Document Title:	Recovery and Interpretation of Burned Human Remains
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Document No.:	237966
Date Received:	March 2012
Award Number:	2008-DN-BX-K131

Project Title: "Recovery and Interpretation of Burned Human Remains"

National Institute of Justice
Award Number #2008-DN-BX-K131

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ABSRACT

Victim remains at fatal fire scenes are typically difficult to detect, recover and handle. All of the burned material at the scene, including biological tissue, is often modified to a similar appearance, and bones, in particular, become discolored, brittle, and highly fragmented. As a consequence, these remains are often missed, disturbed, altered, or even destroyed during scene processing with the existing protocols.

The added postmortem fracturing, fragmentation and bone loss resulting from these recovery techniques hinder the already difficult task of autopsy and laboratory analysis of burned human remains. This is especially problematic for bone trauma analysis, as its most immediate goal is distinguishing perimortem (forensically significant) trauma, from postmortem (not forensically significant) alteration. The substantial addition of trauma features created by fire and then recovery can result in a daunting analytical task.

Lack of on-scene recordation of relevant information related to body positioning and contextual relationships of remains as well as other physical evidence at the scene, further complicate trauma analysis, biological profile estimation, and event reconstruction. For the trauma analyst, it is arguably difficult to detect and characterize atypical, potentially forensically significant trauma, if the extent of exposure of individual portions of the body to fire is unknown. In addition, very little and often contradictory information regarding what is considered “normal” fire alterations of the human body had been presented. This information lacuna notably included specific burn sequences of soft tissue and patterns of hard tissue modification. The same problem affected estimates as simple and relevant as whether a missing element was ever present at the scene, missed during recovery, or totally consumed by the fire.

The present study addressed these problems by linking rigorous scene recovery and documentation methodologies with subsequent laboratory analyses (in particular, bone trauma analysis) of heat altered human remains from fatal fire scenes. This was accomplished by: 1) developing and testing effective fatal fire scene recovery protocols and guidelines, which have proved to maximize the location, documentation and recovery of biological tissues (including bone), while minimizing postmortem bone alteration and damage due to collection and transport methods, 2) precisely documenting and presenting “normal” soft tissue burn sequences and resulting bone modification in fully fleshed human bodies, burned under controlled

(crematorium) conditions and from actual forensic cases and 3) analyzing the macro- and microscopic effects of fire and heat on previously well-described diagnostic characteristics of tool marks in bone, which served to demonstrate that most of these diagnostic traits can be usually preserved, with their full evidentiary value, even after calcination.

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CHAPTER I

Introduction

Statement of Problem

Fatal fire scenes provide some of the most difficult investigative challenges for fire responders, investigators, forensic experts, and law enforcement agents. In addition to determining the cause/origin of fire, investigators must reconstruct *circumstances of death* of the victim, utilizing evidence related to cause and manner of death. In normal (non-burned) human remains, this evidence is derived from body location and positioning at the scene, and identification of perimortem trauma.

Assessments of cause and manner of death are significantly more difficult if the scene and the victim are subjected to fire. Perpetrators often use fire in order to: 1) totally destroy the body; 2) destroy features allowing for victim identification (e.g., facial features or fingerprints); or 3) destroy evidence related to the circumstances surrounding the death. Consumption of soft tissues by fire can significantly hamper analysis by other specialists (such as forensic pathologists) and, therefore, analysis of burned human remains is a common task ascribed to forensic anthropologists.

The forensic anthropological analysis of a set of human remains, whether burned or not, first requires an understanding of the context of the remains. Contextual scene information is best understood when documented and recovered using archaeological methods, which are absent in current fatal fire scene recovery protocols. As a result, forensically significant contextual data pertaining to body location and positioning within the burned structure are often not carefully noted.

In addition, burned human remains and other evidence may go undetected, or worse, be damaged by recovery efforts. Any missing or undetected remains could be potentially recovered during additional searches, but if remains are damaged during the recovery effort they can be rendered useless for the investigation. Modifications at the scene make it difficult to distinguish the body and burned skeletal elements from the surrounding substrate debris, increasing the chance of missing or trampling some of the burned and fragmented remains during a cursory examination of the scene

Once the surviving detected bones arrive to the laboratory, one key inference to be made is whether any missing skeletal elements were present at the scene before the fire, or consumed by combustion. A consideration of recovery methods employed is vital, but a reasonable assessment of the probability of missing elements surviving a typical burn episode, is also needed. This determination requires an in-depth knowledge of typical burning sequences and modification patterns of each area of the body, including normal fire-induced postural changes and the role played by soft tissue. Some critical information regarding how human bodies burn in fires however is currently not available in the literature aside from a few anecdotal discussions on the topic.

With respect to tool marks on bones, much information regarding general tool class characteristics of the inflicting tool or implement can be obtained through macroscopic, but especially microscopic, analysis of the inflicted mark in unburned bone. Before interpreting the absence of a diagnostic feature in a cut mark as evidence that a particular tool was not used as the inflicting weapon, it is imperative to assess whether these diagnostic traits could have been altered or erased as a result of the fire.

It becomes obvious that in order to perform an appropriate forensic anthropological analysis of burned human remains it is necessary to: 1) ensure that all surviving skeletal elements and information related to body location and positioning, as well as other relevant taphonomic influences, are recovered at the scene, and that further alterations of the evidence from scene to laboratory are minimized; 2) recognize the extent and relative sequence patterns in which different body areas are consumed by the fire, taking into account tissue thickness and the temperatures typically reached depending on body positioning; and 3) be cognizant of the effect of fire on the diagnostic traits employed to determine class characteristics in unburned bone, as well as their limitations and necessary modifications when applied to burned bone.

Rationale for Research

The ultimate goal of the research project was to address the problems outlined above through the construction and validation of basic standards and guidelines of utility to forensic professionals and fire investigators involved in the interpretation of burned human remains from fatal fire scenes. This goal was implemented through a set of interrelated experimental and observational studies designed to enhance onsite location, evaluation, and preservation of burnt human remains; forensic laboratory analysis of this type of evidence (especially skeletal trauma); and ultimately, fatal incident reconstruction. From an operational point of view, this translated into the following specific *Research Objectives:*

Research Objective 1

Producing comprehensive guidelines and a user-friendly data collection database for the recovery of human remains from fatal fire scenes. Enhanced fatal fire scene recovery protocols and guidelines are aimed at enhancing the success rates of the location, recovery and preservation of human skeletal elements and tissue at the scene, while maximizing the compatibility of forensic anthropology protocols with those of standard fire investigation.

Research Objective 2

Describing basic, meaningful patterns of fire alteration to the human body. This will produce a Daubert-compliant baseline for the recognition and interpretation of forensically significant perimortem trauma to the body or other forms of intentional body manipulation or modification prior or during the fire episode.

Research Objective 3

Assessing and validating the applicability of conventional (non-burned) protocols for the analysis of sharp trauma to burned bone. This was accomplished by assessing rates of preservation and patterns of alteration of quantitative and qualitative tool class mark characteristics on bone, both under laboratory and near-real conditions, and with animal and human models.

CHAPTER II

Research Component 1: Recovery of Burned Human Remains

Materials and Methods

Research Component 1 had three main objectives: 1) The development and testing of new and efficient fatal fire scene recovery protocols, 2) Provide comparative data relating to contextual information, such as temperature distribution around the body and burn patterns found on human remains from real fires, for use in *Research Component 2*, and 3) Provide comparative osteological materials for *Research Component 3.*

Archival Research

In order to identify key areas that needed improvement in current fatal fire recovery methods, a review and analysis of existing documentation for 93 fatal fire scenes between 2000 and 2006 was conducted. This served to identify: 1) key variables regarding fire and victim investigation, 2) current deficiencies in the recording of variables relating to the fire scene and the victim, and 3) inconsistencies in variable coding affecting data management, sharing, and analysis. A set of 30 qualitative and quantitative variables describing the most relevant parameters of fire scenes was created, based both on anthropological analysis needs and the specifications in current fire investigation protocols (chiefly DeHaan, 2007).

Processing Mock Fatal Fire Scenes

The comparative (*mock*) fatal fire scene exercises served to: 1) test and refine the new forensic archaeological protocols in controlled near-actual conditions, and compare them with the current protocols, 2) provide detailed temperature readings from different areas of the fire scene near the body (for comparison with the experimental conditions in *Research Component 2*), and 3) provide comparative osteological materials for *Research Component 3.*

The proposed recovery protocols represent modifications of conventional forensic archaeological techniques, aimed at non-burned human remains (Dirkmaat 2002, Dirkmaat and Adovasio 1997, and references therein). They include: 1) detailed mapping and excavation of the human remains, using both grid system, electronic total station and GPS data, 2) careful written, photographic and videographic scene documentation of evidence and recovery process, and 3) evidence collection and treatment (Dirkmaat, 2002).

A total of six (6) subsequent mock scenes were processed (one provided no information due to unforeseen circumstances), in each case attempting to improve upon some aspect of the recovery protocol to make them even more efficient and effective. These exercises served to evaluate the advantages or disadvantages of the new guidelines over current standard protocols in terms of efficiency, effectiveness and costs, prior to their implementation and testing in real situations. Independent trained professionals in realistic, non-compromised conditions conducted the testing of the protocols.

Thermocouple Data

Direct temperature readings, obtained with thermocouples attached to a data recorder, in proximity to the animal model at different mock scenes served to assess: (1) the range and maximum temperatures expected to be reached during a regular house fire in different structures; (2) the temperatures reached in around the body, and their relationship to external temperatures; and (3) from the former, assessing the protective (thermal isolation) effect of soft tissues at different temperature ranges, using domestic pigs (*Sus scrofa*) of medium to small size ranges as a proxy for the human body.

Processing Actual Fatal Fire Scenes

Comprehensive analysis of victim recovery methods used at actual fatal fire scenes served to: 1) test the applicability, advantages and weaknesses of the new protocols in real situations, 2) provide a comparison with past cases processed with current protocols (see *Archival Research* section), in terms of information gained, processing times, effort and costs, and 3) provide a realistic baseline for assessing the validity of the results and observations obtained at the mock scenes and controlled cremations.

Results

Archival Research

Analysis of the documentation of the 93 historical fatal fire scenes revealed that the majority of the 30 key variables researched here were not being adequately documented, even when they are typically identified as relevant variables in the fire investigation literature (DeHaan, 2007). In almost all cases, the number of incomplete fields in each category far outnumbers those that are adequately documented. The level of incomplete documentation ranged from approximately six to sixty percent of all fields that should be recorded in the course of an investigation of a fatal fire scene.

