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Review

The forensic evaluation of burned skeletal remains: A synthesis

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ABSTRACT

In recent years, research and case experience have greatly augmented knowledge regarding the effects of extreme heat on skeletal remains. As a result of this effort, enhanced interpretation is now possible on such issues as the extent of recovery, reconstruction, trauma, individual identification, size reduction, thermal effects on histological structures, color variation, the determination if remains were burned with or without soft tissue, DNA recovery and residual weight. The rapidly growing literature in this area of forensic science includes experimental research that elucidates the dynamics of the thermal impact on skeletal structure and morphology.

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Contents

1. Introduction

Although many cases in forensic anthropology involve interpretation of burned bone, until relatively recently few scientific studies have focused specifically on this topic. Since thermal alterations can occur in all types of cases routinely examined in forensic anthropology, analysis is needed to address a variety of issues. These issues include recovery, reconstruction, trauma interpretation, bone recognition, weight interpretation, thermal correlations with coloration, shrinkage and structural changes, distinguishing bones burned in the flesh from those burned without flesh, technological analysis and DNA extraction techniques and success rates. A growing scientific literature is now available to address these issues facilitating interpretation and allowing more precise analysis in the variety of burned cases that enter our laboratories.

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2. Case applications

A variety of events can lead to burned skeletal remains. These include aircraft accidents, bombing and explosions and earthquakes [1]. Homicides, suicides [2] and accidental deaths all can involve the use of fire with variable results on human remains [3]. Fire can be employed to attempt to destroy forensic evidence in criminal cases, often to attempt to prevent identification and recovery [4]. Archeological samples can present evidence of burning [5,6] and thus provide time depth to the issues involved.

Even commercial cremations present problems for the forensic examiner. In 2006 Nelson and Winston [7] reported that in Tucson and Pima County Arizona between 2002 and 2003, 0.8% of cremation requests resulted in being medical examiner cases after review. In addition, disputes over commercial cremations result in civil litigation that can involve forensic analysis of the recovered materials.

Thorough reviews of commercial cremation procedures and equipment are provided by Eckert et al. [8], McKinley [9], Merbs [10], Murad [11], Schultz et al. [12], Warren and Schultz [13] and Wells [14]. These sources report that in commercial cremations, retort temperatures range from 500 °C to 1000 °C but Murad [11] notes that after the heat source is shut down, temperatures can climb to as high as 1278 °C. Analysis of remains resulting from commercial cremations includes assessment of minimum number of individuals and commingling issues as well as identification. Identifications are frequently facilitated by recovery and analysis of inclusions such as identification tags, dental restorations and surgical materials.

3. Recovery issues

Given the nature and context of burned human remains, special care is needed in recovery [15,16]. Two major factors complicate recovery of burned human remains: fragmentation and context. Soft tissue changes with burning include post-mortem muscle contracture. Dehydration and protein denaturation lead to muscle shortening. Since the bulkier flexors contract more than the extensors, the burn victim frequently presents extreme flexion [17] that has been termed the pugilistic pose.

Since burning can lead to extreme bone fragmentation, care must be taken in analysis at the scene. Ideally, forensic anthropologists should participate in the recovery since they are trained to recognize fragmented human remains. Context is important since in most cases, human remains are located in proximity to other burned similarly appearing materials. It can be challenging, even for trained anthropologists to differentiate small fragments of burned bone and teeth from charred fragments of building materials and other items. Methods of recovery, along with mortuary treatment can affect fragment size as well [5]. Guidelines for recovery emphasize recognition of the possibility of fragmentation, utilization of forensic anthropologists and a cautious approach that facilitates in situ assessment of recovered human remains.

4. Analysis

As in all areas of forensic anthropological analysis, the particular procedures employed are case driven and shaped by the nature of the evidence and its context. Publications are available offering detailed information on procedures and methodology [3,18,19,20,21,22,23,24,25,26]. The following presents a focused discussion of the major methodological approaches available and their applications.

