bone	31 - 46%	31 - 42%	31%		
	Calcined bone	24 - 31%	24 - 31%	24 - 31%		
1	Unaltered bone	22%	22%	22%	50 - 99%	50 - 99%
	Charred bone			33 - 99%	33 - 99%	50 - 99%
	Calcined bone				50%	50 - 75%
2	Unaltered bone			50%	50 - 99%	50 - 67%
	Charred bone			50%	50 - 67%	50 - 99%
	Calcined bone				50	50 - 99%
3	Unaltered bone	25 - 33%	25 - 29%	25 - 29%	50%	
	Charred bone				50 - 99%	50 - 99%
	Calcined bone				50 - 99%	50 - 67%
Present	Greasy bone	28 - 31%	28 - 31%	28%		
	Heat border			50 - 99%		
	Heat line		50%	50 - 99%		
	Delineation		50%	50 - 99%		
	Joint shielding				99%	
	Predictable cracking			50 - 99%		
	Delamination			44%	50 - 75%	45 - 56%
	Brown burn/border				50%	50 - 99%
	Heat-induced fractures			31%	31%	36 - 56%
Condition of bone		Fleshed bone		Wet bone		Dry bone

4. Discussion

The discovery of burned remains leads to inquires as to the condition of the body prior to the burn event. Macroscopic burn-related signatures (heat-related traits) are shown to be useful in providing clues as to the condition of bone (fleshed, wet and dry) prior to burning. Heat and flame systematically compromises both flesh and muscular tissue such that a fleshed body presents with distinct signature changes in bone namely heat lines, heat borders and clear delineation between burned and unburned bone. With the advancement of decomposition, pugilistic flexion and soft tissue protection are lost. Soft tissue degradation differentially exposes parts of the skeleton such that burn patterns are not as easily predictable from decomposed remains. Bodies in an advanced state of decomposition or skeletonisation may contain less moisture than fleshed material and, in addition to the absence of soft tissue, may contribute to differential burn patterns among fleshed, wet and dry bone. Different bone conditions presented with different colour-change signatures, along with variable manifestations of heat borders, heat lines, and delineation.

The percentage of charred and calcined bone increased with the advancement of decomposition. Minimal thermal alteration to the skeleton was observed in fresh and early decomposition as the skin and muscle tissues maintained structural integrity and protected underlying bone. In fresh tissue, a gradual retraction and burning of flesh was observed. As the tissue degraded sagged, flesh around the eyes caved in, and tissue in the throat and abdominal cavity was reduced, patches of bone were exposed on the head, trunk and extremities. When burned, the tissues merely sloughed off and exposed broad areas of underlying bone to heat and flame, which was recorded with an increase in the percentage of charred and calcined surfaces. However, decomposition is not uniform across a body such that areas with less tissue with skeletonise and burn prior to areas with more tissue. For example, the torso, in general, burned slower than the other areas of the body because of the higher moisture content of thoracic and abdominal organs and greater tissue mass, which takes longer to decompose than the head and lower limbs. Prior to skeletonisation, tissue shielding greatly contributed to the observed burn patterns.

In early skeletonisation, uniform patterns of charring/calcination (i.e., the entire bone is either calcined/charred or a combination of the two) were observed and was not seen earlier as the presence of tissue provided for a more linear burn progression and colour distribution. In late skeletonisation, all tissue was absent and the surfaces of the bones were dry. Extreme fragmentation of burned remains was often noted and recovery of skeletal elements was often incomplete in this phase. The pattern of colour distribution on the late skeletonised remains was similar to the patterns observed with the remains burned while in early skeletonisation; with the exception of greater areas of calcined bone.