Therefore, it must be concluded that the forms and protocols currently used in fatal fire investigation, do not result in consistent or complete documentation of the information needed to conduct a proper investigation. These deficiencies in the recording of variables relating to the fire scene and the victim, and inconsistencies in variable coding affecting data management, sharing, and analysis indentified in this analysis were used to guide the creation of new fatal fire scene recovery protocols. These new protocols and data collection procedures produce reliable and consistent data collection and sharing between multiple observers, minimize errors in the recording of data, and expedite the data recording process.

Processing Mock Fatal Fire Scenes

1. Pilot Study: Strathroy, Ontario Mock Fatal Fire Scene (February 6-8, 2009)

The first mock fatal fire scene documentation and recovery exercise was conducted February 6-8, 2009. This mock scene served as a preliminary assessment of the utility of data collection forms, allowed for the careful notation of fire dynamics, and identification of potential issues related to conducting future mock scenes recoveries. One important outcome of the new recovery protocols was the simplification of procedures and reduction of time required for scene processing. It was believed that the refinement and streamlining of data collection forms would both simplify and reduce the total amount of time required to process a fatal fire scene.

2. Malahyde, Ontario Mock Fatal Fire Scene (September 25-27, 2009)

A major research design change was introduced for the second mock fire. Additional screening units and increasing screening times were introduced so that sieving efforts could keep pace with the excavation team, however, even these additions proved insufficient to keep pace with the amount of excavated material generated. The excavation team was forced to practice extreme precaution in all areas, and advance at a slower pace in all areas. Consequently, it was decided to reduce the area in which the mock evidentiary items would be planted in future exercises in order to ensure their complete excavation during a two-day period, even if adverse conditions were present.

4. Franklin Center, PA (November 5-8, 2009) and 5. McDonald, PA Mock Fatal Fire Scene (November 20-22, 2009)

A new recovery strategy was devised to speed screening times, reduce the amount of personnel necessary to process the scene, and increase and speed up the feedback between the screening and excavation teams. This strategy was based in the introduction of a “presorting team" between the excavation and the screening teams. The presorting team was able to search, sort and remove irrelevant materials from the sediment on tarps instead of screening. If any potentially relevant item was found during this search, both the excavation and screening teams could be warned, in a timely manner, to be exhibit precaution in sensitive areas.

This strategy proved to be extremely successful and served to reduce the number of screens and screening time, allowing for the processing a large volume of material in a realistic time, significantly increasing detection rates, and increasing evidence recovery rates from 66% to close to 100%, along with reduced screening time and personnel. Recovery rates were also higher for small clustered elements, especially the closer the evidence was to the body or other major evidence.

Protocol improvements resulted in reduced recovery times, with more than half of the total structure areas processed in 1.5 Days (around 8 hours). Fire scenes are more complex than regular crime scenes, and thus should take longer, not shorter to be processed. However, processing a full two story house following these protocols, with the subsequent information gain, should increase processing times by one or two days, not weeks.

6. Waynesboro, PA Mock Fatal Fire Scene (March 25-28, 2010)

Following the results obtained in the previous exercises, it was not necessary to introduce further modifications in either the protocols or the research design. The additional fire exercises performed during the reported period rather served, as a final test of the already modified protocols.

The recovery times and rates obtained in the house exercise were consistent (virtually identical) to those obtained in the previous exercises when the modified protocols were applied. This suggested that reduced, simple scenes such as a mobile home or a partially burned house can be optimally and completely processed under two days while a more complex two-story house can be completed in approximately three days.

Thermocouple Data

All thermocouple readings indicate a rapid and almost linear increases in the overall temperature in unattended fires, well past flash point, and illustrate the protecting effect of the body tissues on the body surface areas not directly exposed to the fire source. Even in the absence of chemical accelerant and in relatively unconfined areas, temperatures above 1000°C (akin if slightly inferior to those in funeral crematory ovens) can be attained in times as short as half an hour in fires of these characteristics. However, these peak temperatures appear to be short lived, with most of the fire cycle typically taking place under 1000-900ºC. Flash point temperatures can be reached between 10 and 25 minutes, depending on the characteristics of fire and structure. Even if unattended, most of the high-temperature (above 500ºC) fire cycle was basically completed within around one hour from initial ignition in all cases.

Even when peak temperatures above 1300ºC were observed in some cases, temperatures on the body surfaces away from the fire typically kept at least around 100ºC lower than room peak temperatures. Body interior and protected surfaces typically do not even reach boiling temperatures until room temperature rises to around 500-600ºC. Before flash point temperatures are reached, temperatures of protected body areas (underneath the body) keep at least around 100ºC below those of exposed areas.

Apart from the comprehensive documentation of physical and contextual data, an important outcome of these protocols was the simplification of procedures and reduction of time required for scene processing. This was accomplished through the application of technological enhancements readily available to law enforcement (e.g., the total station, and Global Positioning System [GPS] units), as well as through the concurrent implementation of appropriate search, location, documentation and recovery steps. This was shown to actually reduce recovery time and personnel, while dramatically improving recovery rates and documentation, even in large, complex mass fatality scenes with highly altered and fragmented remains (Dirkmaat *et al.* 2001, 2005).

Processing Actual Fatal Fire Scenes

The primary consultant (GOO) processed 16 fatal fire scenes from the beginning of 2008 until the end of 2009. Five of those scenes progressed to the point in which an archaeological excavation was used. Employing the methodologies and newly developed protocols significantly increased the amount of evidence and contextual information that is being collected at each scene.

CHAPTER III

Research Component 2: Analysis and Interpretation of Heat Altered Bone

Materials and Methods

This component of the research was aimed at the following objectives: 1) study and document normal burn patterns in fully fleshed human remains cremated under controlled conditions (in a crematorium), 2) assess the validity of these burn patterns when applied to real situations, by comparison with real forensic cases and (3) examine the typical temperature ranges and regimes that can be expected in common fire scenes. These goals were accomplished through (1) comparison of normal burn patterns documented in a crematory setting with (2) those observed in forensic cases, incorporating scene information and documentation.

Burn Pattern Charting of Forensic Cases

A burn and modification patterns of 74 fatal fire victims autopsied at the Office of the Chief Medical Examiner, New York City, NY, was conducted. The burn patterns documented in the photographic evidence from the cases were charted and digitized to produce standard homunculi/ diagram sheets akin to those employed by forensic pathologists to illustrate autopsy findings. These diagrams were then converted to jpeg files and analyzed in ARCGIS.

Documentation of Controlled Cremations

In this research the burn patterns of eight fully fleshed complete bodies in a crematory retort under controlled temperatures was studied. The individuals were either placed on their backs in the prone position in the middle of the retort, or were placed face down in the middle of the retort. After considering a number of study methodologies, the most efficient, realistic, and economic research design consisted of video recording and photographing the cremation process at randomly chosen intervals from the exterior of the retort without changing the temperature or removing the remains from the oven. In addition, detailed notes were taken during the cremation process and again while viewing the video of the cremation. Standardized data collection forms related to the burn patterns were created.

Results

Burn Pattern Charting of OCME Forensic Cases

Composite images based on the surface area and degree of severity of heat alteration observed in 74 forensic cases from OCME were used to document and illustrate the normal burn pattern to be expected in a human body subject to fire conditions, if no other trauma or body modifications are present. The definition of the burn patters was found to be dependent on sample size, so that sample size increases resulted in clearer and better defined alteration profiles, rather than obscuring them by the addition of extra noise, even if atypical individuals were also added to the sample.

A clear relationship with a very strong correlation between the extent of the heat altered area and the severity of the alteration, was observed in those individuals showing altered surfaces below 80% of the total body surface. This is consistent with the combination of both variables being expressing exposure times. Outlayers from this baseline sample, exhibiting low altered surface areas but severe heat alteration showed to be, upon closer examination, individuals with uncommon or criminal manners and circumstances of death. The composite images for homicide and suicide cases showed patterns sharply departing from both the overall normal pattern and that of accidents, the later two being in complete agreement.

This permitted to establish the utility of the produced normal patterns of heat alteration to identify suspicious cases, which appear individual and collectively as outliers respect to the normal patterns. A general rule of thumb would be closely and carefully examining any body displaying a heat-altered area below 80% of the total body surface, while presenting any exposed bone.

As predicted by Symes and colleagues (2008), the obtained overall degree and pattern of heat alteration, as expressed in different body regions, can be most accurately predicted from tissue thickness, particularly in relation to the sequence in which the areas exposed to heat will attain a certain degree of alteration. Areas covered by thin layers of soft tissue, and those exposed in pugilistic posture display higher degrees of alteration earlier than more protected areas, matching the observations in the crematory exercises of this project (see above).

Documentation of Cremations

A total of eight cremations were studied over the course of this research project. Each cremation was documented by photography, videography, and detailed written notes. Biological, medical and biographical information of the individual was also documented. After individual documentation each individual record was identified only by a unique cremation number, in order to preserve privacy and avoid any possibility of personal identification. No perimortem trauma was present on any individual included in this study.

Modification Patterns. The phases described below provide a relative sequence of modifications to the human body; variations in body form, mass, state of health, and other factors of the individuals resulted in quite variable specific timing of the events in the sequence.

Phase 1. Modification of External Skin. In the majority of cases, blistering and splitting of the skin was noted before any other changes to the body occurred.

Phase 2. Flexure of limb units into the Pugilistic Posture. The 'pugilistic posture' is derived from contraction of the denser muscle masses in response to heat. It appeared in all individuals lying face-up. The hands and fingers were the first to flex. This was generally associated with significant fire alteration of first digit (thumb), often was followed by disassociation of the digit from the hand. Pugilistic posture of the upper limb occurred at the same time or slightly after the hands and fingers flexed. In the individuals who were placed on their stomachs, with arms to the sides of their body, flexure at the elbow was not observed. The lower limb always flexed later than the upper limb did, probably related to its larger muscle mass. The individuals placed face down in the retort did not exhibit flexure at the hip joint.

Burn Sequences and Patterns in the Appendicular Skeleton

Phase 3. Retraction of the Muscles from the Bones. Following increased exposure to heat, the muscles of the thigh and upper arm shrank, eventually pulling off and away from the underlying bones (at the elbow, wrist, knee, and ankle). As a result, the distal femora and humeri became charred and calcined much earlier than the proximal ends of these bones.