5. Reconstruction

A frequently overlooked element in the analysis of burned human remains is reconstruction. Reconstruction provides a more holistic opportunity for morphological interpretation and can greatly facilitate determinations of human vs. non-human animal and recognition of specific skeletal elements [27]. Reconstruction can also increase the probability of identification [28] and recognition of trauma. Even fragmented calcined remains can be reconstructed, improving the strength of assessment of the minimal number of individuals present.

6. Trauma

Trauma interpretation in skeletal remains cases involving burning can be difficult due to heat related fractures and fragmentation. However, both experimental studies and casework experience indicate that diagnostic evidence of trauma can survive the burning event. In a 2004 experimental approach working with cranial bone, Pope and Smith [29] documented the post-burning survival of pre-existing trauma. Conducting similar research in 2002, de Gruchy and Rogers [30] were able to identify chop marks in cremated bone but found that their appearance could be influenced by burning-related fragmentation.

Herrmann and Bennett [31] also found that signatures of sharp force trauma survived incineration but argued that an analysis of fracture patterns and surface morphology was required. They suggested that blunt force trauma was difficult to distinguish from heat related fractures. In a major case application, the study of the decedents of the Branch Davidian incident in Waco, Texas [32,33] also demonstrated that various kinds of perimortem trauma could survive the burning process.

Since heat exposure can lead to extensive bone fracturing, differentiating perimortem trauma from postmortem thermal related alterations can be challenging. Symes et al. [34] provide useful discussion of this issue, noting that observations of the pattern of fractures can enhance diagnosis.

7. Survival of material useful for identification

When minimal thermal changes are present on remains, normal procedures for identification can be followed. Extensive heat related alterations can severely disrupt normal procedures but frequently, sufficient evidence survives to facilitate identification. Shrinkage, fragmentation and shape alterations can affect skeletal analysis and must be considered in analysis. Age at death and disease can be factors as well since experimental research indicates that osteoporotic bone tends to fragment with greater frequency than healthy bone [35]. Fragmentation can facilitate degradation of organic materials such as albumin useful for identification [36]. Identification of specific skeletal elements can be useful for the calculation of the minimal number of individuals present and to discover discrepancies in the ages represented.

Even in the calcined fragments resulting from commercial cremations, useful information can survive. For example, evidence of arteriosclerosis has been reported to survive commercial cremation [37]. Non-skeletal inclusions, such as surgical materials, dental restorations and identification tags can survive cremation and be useful for identification [38,12]. Some methodological approaches have been advanced specifically for burned remains [39–41].

Experimental research indicates that in bone samples heated to temperatures between 800 °C and 1200 °C histological structure was preserved for analysis but human mitochondrial DNA and some human albumin did not survive [42]. At higher temperatures, histological structures can be altered as well [43]. Grupe and Hummel [44] found that following cremation, trace element information was limited due to "volatilization and crystal modification". Bones exposed to temperatures above 200 °C can present altered values of nitrogen and carbon isotopes [45].

8. Shrinkage

A growing literature of experimental studies documents the range of bone shrinkage related to burning [46]. Low temperatures (less than 800 °C) of minimal duration produce minimal shrinkage [47]. However, temperatures as low as 300 °C can lead to loss of human albumin [48]. When only minimal heat has been applied, the effects of and evidence for burning can be difficult to detect [49]. The ultimate skeletal effects are determined not just by the temperature of the heat applied but also duration of the heat event, oxygen supply and the extent of flesh or other protective materials in contact with the skeletal remains [50]. The extent of protective materials present represents an important factor since they maximize differences in temperature between that of the heat source and the temperature of the effected skeletal remains [50]. Since temperature of the heat source can differ extensively from bone temperature, the duration of the heat becomes important [51,52].

In a 1970 study, Van Vark [43] provided key information regarding temperature related shrinkage of bone dimensions. Experiments involved combustion of fragments of femur, patella and mandible in an electric oven. Dimensions recorded at successive intervals of 100 degrees at temperatures ranging from 200 °C to 1500 °C. Shrinkage was initiated at 700 °C, augmented at 800 °C and no further shrinkage was found at higher temperatures. Subsequent research has suggested considerable variation in shrinkage, correlated with temperature, duration of heat exposure and bone type [3].

