Journal of Forensic and Legal Medicine 20 (2013) 1112–1117

Contents lists available at ScienceDirect

Journal of Forensic and Legal Medicine

journal homepage: www.elsevier.com/locate/jflm

Original communication

Post-burning fragmentation of calcined bone: Implications for remains recovery from fatal fire scenes

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ARTICLE INFO

Article history:
Received 14 November 2012
Received in revised form
23 September 2013
Accepted 13 October 2013
Available online 21 October 2013

Keywords:
Forensic anthropology
Calcination
Remains recovery
Fragmentation
Cremains
Burned bone

ABSTRACT

This research assesses how short term delays in time-until-recovery can affect the quality and quantity of burnt bone recovered from a fatal fire scene. Knowledge of trends in post-burning remains fragmentation will enable investigators to prioritise remains recovery and implement recovery protocols appropriately. By comparing calcined bone fragments recovered 0, 24, 56 and 168 h (1 week) after experimental burns, this research describes remains fragmentation over time. *Sus scrofa* (domestic pig) limbs were burnt in a series of wood fuelled fires with calcined remains recovered at the specified time intervals. Bone fragments were sorted into 12 size based categories and the proportional weight of each category compared to observe differences in fragmentation over time. Results reveal marked increases in fragmentation when recovery is delayed by 24 h but less change in fragmentation between 24 and 56 h delay when breakage is reduced in the larger fragments. Between 56 and 168 h delay large increases in fragmentation occurred across all fragment sizes. These results indicate that short term recovery delays (24 h) can be detrimental to remains condition, but if remains recovery cannot be completed soon after the fire intermediate delays (56 h) are less significant. Longer term delays (168 h) are again potentially highly detrimental.

1. Introduction

The recovery of calcined bone from a fatal fire scene is a painstaking and complex process. Not only is calcined bone fragile and typically highly fragmented, making identification and collection of remains challenging, but recovery needs to occur within the bounds of the larger investigation.[1,2] Any fatal fire scene needs to be determined safe before investigators can enter and the needs of the police, fire investigator, medical examiner or coroner, and other professionals require coordination to ensure all investigators can complete their work in a timely manner with maximum information acquisition for all.[1,3] To ensure remains recovery is appropriately prioritised and implemented within the needs of other investigators, knowledge of the trends in remains degradation over time is vital. These patterns of remains fragmentation are currently not well recognized and improving our understanding in this area will allow recovery protocols to be adjusted, improving the quantity and quality of material recovered. The ability to predict fragment sizes will enable investigators to determine the best approach for trained searchers, enhancing their ability to detect bone material. It will ensure that optimal equipment and search strategies are used from the beginning of the search and recovery process, minimising recovery-associated damage to the remains.

When human remains are burnt and the soft tissue is destroyed, underlying bone is exposed to the burn environment. As bone burning progresses, the bone material is transformed from its natural state to calcined bone through a number of intermediary stages which result in observable heat-induced changes in gross and microscopic appearance, colour, size and shape.[4–6] During burning, as bone loses water and organic components and the hydroxyapatite crystals increase in size, overall size and shape changes affect the structural integrity of the bone material by altering the stress–stain relationships within each bone element, leading to mechanical failures and fracturing.[7,8] The loss of organic material reduces bone elasticity, further promoting fragmentation of fully calcined material.[7–9] Anthropological analysis is possible on these fragmentary remains, and to capitalize on the information which can be obtained, recovery needs to be maximized for both quantity and quality of material recovered.

2. Methods and materials

To investigate the effect of delayed recovery on bone fragmentation fleshed *Sus scrofa* (domestic pig) limbs were burnt in a series

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1752-928X/$ – see front matter
http://dx.doi.org/10.1016/j.jflm.2013.10.004

of three outdoor wood fires, as outlined in Table 1. Three delay periods (24, 56 and 168 h) were investigated, and compared with fragmentation following recovery the day after the fire (the baseline marked as 0 h delay). The delay periods were selected to represent a range of time more commonly encountered during fatal fire scene investigations as determined from an extensive review of local Alberta case files. Wood burning fires were used to ensure a repeatable burn environment that experienced changes in temperature and physical environment throughout the burn event. *S. scrofa* limbs were sourced from local butchers, and as such their exact age at death was unknown but their similar size and patterns of unfused epiphyses suggest they were of all of a similar age, between eight and 10 months.[10]