Phase 4. Disassociation (detachment) of the hands. The hands, excluding the thumbs, were next to disassociate after the distal radius and ulna were exposed, and always before the feet detached. Metacarpals and phalanges were the first hand bones exposed, followed by charring (black) and calcination (white) of the dorsal surfaces

Phase 5. Disassociation of the feet. Generally, the next major alteration of the body was detachment of the foot from the distal tibia. The plantar surface of the calcaneus generally burned first. The dorsal surfaces of the metatarsals and phalanges were also differentially burned black and later calcined.

Phase 6. Longitudinal and transverse fractures of exposed bones. As the muscle retracted, bones were exposed to heat, which resulted in a loss of moisture, destruction of organic content, warpage, and exhibited longitudinal and transverse fractures

Phase 7. Disarticulation of the patella. Concurrent with the burning of the foot, the patella was modified relatively early in the burn sequence. When the patella did detach, it generally fell to the lateral side of the leg due to the bent-kneed position in the pugilistic posture.

Phase 8. Internal aspects of thorax exposed. The first noted changes to the thorax were the exposure of the ribs to heat resulting in external charring and calcination. Shortly thereafter, a window appeared in the thorax. This window resulted from the burning and then fracturing of the ribs in association with the reduction and destruction of the internal organs.

Phase 9. Midshaft fracturing of upper limb long bones, followed by burning of internal bone structures. The intact bone burns initially on the outside until the bone calcines and eventually portions of the shaft become detached and fall away. When that happens, often the bone will ignite internally and burn from inside out. In most cases, following warping and appearance of significant fractures in the distal portions of the long bones, the distal humeri and femora detached from the rest of the bone shaft. The distal end of the fractured femoral shaft then tends to exhibit a frayed appearance. The distal tibiae also exhibited significant fractures, but the fibulae often remained intact.

Burn Sequences and Patterns in the Skull

Phase 1. Mandible. The inferior and lateral aspects of the body of the mandible burned and become calcined even before all of the facial skin had burned off completely.

Phase 2. The Cranium. The parietal bones exhibited fire alteration earlier than the frontal bone. The cranium fractured as it heated. Fractures were seen throughout both parietals and the occipital as the cranium heated, but they did not occur in the facial bones (e.g., frontal, maxillae, zygomatics) until complete calcination of those bones occurred. The facial bones, with the exception of the maxillae and the superior frontal, were the last bones to calcinate.

Burn Modification Patterns in Individuals Lying Face-Down

All of the heat alteration patterns noted above were observed in individuals who were placed in the retort in the prone (face-up) position. The patterns were fairly consistent and uniform from individual to individual. However, when the body was placed face down in one cremation, the burn pattern noted was dissimilar to the pattern noted in the prone individuals.

The general sequence of changes noted for this individual:

1. The distal phalanges of the hands were the first bones to become exposed, following removal of skin and became detached prior to any other bone being affected.

2. The spinous processes of the vertebrae, vertebral ends of the ribs, medial borders of the scapulae, and the occipitals became calcinated early in the burn process. No abdominal window or rib end fraying was observed when the body was face down.
3. The lower legs flex at the knees, assuming the typical pugilistic posture that the arms had assumed in the previous burns.
4. The medial and inferior edge of the scapulae were flexed dorsally to the point that the inferior border of the scapula was facing away from the body.
5. The feet disassociate before the leg has finished moving into final pugilistic posture.
6. The lower leg continues to flex at the knee, even to the point of pulling the tibia and fibula up and toward the back. The tibiae and fibulae flex over the posterior of the femora with the distal tibia and fibula close to the proximal femora and pelvis.
7. The sternal end of the ribs, anterior iliac crests, and sternum were the last regions of the body to burn.

The first bone of the cranium to calcinate was the occipital and the parietals quickly followed. The frontal and facial bones began charring at approximately the same time as the calcination of the occipital. The cranium fragmented into disassociated pieces soon after being completely exposed.

Discussion: In Symes *et al.* (2008), a detailed discussion of burning and fracture patterns of human bones of fire victims was presented. Although most of these observations were confirmed in the present controlled study, deviations from this pattern observed in real-case experiences suggests that the sequence of fire alteration to bones is dependent upon body and limb positioning and orientation prior to burning. Additionally, the weight and composition of fat and muscle of the individual and prior pathological conditions must be considered when assessing a burn pattern in a fatal fire victim.

CHAPTER IV

Research Component 3: Heat Alterations in Traumatized Bone

Materials and Methods

Once normal, expected heat-induced bone trauma and damage due to recovery have been identified and controlled for, the remaining question is whether the same diagnostic traits used to detect, assess and identify forensically significant perimortem trauma in non-burned bone (including the identification of inflicting tool class characteristics), are still present and effective after fire alteration. This component of the research addresses this question for sharp trauma, through the analysis and documentation of saw marks in human bone and an animal model (*Sus scrofa* limbs), before and after burning in near real and laboratory conditions.

Data were collected from three sources: 1) a sample of human bones previously subjected to trauma under experimental conditions in a previous research NIJ project; 2) a sample of animal bones generated during the mock scene exercises in *Research Component 1*, and 3) a second animal sample that was generated by applying the same trauma-induced treatment as the other two samples, and then burned under controlled conditions in the laboratory.

Results

Comparing Organic Compositions

The human and pig samples in data sources A and C did not show significant differences in initial wet weights (Welch-corrected $t_{14}=0.0669$, $p=0.948$) although, as mentioned above, the animal bones showed a much higher dispersion.

Wet (initial) weight was a perfect predictor of water loss in both samples, with perfect correlations ($R=1$, $p<0.001$.) Animal and human bones did not show either differences in the slope of the relationship between wet and dry bone, this is to say, in the rate of increase of water loss per unit of wet weight ($F_{1,24}=0.3977$, $p=0.534$.) However, they showed a significant, if small difference in the intercept ($F_{1,25} = 34.7826$, $p<0.001$) with the human bones losing on average around 0.02 g more water content than animal bones, independent of initial weight. This is consistent with the higher density expected in animal bones, although the differences are almost negligible.

When dry versus ash weights were compared (indicative or organic matter content), no differences between samples were in the slope of the relationship ($F_{1,24}=2.6448$, $p=0.117$), this is to say, in the rate of organic content loss as dry weight increases. However, human bone lost much more organic matter on average (more than 0.6 g for any given initial dry weight, F1,25=12.103, p=0.002.) Dry weight was an almost perfect predictor of ash weight in *Data Source C* (animal), explaining more than 99% of the variance in organic matter loss ($p<0.001$), by just around 68% of variance explained in the human tissue ($p<0.001$.) These results are again indicative of the lower density of human bone, with a higher ratio of organic to inorganic matrix content.

Preservation of Metric Characteristics: Minimum Kerf Width

No significant differences were found in average kerf widths before and after burning, either in pigs ($t_{24}=0.5337$; $p=0.299$) or in humans ($t_6=0.2127$; $p=0.4193$.) Neither pigs ($p= 0.7468$; Gaussian approximation) nor humans ($p=0.6875$; Gaussian approximation) showed any directionality, indicating that the kerfs did not tend to either contract or expand in a consistent manner.

Finally, no differences were found either between the degree of pre- to post-burn alteration of the human and animal samples ($t_{11}=0.7258$; $p=0.2416$, Welch corrected.)

Calcination does not seem to result in any definite pattern of changes in the dimensions of kerf defects, either in human or pig remains. As a matter of fact, the observed average absolute change in dimensions after burning is smaller than the respective standard deviations of kerf widths before burning (0.0043 for 0.0056 in humans, and 0.0055 for 0.0137 in suids), even with the small sample size of the human sample, with the assumption of the usually attached underestimation of the standard deviation. In other words, the differences in kerf width after and before burning are smaller than the variability observed in the original samples. Given that all the original cutmarks were inflicted with virtually identical blades, and thus the original differences between cutmarks can be positively attributed to measurement error or random noise, the apparent changes in pre- and post-burn dimensions can be attributed to the same sources.

These results indicate that (1) at least in the case of kerf width, extreme heat alteration does not seem to affect metric measurements, which therefore will conserve their diagnostic and evidentiary values, and (2) consequently pig bones are also a valid proxy to human remains when analyzing these metric traits.

Comparison of Trait Preservation Among Species

Both the *Data Source A* sample of human remains and *Data Source C* sample of animal bones received the exact same treatment, serving to compare the effects of fire on trauma class characteristics in human and animal remains. Additionally, the comparison of results from identical experiments in human and animal remains will serve to assess the validity for future research of observations based on animal models.

A comparison was done between the observed "presence" of specific traits before burning (pre-burn) and after burning (post-burn) for *Data Source A.* The frequency of each trait was then calculated in order to access the frequency in which individual traits were observed before and after burning. There is an increase in total number of observed traits after the bone sections were burned, increasing from 67 observed traits to 77 observed traits. For *Data Source A* individual traits were never observed in higher frequencies before burning than after burning. In fact, for four traits (exit chipping, blade drift, tooth hop, and pull out striae) there was an increase in the number and frequency of observations in the bone sections after being burned. The conclusion is that not only are class characteristics and traits preserved but also in some cases they are actually easier to observe after exposure to burning in the human bone sample.

A comparison was then done between the observed "presence" of specific traits before burning (pre-burn) and after burning (post-burn) for *Data Source C.* The frequency of each trait was then calculated in order to access the frequency in which individual traits were observed before and after burning. The total number of observed traits was the same before and after burning. There are three traits (kerf flare, tooth hop, and tooth imprint/floor dip) in which there was an increase in frequency of observed traits after burning. Unlike in Data Source A, more often there is a decrease in the frequency of observed traits after burning. However, the rate of destruction of traits is slight. The conclusion is that class characteristics and traits are preserved after exposure to fire. This comparison also provides evidence supporting the use of an animal model as an appropriate proxy for accessing preservation of class characteristics in saw trauma analysis.

A comparison was made between the total number of observed traits after burning that were not observed before burning. For Data Source A, 10.26% of all trait observations made were present after burning and not observed before burning. For Data Source C, 10.22% of all trait observations made were present after burning and not observed before burning. The gain in observable traits after burning is virtual identical (roughly 10%) for human and pig. This also provides evidence supporting that an animal model is a suitable proxy for accessing trait preservation and the analysis of sawmarks in humans.

