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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 and late skeletonisation) were exposed to fire for 30 min. 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.

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

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and is 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 h 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 4–16 are assigned to the early stage, TBS scores between and including 17–24, fall within the advanced stage of decomposition. A TBS score that fell in the 25–32 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 × 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 min. The time period was chosen because a fleshed human has been shown to display thermal alteration to bone as soon as 10 min after exposure and at 30 min the majority of bony elements are exposed enough to undergo thermal damage [5]. A timeframe extending beyond 30 min 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 (Figs. 1–7) for these heat-related traits are provided. A ranking

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 (Fig. 1)
Charred bone	Cha	Represents carbonised skeletal material and is black in colour (Fig. 1)
Calcined bone	Cal	Is grey/white/blue/ash-brown coloured bone (Fig. 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 (Fig. 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 (Fig. 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 (Fig. 4)
Delineation	D1	Is present when a clear distinction is observed between unaltered bone, the heat line, heat border and charred area (Fig. 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 (Fig. 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 (Fig. 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 (Fig. 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 (Fig. 7)