9. Structural changes

Transmission electron microscopy study on sheep humeri indicates that relatively minimal heat causes changes in collagen fibrils within bone [53]. Scanning electron microscopy indicates that between 150 °C and 1150 °C heat temperature effects on bone structures were not apparent [54]. However, the general literature suggests that between 800 °C and 1400 °C new crystals appear, with some crystal fusion above 1000 °C. At 1600 °C and above, melting of bone mineral can occur with recrystalization after cooling [54]. Shipman et al. [52] document growth in the crystal size of hydroxyapatite during experiments with controlled burning of sheep and goat bones. Experimental research by Sillen and Hoering [55] found some increase in crystallinity between 200 °C and 700 °C and with temperatures above 700 °C apatite was transformed into whitlockite. Sillen and Hoering [55] also found that char was produced between temperatures of 300 °C and 500 °C.

Holden et al. [56] documented that the organic component of bone survived until temperatures of 400 °C. Beginning at 600 °C the bone mineral recrystallized. Melting of bone mineral occurred at 1600 °C.

Experimental studies with wood fires in natural environments indicate that crystal changes can occur [57]. Calcination is closely linked to contact with live coals [57]. With such fires, minimal changes in surface texture are observed below temperature of 500 °C and staining results from materials in the immediate environment [58]. The Spennemann and Colley [58] research indicates that considerable fragmentation occurs during recovery.

Wilson and Massey [59] found in their scanning electron microscopy study of incinerated teeth that dentin presented structural changes beginning at about 600 °C. Beginning at about 800 °C enamel rods presented altered structure.

10. Coloration

The color of bone fragments affected by high temperatures is a function of oxygen availability, duration and temperature [60,61]. David's 1990 experimental work [51] found that in a controlled brushfire, no calcination occurred and fragments appeared brown and black. A campfire size burn using eucalyptus wood reached a temperature of 840 °C in one hour and five minutes and produced white, calcined fragments with some grey and black coloration. Bones removed from this fire after only 25 min displayed a color range of black, brown, grey and white/blue.

Of course, the full range of color alterations can be found within a single skeleton and even on a single bone, especially in cases of the burning of fleshed remains [34]. Recently, Symes et al. [34] have called attention to the protective role played by soft tissue in thermal color changes in bone. They note that within a relatively short distance, soft tissue protected bone can display a sequence of calcined, charred, border and heat line zones which define the area of bone exposure to heat and help to differentiate bones burned in the flesh vs. those burned as dry bone. Color changes in teeth are similar to those documented in bone [62,63].

Experimental work by Spennemann and Colley in 1989 [58] documented that augmented heat and fire duration increasingly produced white fragments but with considerable variation. Staining of bone fragments producing a variety of colors resulted from contact with different materials in the environment. Earlier, Dunlop [64] had reported that copper produced a pink color in cremated bones, iron a green color and zinc a yellow color. Bone color can vary within different areas of a recovery site, reflecting variation in soil composition, the specific skeletal elements exposed and related factors [65].

11. Fleshed vs. dry bone

Early experiments by Baby in 1954 [66], Binford in 1963 [67] and Thurman and Willmore in 1981 [68] helped define differences between bones burned in the flesh vs. those burned without flesh. These studies documented that dry bones exhibited longitudinal splitting and superficial checking of the external surfaces and less evidence of warping. In contrast, those burned with flesh displayed considerable warping, transverse fractures, frequently in a curvilinear pattern, and more irregular longitudinal splitting.

Whyte [69] conducted experiments with non-human animal remains. Burning of fleshed remains produced distinctive fractures sometimes in association with warping. Those burned as dry bone produced less variation in fracture patterns and less evidence of warping.