For each burn event limbs were placed in two fires, one with material for immediate recovery, and a second with material for recovery following the three delay periods. In the second fire, limbs for each of the delay periods of 24, 56 and 168 h, were separated by 1.25 cm diameter, 0.5 m iron rods (rebar). In the first burn event limbs were placed directly on the ground and in latter burn events limbs were placed on a wood base to promote burning and calcination of inferior surfaces. Wood and newspaper were used to build stable, burnable structures that were lit and left undisturbed except for periodical additions of wood fuel. No solvents were used to ignite, or sustain the fires. Wood fuel was added by hand, avoiding any direct contact with the bone. Fires were sustained for four to five hours until full calcination was observed, at which point they were left to burn out and cool overnight. The wood fuel consisted of a spruce/pine mix of 2″ × 4″ and 2″ × 6″ lumber, commonly found in the Alberta region and often used in home construction.[11] Similar time and temperature profiles for each fire segment was confirmed by temperature data collected from type J thermocouples placed amongst each limb group (0, 24, 56, and 168 h delay) with temperatures recorded at one minute intervals using a DaqPRO 5300 data logger (See Table 1).

Following burning, bone remains were recovered from the burn site at the specified delay periods. Recovery at 0 h delay occurred in the mid-morning of the day after burning, allowing for full cooling and temperature stabilization. Prior to collection the area was assessed for any evidence of animal disturbance. Bone remains were collected by the author by hand, using tweezers for smaller fragments with care taken to ensure no additional damage to any bone fragments. Bone fragments were stored in partially air filled polyethylene, sealable bags and supported in the short term by toilet tissue for immediate transport to the laboratory where they were removed from the bags without delay, evaluated for any possible transportation damage, and stored on soft-surfaced paper trays. In the laboratory the bone material was sorted into one of 12 defined categories within three series based on size and shape (See Fig. 1). The *Small series* consists of three categories, numbered 1 through 3, where the shortest fragment dimension is less than 5 mm. The second series, the *Longitudinal series*, consists of 4 categories, Categories 4 through 7 and in this series the longest dimension is greater than twice the second longest dimension. In the third series, the *Non-longitudinal series*, the longest dimension must be less than twice the second longest dimension and there are 5 categories within this series, Categories 8 through 12. The size categories were developed from a number of preliminary test/practice burn events where material was sorted into perceived naturally occurring clusters. Fragments with two dimensions less than 5 mm and one dimension less than 10 mm were excluded from analysis as although potentially informative, these could not be collected consistently and thus true comparisons were not possible.

Sieves were not used to separate material as they can cause considerable mechanical damage to fragile materials and do not separate shape differences. By measuring three dimensions fragments could be separated into three distinct shape series (Small, Longitudinal and Non-longitudinal) and fragmentation characteristics could be assessed within each series. The number of categories used was based on preliminary test/practice burns to ensure that size categorisations reflected the material at hand and did not arbitrarily divide clear size groupings and thus obscure any trends in the data. The size categories selected reflect clear clusters observed in the preliminary test/practice burns. Following sorting each category was weighed and the proportional mass determined. Proportional mass was calculated as percentage weight for each category within each limb group (0, 24, 56 and 168 h delay). Proportional masses were calculated to allow direct comparisons between each category in the differing delay periods.

3. Results

3.1. 0 h and 24 h delay

When the recovery of remains is delayed by 24 h the effect on fragmentation is mixed, as seen in Fig. 2. In the Small series there is a clear trend of higher fragmentation when recovery is delayed with higher proportional masses seen in all categories for almost all burn events. In Category 2, burn 3, lower proportional masses were recorded following 24 h delay, but both other burn events showed large increases in proportional mass. This increase in proportional mass is interpreted as being the major trend with the isolated data point showing a reduction in fragmentation originating from variable factors in the burn or post burn environment altering proportional mass in this specific burn event and category.

In the Longitudinal series the effect of delayed recovery is more complex. In Category 4 there is no indication of a difference in fragmentation between 0 and 24 h delayed recovery. In Category 5 responses vary between the burns, but both burns 1 and 3 show clear reductions in proportional mass when recovery is delayed. In

Table 1
The number of *Sus scrofa* limbs used in the burn events and burn characteristics for each limb group.

Burn event	Fire 1			Fire 2								
	0 h delay			24 h delay			56 h delay			168 h delay		
	# of limbs	T_{max} (°C)	Time at T_{max} (min)	# of limbs	T_{max} (°C)	Time at T_{max} (min)	# of limbs	T_{max} (°C)	Time at T_{max} (min)	# of limbs	T_{max} (°C)	Time at T_{max} (min)
1	2	741	100	2	790	100	1	843	60	2	876	80
2	3	701	70	2	562	70	2	–	–	2	602	100
3	1	848	80	1	869	90	1	843	70	1	820	110

All limbs used were forelimbs except for burn 3 which used hindlimbs.
T_{max} refers to the highest temperature reached in any one 10 min interval, averaged from 1 min data.
Time at T_{max} refers to the time since fire start and marks the beginning of the 10 min interval.
No temperature data was recorded for Burn 2, 56 h delay due to thermocouple probe failure.