A comparison was made between the total number of observed traits after before burning that were not observed after burning. For *Data Source A*, 1.71% of all trait observations made were present before burning and not observed after burning. For *Data Source C*, 8.89% of all trait observations made were present before burning and not observed after burning, but the differences in trait preservation between species are not statistically significant. This supports that an animal model is a suitable proxy for assessing trait preservation and the analysis of sawmarks in humans. In spite of the higher density and surface area of the bone in the animal model, trait loses (traits that were observed before but not after burning) are not significantly different between species. Even if, in the worse case scenario, this were an effect of sample size, the observed values are higher in the animal model, indicating that results obtained from animal bones would in any case represent conservative estimates of the degree of trait preservation expected in humans, minimizing the risk of type I error in the interpolation of animal results to human bone. Once again, this supports the idea that pig bones are an appropriate proxy for the study of saw marks in human bone.

Treatment Comparison: Laboratory vs. Fire Scene Conditions

Finally, the comparison of diagnostic trait frequencies between animal bones burned at the laboratory under controlled conditions and fleshed limbs burned in realistic house fires revealed the presence of significant differences between both treatments ($p<0.001$). However, these differences where in favor of the sample from real house fires, for the vast majority of diagnostic traits considered. This suggests that the degree of diagnostic trait preservation to be expected in real fatal fire victims would be even higher than that observed under laboratory conditions and presented in this report. Once again, essential traits and surface marks essential to identify and diagnose tool class characteristics are not completely (or even importantly) consumed by the fire, imposing a careful recovery and handling of the remains in order to avoid the destruction of relevant evidence.

Discussion

The analyses in this portion of the project confirm the idea that animal bones (in this case pigs) are an appropriate proxy for studying sawmark class characteristics in human bone, at least in controlled laboratory conditions such as those employed in this study. Most importantly, all data support the conclusion that class characteristics and traits are preserved in bone even after heat alteration, preserving even their overall metric characteristics. Evidence of class characteristics is still present after cremation, which imposes proper recovery in order to preserve the sawmarks in bone. Improper, incomplete or careless handling and recovery at the scene can result in loss or damage of relevant forensic evidence.

CHAPTER V

Conclusions

Discussion of Findings

Research Component 1

The results of the studies encompassed in Component 1 (basically archival studies and field scenes) have both negative and positive implications. The examination of archival records of past but recent fire scenes revealed a level of inconsistency and data losses beyond the most pessimistic initial expectations. Basically scene information appears to be mostly recorded in a case-to-case anecdotal fashion, with the vast majority of case reports missing not only key elements for the anthropological analysis of human remains, but often also for fire investigation.

Conversely, the field exercises demonstrated that the classic fire scene recovery protocols are extremely prone to cause information and evidence losses. The upturn is that the new protocols developed in this research demonstrated that a fatal fire scene can be completely excavated, with comprehensive documentation, high evidence detection and recovery rates, as well as minimal evidence alteration in a matter of days, rather than weeks. Results indicate that a complex scene, like a two-story house that has burned to collapse can be processed and documented in two to three days. Burned to the ground mobile homes in one to two days.

The high rate of evidence recovery, as well as the identification of spatial and stratigraphic patterns attained during the fire exercises also demonstrated that these elements can still be detected, identified and analyzed even after aggressive fire suppression efforts.

Research Component 2

The results of Component 2 demonstrate that regular, clear normal patterns of heat alteration of the human body can both be identified and successfully employed to identify suspicious cases. In particular, the agreement between the patterns observed in funerary cremations and those inferred from regular case documentation strongly indicate that efficient and systematic case documentation, analysis and comparison may represent the most promising research line to improve our understanding of heat related trauma to the human body.

Concurrently, the information provided by thermocouple readings from fire structures, illustrating the dynamic nature of temperature regimes in and around the body, coupled with the crematory observations on the influence of body position and posture on burn patterns further stresses the importance of careful scene documentation and processing.

Research Component 3

Research Component 3 provided clear answers to two main questions, relevant both for forensic practice and future research. First, the high rate of preservation even after calcination of forensically significant tool marks indicates that it is extremely wrong assuming that fatal fire scenes can be processed more rapidly than conventional ones, or using substandard recovery protocols, as most evidence is destroyed. Actually, diagnostic traits indicative of the class characteristics of the tools used to inflict trauma on the bone appear to be easier to detect and identify in burned bone. Due to the brittleness of burned bone, especial care should be taken during scene recovery, in order to minimize the potential damage to this type of evidence. On the other hand, the mimetic appearance of burned remains, which during a fire acquire a coloration and texture identical to the substrate, would recommend the presence of forensic specialists trained to identify burned human bone at the scene, from the very early stages of identification.

The combination and internal consistency of the temperature ranges and conditions recorded in and around the bodies in the fire exercises, those at the crematoria and the laboratory and the preservation rates of both skeletal elements and bone surface marks observed in the later, strongly indicates that attributions of missing limbs or major elements to complete destruction by the fire must be very cautiously proposed, when not completely abandoned in the forensic practice.

Secondly, the results of the furnace experiments indicate that animal bones (at least in the case of domestic pigs) can serve as an efficient proxy to study sharp trauma on burned bone, in spite of the differences in density and composition between both types of bone.

Implications for Policy and Practice, as Well as Future Research

Basically, the results obtained in the present can be summarized in four major points relevant for forensic policy and practice. The study demonstrates that (1) Significant osteological evidence and its contextual relationships are still preserved in a fatal fire scene, and this evidence can and is frequently lost or damaged when the classic scene processing protocols are applied, (2) heat alteration of the human body follows clear, normal and regular patterns, which can be detected and inferred through different means, both experimentally and through the proper documentation of forensic cases, and that can serve to identify potential criminal cases as departures from these patterns; (3) at the laboratory level, key diagnostic traits indicative of the type of trauma as well as of the tool used to inflict such trauma, can be preserved and analyzed in burned human remains, with little or no loss of their analytical value; and (4) animal bones can serve as a valid human proxy for human remains for sharp trauma research purposes.

The first three elements point especially toward the necessity of improving fatal fire scene processing, in order to minimize the loss, alteration or destruction of forensically relevant evidence, as well as the documentation of fire scene, fire response and body alteration in order to facilitate both ongoing forensic investigations and future research. Within this framework, this study provides:

1) Rigorous and detailed fire scene processing protocols, tested in the field demonstrating optimal evidence recovery rates. Their application in mock fires and real crime scenes have also demonstrated that they are realistically applicable to most fatal fire scenes, resulting in processing times that do not exceed significantly those of a common forensic scene, in spite of the much higher complexity of fire scenes. This is expected to benefit the analyses of all professionals involved, from anthropologists, to arson, and crime scene and fire investigators. The enhanced contextual data and evidence integrity (precise body position, detection and recovery of *all* bone elements, relationship of other physical evidence to the body) will benefit the morgue/laboratory analysis of burned human remains, and the final determination of events surrounding death.

   Furthermore, the standardized data collection forms provided in this report are aimed at enhancing and simplifying fire scene documentation and information sharing, allowing for rapid comprehensive documentation of all aspects relevant for the investigation not only of the human remains but also of the fire, without adding additional burdens to responders and investigators. The standardization of data coding and collection, as well as the integration of all scene data in a single dataset are expected to enhance team collaboration and coordination.

2) The normal heat alteration patterns produced in Component 2 provide a new baseline for the detection and analysis of atypical cases departing from this patterning, which may be indicative of criminal activities.

   Additionally, precise step-by-step explanations of the mapping and analysis process employed to produce the general patterns provided in this study are provided, allowing for their replication and refinement by other researchers and investigators. The clarity and explanatory power of the patterns has been found to depend largely on sample size, and our knowledge of heat alteration patterns would benefit enormously from new additions and samples.

3) The research protocols described in Component 3, paired with the demonstrated validity of animal models to approximate the response of human bones, open a wide window for the replication and further enhancement of laboratory research in this field. In particular, the forensic community would benefit from more detailed metric analysis, as well as the exploration of the effect of fire on the evidentiary value of other types of trauma.

In the same line, while the project demonstrates the utility as well as the research and inter-disciplinary information sharing opportunities of fire response training exercises, it also showed the difficulties for obtaining large sample sizes by a single team. Issues like the placement at the scene of obtrusive equipment like thermocouple wires, exercise scheduling, or funerary cremation donations evidenced the difficulties of obtaining large sample sizes under tight schedules. However, the number of these exercises, extremely common in the US, would allow for the compilation of large sample sizes and extremely useful information if approached from a clinical trial strategy. This is to say, combining the effort of a large number of teams who would collect and share the information following standardized protocols and data formatting.

We would like to close this report encouraging law enforcement officials and fire responders and investigators to contact each other and collaborate in this type of exercises in their jurisdictions. There is a very good chance of somebody in your area organizing these exercises or being very interested in attending to yours. Simple additions, like introducing animal models to simulate victims and processing the scene together, in multidisciplinary teams, discussing each other needs and approaches can result in extraordinary information gains and a very rewarding experience, apart from serving to improve exponentially our preparedness for the response to this type of scenarios. Whenever the technology is available, additional data, like basic thermocouple readings, are enormously useful and badly needed. Of course, we also invite any fire or scene investigator, or fire responder, to contact us to ask for any additional advice, information or assistance.

CHAPTER VII

Dissemination of Research Findings

Funding from the NIJ has afforded the investigators of this project the opportunity to disseminate information on proper fatal fire scene recovery protocols as well as soft tissue and skeletal trauma analysis of heat altered human remains. Workshops and lectures in the early phases of the project provided impetus for the creation and modification of the fatal fire scene recovery protocols. One of the objectives of the investigators was to reach out to other professionals involved in the investigation of fatal fire scenes to gain feedback on current practices, current deficiencies, and to better understand the importance of specific protocols for the investigation of the cause and manner of the fire. During these workshops, lectures, and discussions the investigators of the project were able to garner a better understanding of the procedures and goals of fire scene investigators and fire fighters. Information gleaned regarding current practices was used to justify and shape the current proposed scene processing protocols based on forensic archaeology.

Over the past two years, one of the primary consultants (GOO) has delivered over 40 lectures and presentations pertaining to fatal fire scene recoveries utilizing forensic archaeology. Recently, the Canadian Police Research Centre published his Master's thesis on proper fatal fire scene recovery based on forensic archaeological methodologies. His thesis has also been published in the magazine for the Canadian Association of Arson Investigators (CAFI), which was distributed to all CAFI members and every fire department in Canada.

The handling and transportation of human remains to the autopsy or laboratory is another area of concern. The ability of the investigators and forensic anthropologists to reconstruct a scene and interpret trauma is solely dependent upon proper recovery and documentation efforts. Through lectures and workshops the investigators of this project were able to disseminate imperative information regarding differentiating perimortem trauma from taphonomic influences caused by fire in human remains. The project has provided evidence that perimortem trauma can be distinguished from postmortem taphonomic influences of fire. Research has also provided a better understanding of burn pattern recognition. All information collected and analyzed during the project period will be published and distributed throughout the scientific and forensic community.