Burn-related colour changes were uniform across most of the skeleton and fragments varied from white calcined to blackened char and various combinations thereof. This colour variation in a single element can relate to differences between fleshed, defleshed/wet/green, and dry bone [24,25]. Previous authors suggested that the uniform pattern of calcination or charring occurs on defleshed, green bones [6,26-29]. However, the burn uniformity was not necessarily exclusive to defleshed/green bone and does present in dry bone. In this instance, the absence of flesh was more important in producing uniform burn patterns than the wet/dry condition of the bone. Colour alteration on its own cannot aid in distinguishing between fleshed, wet or dry bone, but the relation of colour to other burn signatures (heat line, heat border) may provide more information as to the bones condition prior to burning.

Heat borders, heat lines with distinct delineation and predictable/minimal cracking were noted in fresh to advanced decomposition stages where a combination of soft tissue and muscular structures were present. In many cases, heat borders were noted without the presence of a heat line. The absence of a heat line was often observed in remains burned while partially fleshed. The denatured periosteum in advanced decomposition may permit tissue to burn away with less resistance, thus preventing a distinct heat line from forming. Heat lines, heat borders and delineation were absent on skeletonised remains, as soft tissues may be necessary to produce these signatures. [1,12,13,22,30].

Brown burn/borders, delamination and other heat-induced fractures were associated with early and late skeletonisation, demonstrating that organic composition of bone and amount of flesh present affects the burn morphology. Non-delineated brown borders were observed in wet or early skeletonised and dry bone. A brown burn/border replaced the previously observed distinctive heat border and line in fleshed and advanced decomposition. A brown burn/border may be the chemical alteration of bone with remnant organic content and moisture in direct contact with heat/fire. The brown burn/border observed in late skeletonisation (dry bone) may be attributed to the last remnants of organic materials present in bone.

Contrary to other studies, a small percentage of remains in the advanced and early skeletonisation stages displayed joint shielding. Joint shielding were neither expected nor observed in dry, skeletonised and disarticulated remains and was shown to be more dependent on the presence of ligaments holding the joints together rather than the percentage of soft tissue present.

While transition analysis showed promising results for estimating the stage of decomposition, the probability tables should be considered with caution if applied to cases outside of a 30-minture burn interval. Even though statistical tests assisted in elucidating a clear pattern in burned skeletal remains within the predefined conditions of this study, application to unknown cases must be used cautiously due to various other factors that cannot be controlled such as duration of exposure, context of remains, climatic conditions and body positioning [31]. However, aside from the above-mentioned challenges associated with fire-related taphonomic studies, the authors strongly suggest that the degree of heat-related/heat-induced changes on bone can be positively associated with the various stages of decomposition and their relevant bone condition (fleshed, wet and dry).

5. Conclusion

This study demonstrated a suite of reliable heat-related traits that can be utilised for estimating the state of the remains prior to a burn event when confined to the parameters of this study (30 minute burn interval). In particular, the differential ratio of colour distribution (unaltered, charred, calcined) on the bones is associated with the relative level of decomposition when exposed to a veldt fire. The presence of heat borders, heat lines, delineation and greasy bone are linked to early stages of decomposition when a body is fleshed or partially fleshed. Joint shielding is a trait observed in remains that remain articulated and undisturbed during the burning process. This trait is more common in remains that are fleshed or partially fleshed but is not restricted to a specific bone condition. Delamination and heat-induced fractures are associated with the later stages decomposition and the more fractures present, the greater the likelihood of the remains being in more advanced states of decomposition. The number of fractures does not necessarily indicate extreme decomposition, instead it can be said that the duration of the fire and the percentage of flesh present prior to exposure has a major role in the production of fractures. Based on the data analysis, heat-induced changes may assist in estimating decomposition stage from unknown, burnt remains thereby aiding in estimating bone condition with relevance to the stage of decomposition.

When interpreting these results, it should be taken into account that this study was done using a pig model. Different anatomy, such as the fact that pigs are quadripedal, will inevitably lead to joint shielding patterns etc. that are different from those observed in humans. The texture and quality of porcine bone as opposed to that of human bone can also potentially contribute to variations between burn patterns observed in animals and pigs. Nevertheless, this study contributes valuable information that can be used to study thermal observations on bone in future studies.

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