12. DNA recovery

Some success has been noted in the recovery of DNA from burned remains. In 1991, Sajantila et al. [70] reported successful DNA typing on all 26 samples extracted from 10 fire victims exhibiting extreme charring. Brown et al. [71] recovered DNA from human early Bronze Age cremated bone from Bedd Branwen, Anglesey.

Experimental work by Tsuchimochi et al. in 2002 [72] indicated that DNA could be amplified and typed successfully from dental pulp after teeth had been exposed to temperatures up to 300 °C. Attempts were not successful using teeth exposed to temperatures

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above 300 °C. However, technology to improve the purity and yield of DNA continues to advance [73].

13. Weights

In 1997 Warren and Maples [74] published results of their examination of 100 individuals before and after cremation. Weights of cremated material from each adult individual ranging from 876 to 3784 g with a mean of 2430 g. All males presented post cremation values above 2750 g and all females had values below 1887 g. The percentage of cremains weight to pre-cremation body weight was 3.5% in adults, 2.5% in children and only 1% in infants.

Murad in 1998 [11] summarized previously unpublished research by Sonek in 1992 documenting that the post cremation weights of 150 individuals ranged from 892 to 4045 g with a mean of 2348 g. In 2004 Bass and Jantz [75] reported post cremation weights from adults in East Tennessee. Male values ranged from 1865 to 5379 g with a mean of 3380 g. Female values ranged from 1050 to 4000 g with a mean of 2350 g. The weight data are important to estimate the minimum number of individuals in large commingled samples and to examine the possibility of commingling in civil cases relating to commercial cremations.

14. Additional experimental approaches

Van Vark's 1970 experimental work [43] documented that between temperatures of 400 °C and 800 °C the bone fragments became increasingly brittle and microscopic images became unclear. At temperatures of 800 °C and above, microscopic imagery changed dramatically with only traces of lacunae being visible.

In 1986 Carr et al. [76] used scanning electron microscope technology to examine incinerated teeth. They found that approach was useful to recognize dental structures in fragmented dental remains.

Experiments by Christensen [35] revealed that osteoporotic bone is more likely to fragment than normal bone. In 1988, Herrmann and Grupe [77] studied trace elements in prehistoric cremated human remains. They found that in cremated bone, the ratio of calcium and phosphorus remained normal but values for magnesium varied. They noted that trace element values are subject to environmental factors.

In 1995, Holden et al. [56] evaluated incinerated human femoral bone using the scanning electron microscope. They documented combustion of the organic component at temperatures up to 400 °C. Beginning at 600 °C bone mineral began to recrystallize. At 1600 °C, bone mineral melted.

A 2006 study by Brooks et al. [78] focused on issues in using elemental analysis to distinguish legitimate cremated remains from those that were contaminated with other materials. In related research, Schultz et al. [12] demonstrates how elemental analysis can aid interpretation when documented reference samples are utilized.

Bush et al. in 2006 [79] used SEM/EDS analysis to examine dental restorative resins. They found that following cremation, values could be utilized to identify the manufactures.

In a recent (2008) innovative geochemical study of ash and soil at an archeological site in Chan Chan, Peru, Brooks et al. [80] examined a 20–30 cm thick ash deposit documenting a content consistent with coal ash. Comparative soil geochemistry revealed that the ash deposit, radiocarbon dated at AD 1312–1438 contained elevated levels of calcium and phosphorus consistent with the practice of cremation. One calcined skull fragment was recovered and confirmed as being human using solid-phase double-antibody protein radioimmunoassay [81]. The technique of X-ray diffraction was employed to suggest that the bone had been burned to temperatures of about 520 °C.

15. Summary

In recent decades, research and case experience have greatly augmented our scholarly capability to recognize and interpret burned skeletal remains. However, additional research, especially innovative experimental approaches, are needed to clarify key issues such as differentiating bones burned in the flesh vs. those burned as dry bone, interpretations of perimortem trauma and clarification of the variety of factors that lead to the myriad of thermal effects that have been documented to date.

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