CHAPTER I

Introduction

Statement of Problem

Fatal fire scenes provide some of the most difficult investigative challenges for fire responders, investigators, forensic experts, and law enforcement agents. In addition to determining the cause/origin of the fire, investigators must reconstruct *circumstances of death* of the victim(s), utilizing evidence related to cause and manner of death. In normal (non-burned) human remains, this evidence is derived from body location and positioning at the scene, and identification of perimortem trauma.

Assessments of cause and manner of death are significantly more difficult if the scene and the victim are subjected to fire. It is not surprising that fire is a common method for attempting to conceal evidence of criminal activity inflicted on human victims. Perpetrators often use fire in order to: 1) totally destroy the body; 2) destroy features allowing for victim identification (e.g., facial features or fingerprints); or 3) destroy evidence related to the circumstances surrounding the death. Consumption of soft tissues by fire can significantly hamper analysis by other specialists such as forensic pathologists and, therefore, analysis of burned human remains is a common task ascribed to forensic anthropologists.

The forensic anthropological analysis of a set of human remains, whether burned or not, first requires an understanding of the context of the remains and the identification of specific factors that have led to the disturbance of the elements from their original anatomical position, loss of bone, and modification of individual elements. Contextual scene information is best understood when documented and recovered using archaeological methods, which are absent in current fatal fire scene recovery protocols. As a result, forensically significant contextual data pertaining to body location and positioning within the burned structure are often not carefully noted (particularly by precise mapping).

In addition, burned human remains and other evidence may go undetected, or worse, be damaged by recovery efforts. Investigators can return to a seen to re-search and locate any missing or undetected elements but if remains are damage from recovery efforts it is very difficult to reconstruct elements and conduct subsequent taphonomic and trauma analyses. Fatal fire scenes are much more complex not only because the body and individual elements are modified by fire, but because the entire surrounding contextual environment is similarly modified, resulting in a homogeneous coloration and intermingling of all materials. The drastic modification makes it difficult to distinguish the body and burned skeletal elements from the surrounding substrate debris, increasing the chance of missing some of the burned and fragmented remains during a cursory examination of the scene. If not detected, these important skeletal remains may even be trampled upon at the scene. Additionally, given the frail and brittle nature of burned bone, transport methods that include placing the body in flexible body bags, make them susceptible to further fragmentation and postmortem damage before they get to the forensic pathologist's examination table.

Once the surviving detected bones arrive at the laboratory, one key inference to be made for the forensic anthropological analysis is whether any missing skeletal elements were present at the scene before the fire, or consumed by combustion. A consideration of recovery methods employed is vital (as discussed above), but a reasonable assessment of the probability of missing elements surviving a typical burn episode is also needed. This determination requires an in-depth knowledge of typical burning sequences and modification patterns of each area of the body, including normal fire-induced postural changes and the role played by soft tissue. Critical information regarding how human bodies burn in fires, however, is currently not available in the literature. The available literature is often anecdotal or somewhat inaccurate and subsequently provides very little useful knowledge for the interpretation of patterns of thermal alteration.

Fire alteration of human bone is seemingly more detrimental to the analysis of skeletal trauma in the laboratory. The typical analysis and interpretation of perimortem skeletal trauma in non-burned bone relies primarily on the understanding of timing of bone modification in the case of fracture patterns, or the type of implement used to inflict tool marks or cut marks on the bones. The introduction of additional bone fractures resulting from fire modification without considering recovery and transport factors, further complicates the analysis and requires an understanding of how bodies are typically modified by fire.

With respect to tool marks on bones, much information regarding general tool class characteristics of the inflicting tool or implement can be obtained through macroscopic, but especially microscopic, analysis of the inflicted mark in unburned bone (see *Review of Current Literature* section below). Before interpreting the absence of a diagnostic feature in a fracture or cut mark as evidence that a particular tool was not used as the inflicting weapon, it is imperative to assess whether these diagnostic traits could have been altered or erased as a result of the fire.

In consideration of the issues discussed above, it becomes obvious that in order to perform an appropriate forensic anthropological analysis of burned human remains it is necessary to: 1) ensure that all surviving skeletal elements and information related to body location and positioning, as well as other relevant taphonomic influences, are recovered at the scene and that further alterations of the evidence from scene to laboratory are minimized; 2) recognize the extent and relative sequence patterns in which different areas of the body are consumed by the fire, taking into account tissue thickness and the temperatures typically reached depending on body positioning; and 3) be cognizant of the effect of fire on the diagnostic traits employed to infer fracture and tool class characteristics in fresh unburned bone, as well as their limitations and necessary modifications when applied to burned bone. In this consideration, the scene, fire, and osteological analysis are intimately interrelated. The purpose of this project was to improve all three of these essential and interrelated components of the forensic anthropological analysis of burned bone.

Review of Current Literature

A review of the existing anthropological literature reveals a striking scarcity of research regarding fatal fire scene processing, normal burn patterns of the body as a whole, and unambiguous effects of fire on skeletal trauma evidence. Instead, most of the research on burned bone has focused on heat alteration of unfleshed individual bones.

Fire Modification to Bone

In spite of the long history of research on this topic, our current knowledge on the subject of burned bone suffers from two major problems: 1) a lack of consistency in terminology, study sample design and outcomes; and 2) a low applicability of the results to real forensic contexts.

To a great extent, the lack of agreement of the results of previous research on burned bone, and even the inability to scientifically compare research results and conclusions, is a product of inconsistencies in terminology, experimental methods, and the type and variety of skeletal materials employed. These problems were already noted by Mayne Correia (1997), and reiterated in Schmidt and Symes (2008), and references therein.

Apart from the difficulty of replicating real forensic conditions in laboratory simulations, the focus on fracture patterns on a single burned bone, most often without flesh, probably derives from the archaeological roots of burned bone research. Early studies in the field largely relied on post-facto examination of archaeological cremations or experimental studies focused on distinguishing fleshed and de-fleshed burning patterns. For instance, Krogman (1943) proposed studying the patterning of surface patina as a way to infer whether the bone was fresh when burned. Baby (1954) and Binford (1963) later confirmed this concept and added that certain cremated dry bone characteristics (e.g., warping) were not present in fresh bone. However, Buikstra and Swegle (1989) questioned these conclusions, finding warping also in fresh bone. These studies have a low degree of application to forensic settings, but illustrate the focus and tradition of the field.

Fatal Fire Scene Recovery

In a recent book on fire investigation, John DeHaan, a former fire investigator and well-known authority on the subject, has noted the relevance of incorporating better recovery routines and the employment of professionals devoted to the detection, analysis and preservation of all types of evidence, in fire scene investigation protocols (DeHaan 2007:4-5).

As with conventional scenes, contextual evidence provides a key element not only for understanding trauma patterns, but also for identifying potential indicators of “foul play” or evaluating witness accounts. Still, despite the importance and added difficulty of the task, exact procedures for the location, recovery and documentation of human remains at fatal fire scenes are virtually absent from the fire investigation and forensic anthropology literature. The protocol for victim recovery typically consists of contacting medical or mortuary professionals to recover and remove the body from the scene (Churchward 2004, Lentini 2006). Olson (2006) has also noted that a common practice is to circumvent forensic and fire scene investigation protocols when a victim is present, rather than modifying procedures, in order to speed victim removal to quickly return the remains to the family.

Mayne Correia and Beattie (2002) provide a critical review of fatal fire recovery techniques, stressing the need for improvement. This project proposes an approach based on high resolution archaeological recovery methodologies (Lovis 1992, Dirkmaat and Adovasio 1997, Morse *et al.* 1976, Sigler-Eisenberg 1985), suitably modified to fit the characteristics of fatal fire scenes (Dirkmaat 2002). The two key elements identified as essential to the recovery process of the fatal fire scene are: 1) the initial recognition and identification of potentially significant physical evidence; and 2) the comprehensive documentation of contextual and associated relationships of the body relative to the environmental setting and other physical evidence, potentially related to the death (e.g., fire-altered debris). From this point of view, the core of fatal fire scene investigation also includes comprehensively locating, recovering and documenting the human remains and associated artifacts, rather than simply determining the cause of the fire. This information cannot be found through casual documentation and low-resolution recovery methods such as random searches, minimal photography and rapid collection of the remains. It is only procured through exacting forensic archaeological recovery methods, the benefits of which are well documented in all manner of outdoor forensic scenes (Dirkmaat and Adovasio 1997, and references therein).

In summary, a review of the literature reveals that the analysis and interpretation of burned human remains from fatal fire scenes is currently hampered by: 1) the lack of standard recovery protocols specific to this type of scene; 2) a poor understanding of general patterns of fire destruction of the human body; and 3) the lack of standards (including terminology), and guidelines for the laboratory analysis of burned human remains, particularly regarding the detection and analysis of perimortem trauma. The research addresses these issues by developing and testing new fatal fire scene recovery protocols, analyzing “normal” sequences of fire destruction to human remains, and studying the effects of fire alteration on perimortem sharp force trauma.

Fire Alteration of Skeletal Trauma Evidence

As a consequence of burned bone research primarily focusing on archaeological materials, the effect of heat alterations on forensically significant traumatized bone has been, until recently, researched infrequently. Hermann and Bennett (1999) used an animal model to study the persistence of recognizable trauma after exposure to fire, but do not discuss specific diagnostic traits. Pope and Smith (2004) studied the persistence of some trauma characteristics in fleshed human heads after controlled cremation, and reported results that confirmed previous findings of the first author (Symes *et al.* 1996, 1999a, 1999b). Emanovsky *et al.* (2002), Devlin *et al.* (2006), Schmidt and Symes (2005) and Symes *et al.* (1996, 1999a, 1999b, 2005a, 2005b, 2008) all show that careful examination of the heat altered skeletal remains can differentiate perimortem trauma (sharp force and blunt force trauma, respectively) from postmortem thermal destruction. Still, there is an almost complete lack of experimental or observational studies based on fleshed remains, and all of the extant research is typically limited to isolated body areas and tissues (*e.g.,* Christensen 2002, Pope and Smith 2004).

Recent research by the first author (Schmidt and Symes 2005, Symes and Dirkmaat 2005, Symes *et al.* 1996, 2008) has served to identify three major process “signatures” recognizable in normal burned bone destruction. The recognition and analysis of these signatures mandates examination of the body at a number of different levels, from full body to individual bone fragments. Specific factors to be considered are: 1) body positioning/tissue thickness; 2) bone color change; and 3) fracture biomechanics.

Body positioning refers to the characteristic body and limb postures, often termed *pugilistic pose*, induced by the heating and shrinking of muscle fibers. Symes *et al.* (2008) demonstrates how departures from the normal expected patterns of body positioning allow for the detection and interpretation of forensically significant perimortem trauma. These studies emphasize the importance of precisely noting victim position and orientation at the fire scene (context) and understanding normal burn patterns in an attempt to detect and analyze bone trauma. DeHaan (2008) recently noted the importance of understanding body positioning and its relationship to fire characteristics.

Rationale for Research

The ultimate goal of the research project was to address the problems outlined above through the construction and validation of basic standards and guidelines of use to forensic professionals and fire investigators involved in the interpretation of burned human remains from fatal fire scenes. This goal was implemented through: 1) a set of interrelated experimental and observational studies designed to enhance onsite location, evaluation, and preservation of burnt human remains; 2) forensic laboratory analysis of this type of evidence (especially skeletal trauma); and 3) fatal fire incident reconstruction. From an operational point of view, this translated into the *Research Objectives* described below.

Research Objective 1

Produce comprehensive guidelines and a simple, user-friendly data collection database for the recovery of human remains from fatal fire scenes. The improved fatal fire scene recovery protocols and guidelines are aimed at enhancing the success rates of the location, recovery and preservation of human skeletal elements and tissue at the scene, while maximizing the compatibility of forensic anthropology protocols with those of standard fire investigation. This will result in timely scene processing and efficient onsite cooperation between different types of investigators. Better *in situ* recovery methods will also benefit subsequent laboratory analyses by providing better preserved bone elements and relevant information on contextual factors such as body location and orientation which are essential for biological profile, taphonomic and trauma analyses. The result is better past event reconstruction.

Research Objective 2

Describe basic, meaningful patterns of fire alteration to the human body. This will produce a Daubert-compliant baseline for the recognition and interpretation of forensically significant perimortem trauma to the body or other forms of intentional body manipulation or modification prior to or during the fire episode.

Research Objective 3

Assess and validate the applicability of conventional, non-burned human remains protocols for the analysis of sharp trauma to burned bone. This was accomplished by assessing rates of preservation and patterns of alteration of quantitative and qualitative class mark characteristics on bone, both in the laboratory and near-real conditions, and with animal and human models employed.

The main methodological assumption underlying these operational objectives is that scene recovery and documentation and trauma analysis of burned human remains cannot be uncoupled. As with other types of evidence, it can be said that trauma analysis begins at the scene. Effective, reliable, court-defendable interpretations of burned bone evidence (especially related to trauma analysis) require a comprehensive recovery of all human remains and associated physical evidence, including contextual and spatial data, as well as proper handling of the evidence in order to avoid additional postmortem alteration.

Introduction to Methodology of Research

The central rationale behind the methodology was that the analysis of perimortem trauma in burned bone requires first identifying bone alteration resulting from the recovery process, as well as identifying the normal effects of heat exposure on the human body in fatal fire circumstances. The research objectives were pursued through three primary *Research Components* that integrated previous and current independent research of two of the principal investigators of the project (SAS and DCD).

The three research components were aimed at identifying, assessing and, when appropriate, controlling: 1) additional trauma and bone loss inflicted during scene recovery, 2) the patterns of bone trauma resulting from exposure to fire, and 3) the heat alterations normally expected on inflicted perimortem trauma, particularly diagnostic characteristics normally employed to assess forensic significance and inflicting tool characteristics in fresh, unburned bone. The three research components included *Recovery of Burned Human Remains*; *Analysis and Interpretation of Burn Patterns*; and *Heat Alterations in Traumatized Bone*. These intimately linked research components were designed to provide comparative data through their complimentary nature; each component builds off of materials provided by the previous component.

The proper recovery of burned human remains (*Component 1*) using high resolution archaeological techniques ensures that all possible human biological tissue that can be found is located and will greatly reduce the risk of postmortem trauma to the remains caused by unexacting methodologies. The location and preservation of the remains will then allow for a more comprehensive and accurate analysis and interpretation of the burn patterns (*Component 2*). Due to the predictable nature of a body's response to burning under normal circumstances, it is necessary to have as much human material as possible to confidently analyze burn patterns. The analysis can also be confused by pseudo-trauma caused by improper recovery methods. Lastly, understanding and accurately interpreting burn patterns will aid in the investigation of heat alterations in bone inflicted with perimortem trauma (*Component 3*). Understanding the mechanisms present during a cremation will significantly enhance analysis of the material and identification of real trauma versus pseudo-trauma caused by the action of the fire or unexacting recovery methodologies.

CHAPTER II

Research Component 1: Recovery of Burned Human Remains

Materials and Methods

There were three main objectives of *Research Component 1*: 1) the development and testing of new and efficient fatal fire scene recovery protocols, 2) provide comparative data relating to contextual information, such as temperature distribution around the body and burn patterns found on human remains from real fires, for use in *Research Component 2*, and 3) provide comparative osteological materials for *Research Component 3.*

The fatal fire scene recovery protocols aim to increase the success rates with respect to the location, recovery and preservation of evidentiary items, and the documentation of relevant contextual information, as compared to currently employed protocols (see *Fatal Fire Scene Recovery Protocols* below). The new protocols have been devised to avoid delays in the processing of the scene or the addition of unnecessary burdens on investigators, as compared to the way in which scenes are currently processed in many jurisdictions. In addition, these protocols were designed to be as economical as possible in terms of time, personnel, and the expenditure of financial resources.

Research Component 1 was sub-divided into three interrelated areas of study: *Archival Research*, *Processing Mock Fatal Fire Scenes,* and *Processing Actual Fatal Fire Scenes*.

Archival Research

A critical objective of this research was to streamline and maximize fatal fire data recovery by improving existing protocols. To identify key areas needing improvement, a review and analysis of existing documentation for 93 fatal fire scenes was conducted. This served to identify: 1) key variables regarding fire and victim investigation, 2) current deficiencies in the recording of variables relating to the fire scene and the victim, and 3) inconsistencies in variable coding affecting data management, sharing, and analysis. The data collected from the documented fatal fire scenes was compared with the results generated at the mock fatal fire scenes under controlled conditions to assess the validity and representativeness of the experimental conditions selected for the simulation studies discussed below.

The Office of the Fire Marshal, Province of Ontario, Ministry of Community Safety and Correctional Services, granted access to all the documentation pertaining to their investigation of fire scenes, both current and historical. Ninety-three cases occurring between 2000 and 2006 were used in this analysis.

Research Design

The methodology for this study was based on a pilot study conducted by one of the key consultants for the project, Gregory O. Olson (GOO). Based primarily on current standard fire investigation protocols in use in the US and Canada (Churchward *et al.* 2004), a set of 30 qualitative and quantitative variables describing the most relevant parameters of fire scenes was created (Appendix II-1). These variables were then recorded from the investigation and court files of 93 recent fatal fire scenes in Ontario, Canada. No data pertaining to victim identity, geographical location of the structure, or any detail that could allow for the identification of a specific fire event were recorded.

The study conducted resulted in the analysis of 93 cases. To allow for reliable data collection and sharing between multiple observers, minimize errors in the recording of data, and expedite the data recording process, the improved paper version of the data recording form was translated into a list enabling a menu-based electronic database requiring minimal typing.

The pilot study indicated that current data recording is highly inconsistent, with a pronounced diversity of both the variables taken into consideration and the way in which they are coded and expressed. Significantly, important contextual data regarding body position and taphonomic factors highly relevant for forensic anthropological analysis are rarely recorded. The electronic database forms developed to record the historic data simplified scene data collection by providing a user-friendly electronic checklist of key variables that are to be recorded. The primary significance of this electronic database is to ensure important and relevant scene data will be collected consistently from scene to scene, enhancing scene comparison. This data is useful to both forensic anthropologists and fire investigators as it reduces redundancies in data collection efforts and allows for easy data sharing between the two professional groups.

Information on number and biological characteristics of the victims, their position and location within the scene, and graphic and autopsy documentation of the burned remains, will serve as a baseline for comparison with the patterns observed in the controlled cremations of human remains, as well as the documentation of soft tissue burn patterns in actual cases (see *Research Component 2*). These factors were also employed to assess the degree of realism of the experimental conditions set for mock scenes and laboratory experiments.

Processing Mock Fatal Fire Scenes

The comparative (*mock*) fatal fire scene exercises served to: 1) test and refine the new forensic archaeological protocols in controlled near-actual conditions, and compare them with the current protocols, 2) provide detailed temperature readings from different areas of the fire scene near the body (for comparison with the experimental conditions in *Research Component* 2), and 3) provide comparative osteological materials for *Research Component 3.*

The Office of the Fire Marshal, Province of Ontario, Ministry of Community Safety and Correctional Services, granted permission to conduct this research during fire response and investigation training exercises at their facilities. Cooperative support with the Ontario Fire College, and the Ontario Police College, was obtained for these exercises. Similar agreements were obtained with other fire investigation agencies to conduct additional mock fire scene recoveries, including the Erie International Airport Fire Department (Erie, PA), the Franklin Township Fire Department, Station 72 (Franklin Center, PA), the Cecil Township #3 Volunteer Fire Department (McDonald, PA) and the Montgomery County Fire Department (Waynesboro, PA).

Research Design

The basic methodology for this study was based primarily on previous research and case experience by one of the principal investigators (DCD). The proposed recovery protocols represent modifications of conventional forensic archaeological techniques, aimed at non-burned human remains (Dirkmaat 2002, Dirkmaat and Adovasio 1997, and references therein). They include: 1) detailed mapping and excavation of the human remains, using both grid system, electronic total station and GPS data, 2) careful written, photographic and videographic scene documentation of evidence and the recovery process, and 3) evidence collection and treatment (Dirkmaat, 2002). Data collection was not limited to evidentiary items, but also included information related to the contextual and physical characteristics of the scene, which may have influenced taphonomic factors associated with the human remains. In the extension of these protocols, as applied in this project, collected data also included fire-specific parameters from standard fire investigation protocols (Churchward *et al.* 2004), which are of potential utility to forensic anthropological analysis.

Apart from the comprehensive documentation of physical and contextual data, an important outcome of these protocols was the simplification of procedures and reduction of time required for scene processing. This was accomplished through the application of technological enhancements readily available to law enforcement (e.g., the total station, and Global Positioning System [GPS] units), as well as through the concurrent implementation of appropriate search, location, documentation and recovery steps. This was shown to actually reduce recovery time and personnel, while dramatically improving recovery rates and documentation, even in large, complex mass fatality scenes with highly altered and fragmented remains (Dirkmaat *et al.* 2001, 2005).

Pilot Study

As with the archival study above (*Archival Research*), the methodology for this study was developed and tested through a pilot study comprising of a mock (*comparative*) fire scene, taking advantage of regular training exercises by the Office of the Fire Marshal, Province of Ontario, Canada. The proposed research utilized this methodology with some modifications. In these exercises, a number of pig (*Sus scrofa*) limbs and carcasses (serving as an animal proxy to human remains), and other mock evidentiary items, were emplaced at different locations inside a real structure (a donated building) by the assistant to primary consultant Fire Marshall Olson (GOO) who was not involved in this process. In addition, the pig limbs were pre-processed with a variety of carefully documented fresh-bone trauma (fractures, cut marks and a variety of saw cuts). Mark Duval (MD), a crime scene investigator from the York Regional Police, New Market, Ontario, who has forensic archaeological training and experience, filled this role. The scene and the distribution of evidence were then carefully documented via written notes, photography, and maps by the assistant. An important question in forensic anthropological analysis of burned human remains is whether missing bone elements were originally not present at the scene, or, instead, went undetected. Consequently, metallic plates were used to tag the animal remains, and their exact location recorded. This allowed for the location and identification of tissues after the fires, even if they were completely degraded by the fire, or disturbed by recovery efforts.

A number of thermocouples were placed in different key areas of the house, as well as close to, above, underneath and inside the pig carcasses. The structure was then set on fire and allowed to burn for a specified amount of time or until total collapse. Temperature readings from the thermocouples were recorded with a *2635T Fluke* recording thermometer in 10-second intervals during the combustion process (Figure II-1).

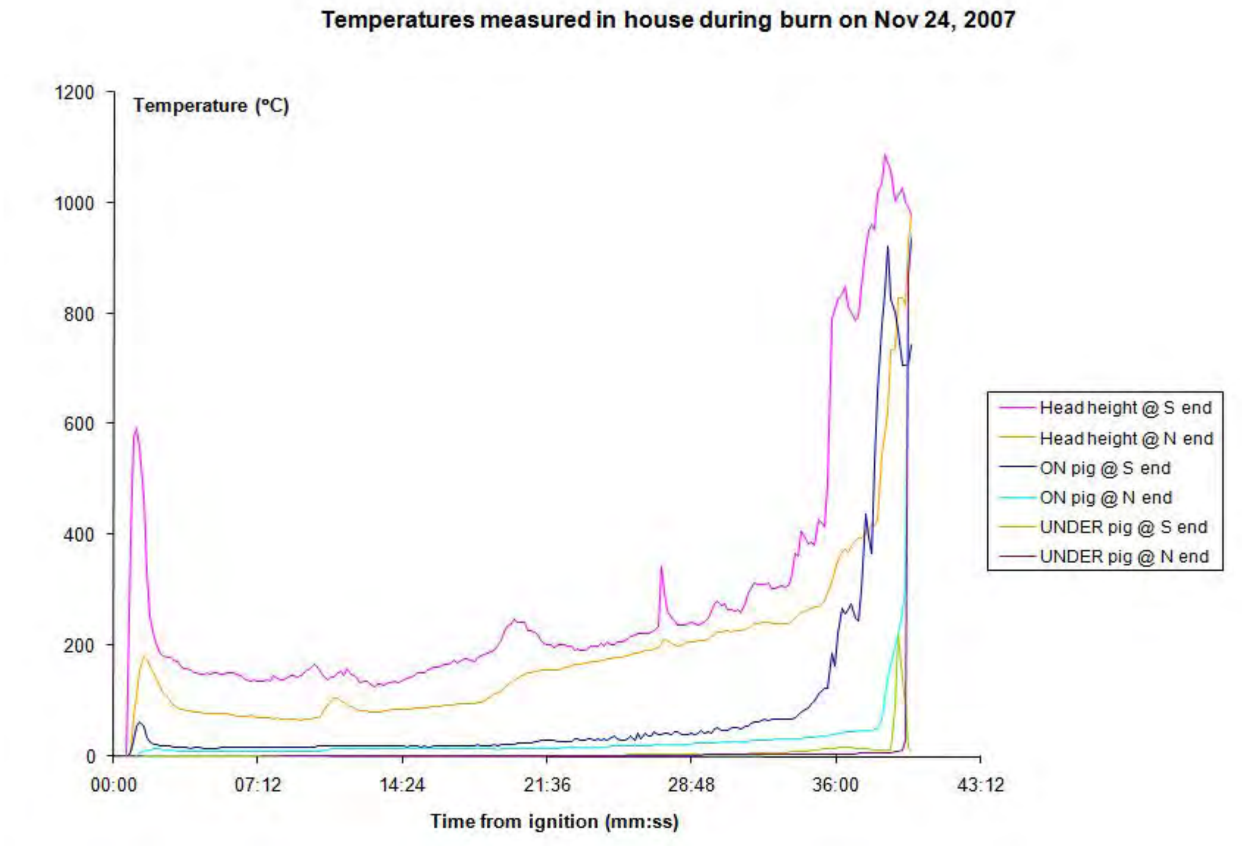


Figure II-1. Temperature readings obtained in one of the mock fire scenes described in the original proposal (pp. 11-14). Note the low temperatures registered under the body, and the acute differences observed between the north and south ends of the body, matching the orientation observed in the surrounding environment.

After the fire was extinguished, the structure was processed according to conventional fire investigation protocols (Churchward *et al*. 2004), by fire responders with fire-fighting background (fire investigators and students currently involved in fire fighting training), but with *no* anthropological or archaeological training (see Appendix II-2 for a more detailed explanation of the protocol and results of one of the pilot mock scenes).

Once the first recovery team had completed conventional scene processing, the scene was re-processed by a team of 10-15 Mercyhurst graduate students using forensic archaeological protocols, under the supervision of the primary consultant (GOO). In addition to detailed maps, temperature readings, and the information recorded in the mock scenes, the recordation forms developed from the archival studies were used and included more precise information regarding total and individual processing times and training. This allowed for comparison of protocol efficiency in terms of processing efforts and learning curves for the new protocols. A Student's *t* analysis for repeated measurements was employed to compare total times between methods. When necessary, a correction for small sample sizes was applied (Vallejo and Livacic-Rojas 2005). Factors such as the correlation between number of responders and processing times were controlled through regression models.

After the pilot study, six (6) subsequent mock scenes were processed, in each case attempting to improve upon some aspect of the recovery protocol to make them even more efficient and effective. Each fire investigation agency involved completed a questionnaire regarding the utility, effectiveness, efficiency and user-friendliness of the new protocols. In this way, professional fire fighters served as independent testers and provided feedback on the protocols, particularly regarding the difficulty of their implementation in terms of learning curve and their applicability to real situations.

Preliminary results derived from the mock scenes processed in 2007 by primary consultant (GOO) indicated that processing fire scenes through conventional protocols resulted in missing evidence (later recovered through the archaeological protocols), some trampled and damaged evidence, substandard documentation, and no significant decrease in recovery times. It was also noted that the participants in the archaeological recovery showed a steep increase in their efficiency and effectiveness after just one training session and processing one mock scene, suggesting that the new protocols are not too costly in terms of training requirements.

Mock scene exercises provided tests for enhanced and more realistic recovery protocols and electronic recordation forms and guidelines. These exercises served to evaluate the advantages or disadvantages of the new guidelines over current standard protocols in terms of efficiency, effectiveness and costs, prior to their implementation and testing in real situations. Independent trained professionals in realistic, non-compromised conditions conducted the testing of the protocols. See the *Fatal Fire Scene Processing Protocols* (below), which were developed from the results of these mock fatal fire scene exercises.

Continuous temperature readings at different scene and body locations, combined with the pattern of alteration observed in the animal model, provided an opportunity to compare data and propose corrections to the burning patterns observed in the controlled cremations (*Research Component 2*), which were conducted under ideal conditions and with a homogeneous distribution of temperatures around the body. Finally, the mock scenes provided osteological materials for *Research Component 3* (*Data Source B* below).

Thermocouple Data

Direct temperature readings at the mock scenes served to asses: 1) the range and maximum temperatures expected to be reached during a regular house fire in different structures, 2) the temperatures reached in and around the body, and their relationship to external temperatures, and 3) from the former, assessing the protective (thermal isolation) effect of soft tissues at different temperature ranges, using domestic pigs (*Sus scrofa*) of medium to small size ranges as a proxy for the human body.

The first (1) of these objectives served to compare the temperatures observed in realistic fire scenarios with those observed or employed in *Component 2* and *Component 3* of the research.

Objectives (2) and (3) were intimately related. The distribution of temperatures reached at different locations of a house fire (2), as well their temporal change sequences as the fire affects different areas of the structure, such as floors, ceiling or furniture, served to determine the different body areas affected by the fire, depending on body placement, posture and position. The measurement of temperatures reached in different areas of the body (3) served to correlate body and room fire temperatures, as well as to assess the extent of the differences in thermal alteration that can be expected due to the isolating effect of soft tissues (muscle and fat) in the anatomical regions directly facing or away from the heat source.

All these elements were key in predicting and interpreting patterns of thermal alteration of the body in real conditions, as well as in the assessment of the influence of factors such as body positioning, body posture, victim characteristics such as overall body size or condition or fire characteristics such as fire duration and intensity.

Research Design

As specified in the original proposal, a number of thermocouples (four to six per room) were placed at different locations of the burning structure, including in close proximity, above, underneath and inside (typically through the snout) of the pig carcasses. The structures were then set on fire and allowed to burn until total collapse. Temperature readings from the thermocouples were recorded to the closest 0.01ºC with a *2635T Fluke* recording thermometer in ten-second intervals during the combustion process, which typically was around or under one hour. The thermocouple wires allowed recording temperatures up to approximately 1,300ºC, although their precision decreased above temperatures of 1,100ºC.

Thermocouple wires were typically placed on ceilings, wall vertical midpoints (usually around 60 or more cm above the body, although this depended heavily on the characteristics of the structure, as well as the security needs of the fire extinguishing crews), floors, as well as on the surfaces immediately beneath and above the carcass. Thermocouple wires were also introduced into the carcass body, usually through the snout.

In some cases thermocouple placement and reading was more difficult than anticipated due to the obstructive effect of the thermocouple wires in the normal development of fire control and extinction by the fire response crews. Given that the project took advantage of regular fire response training exercises, a especial concern was interfering as little as possible on the normal development of these exercises (i.e. keeping out of the way) particularly and logically when this might compromise the security of other structures or of the participants in the exercise. The thermocouple wires had to run from the fire structure to a safe location where the thermocouple reader and a computer could record the observed temperatures. Depending on the characteristics and location of the structure, (for example in close proximity to other structures that had to be protected from the fire through hosing or additional isolation or facing areas of difficult access for the extinguishing crews) it was difficult to place the metallic and thick thermocouple wires in a way and location in which they would not be an obstacle for the fire responders.

In some of these cases the thermocouples were run across the ground, protecting them with wood planks, but almost invariantly they were still trampled or cut by the fire crews, resulting data loss or inconsistencies. In most of these fires it was possible to record maximum fire temperatures or more or less complete profiles from some of the locations (in which the thermocouples were intact), which are consistent with the ones described below. The continuous monitoring of data was not reliable in order to compare the distribution of temperatures in different areas of the structure.

However, optimal readings were obtained from different locations in two separate fire exercises in Montgomery County (Waynesboro), PA (one of which, at a mobile home, was used exclusively to obtain additional temperature readings). In these exercises, a two-story house and a mobile home were wired at a various locations, and processed following the protocols above. A total of three pig carcasses and an additional sample of pig limbs (described in

Component 3 below) were utilized in these fires (one carcass at the house, and two carcasses at the mobile home), recording a total of 15 different clean and complete thermocouple readings from different room heights, as well as around and inside the body. Figure II-2 illustrates schematically the placement of the thermocouples at the mobile home.

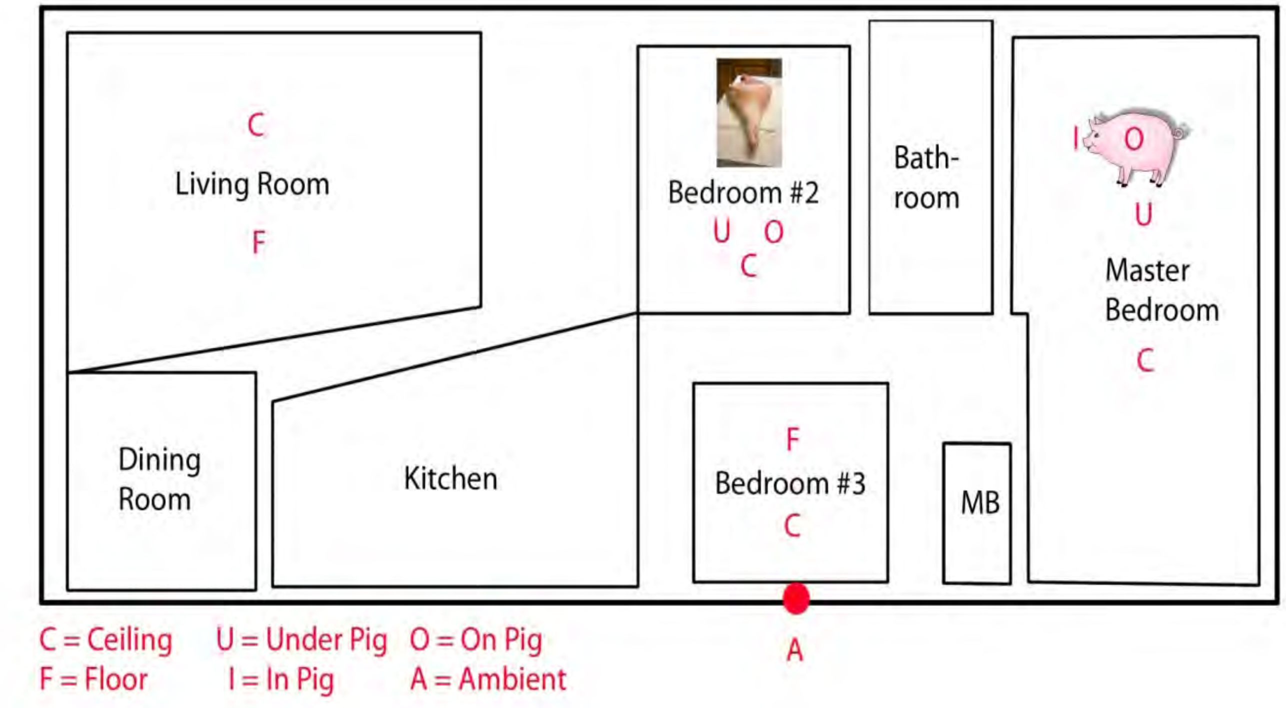


Figure II-2. Schematic diagram illustrating the general floor plan and the placement of animal models and thermocouples at the mobile home in Montgomery County.

Processing Actual Fatal Fire Scenes

Comprehensive analysis of victim recovery methods used at actual fatal fire scenes served to: 1) test the applicability, advantages and weaknesses of the new protocols in real situations, 2) provide a comparison with past cases processed with current protocols (see *Archival Research* section), in terms of information gained, processing times, effort and costs, and 3) provide a realistic baseline for assessing the validity of the results and observations obtained at the mock scenes and controlled cremations.

The data for this part of the study was collected during the processing of real fatal fire scenes investigated by the Office of the Fire Marshal, Province of Ontario, Canada, specifically fire investigator Gregory O. Olson (GOO).

Research Design

One of the primary project consultants (GOO), processes actual fatal fire scenes as part of his job with the Ontario Office of the Fire Marshal. The application of forensic archaeological recovery protocols to each scene he investigates provided much needed feedback for the investigators of this project. The same data described above for the mock scenes were recorded at each actual fatal fire scene. The proposed improvements developed during the project were gradually incorporated into the real-scene protocols, as they were tested and refined. This gave the researchers of this project the ability to test and fine-tune the protocols in real world situations.

Although comprehensive protocol testing in real situations may seem risky in a forensic setting, the validity of this approach was proven by the customary application of forensic archaeological protocols in the fatal fire scenes processed by AFSD, Mercyhurst College to date. Further, the exact methodology proposed for this project was applied to six (6) mock fatal fire scenes investigated by the Office of the Fire Marshal, Province of Ontario, Canada in a pilot study carried out by GOO (see *Processing Mock Fatal Fire Scenes* above). In these scenes GOO acted as the first responder and primary fire investigator and applied the same methodologies and data recording techniques described above for the mock scene pilot study.

Olson's pilot study showed that the scene processing protocols, even in their gestational stage of development, could be realistically applied in real fatal fire scenes, without adding an unnecessary burden to the investigation or delaying scene processing. In virtually all cases, data pertaining to: 1) body location and positioning, 2) contextual information pertaining to relative location of evidentiary items, and/or 3) the comprehensive *in situ* identification and preservation of small skeletal elements and evidentiary items was critical to the reconstruction of the events surrounding fire and death.

Olson has been involved in the investigation and recovery of human remains from 16 fatal fires, beginning in 2008 through the end of 2009. In five of those cases the scene had progressed to the point in which archaeological methodologies were required and utilized.

The real scenes provided the final product in the recovery protocols, with fully operational methodologies and data-recording databases and protocols (refer to the *Results* section below). Additionally, they provided realistic estimates of the relative efficiency, effectiveness and costs of the new protocols, as compared with the ones reflected in the archival material. Finally, they provided comparative information regarding the consistency and representativeness of the normal burn patterns observed in the controlled cremations.

Results

Archival Research

To properly reconstruct and analyze fatal fire scenes and the remains found in them, crucial variables, such as the length of time the fire was burning, the construction of the building, and the position of the victims must be recorded. Analysis of the documentation of the 93 scenes collected for this portion of the study revealed that the majority of the key variables identified were not being adequately documented. As is shown in Figure II-3, in almost all cases the number of incomplete fields in each category far outnumbers those, which have been adequately completed. The level of incomplete documentation ranged from approximately six to sixty percent (6%-60%) of all fields that should be completed in the course of an investigation of a fatal fire scene (Figure II-4).

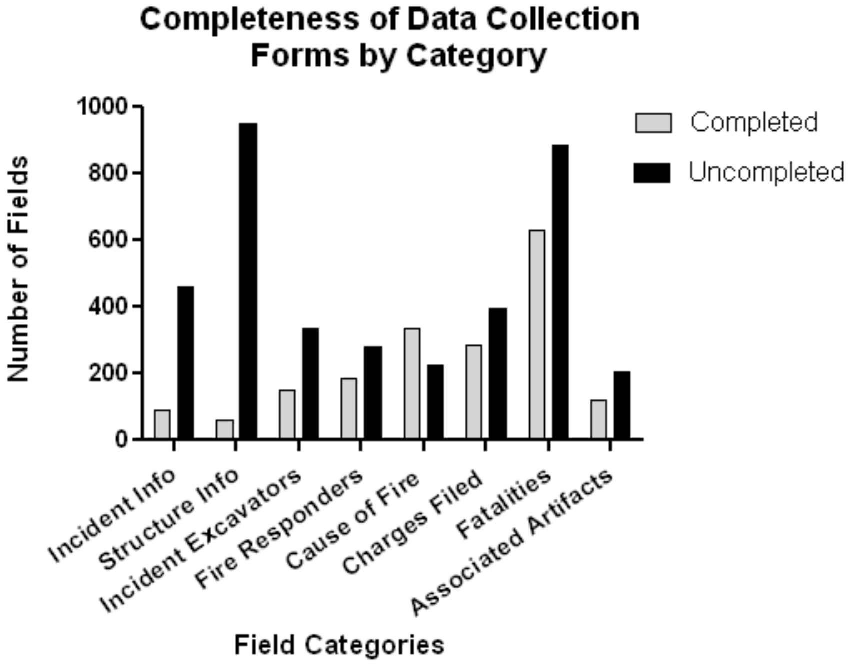


Figure III-3. Number of completed versus uncompleted fields on fire scene data collection forms by category

Of the 93 scenes analyzed, the response time of the fire department, roughly corresponding to the length of time the fire was burning, was not recorded in 63 cases (67.7% of the cases). For the cases where this information was recorded, response times range from two to thirty-two minutes, indicating great variability in the response times of the fire departments and thus, the length of time the victims were exposed to the fire (Figure III-5 and Table II-1). The distance of the scene from the fire station and the number of responders was not documented in any of the case records analyzed.

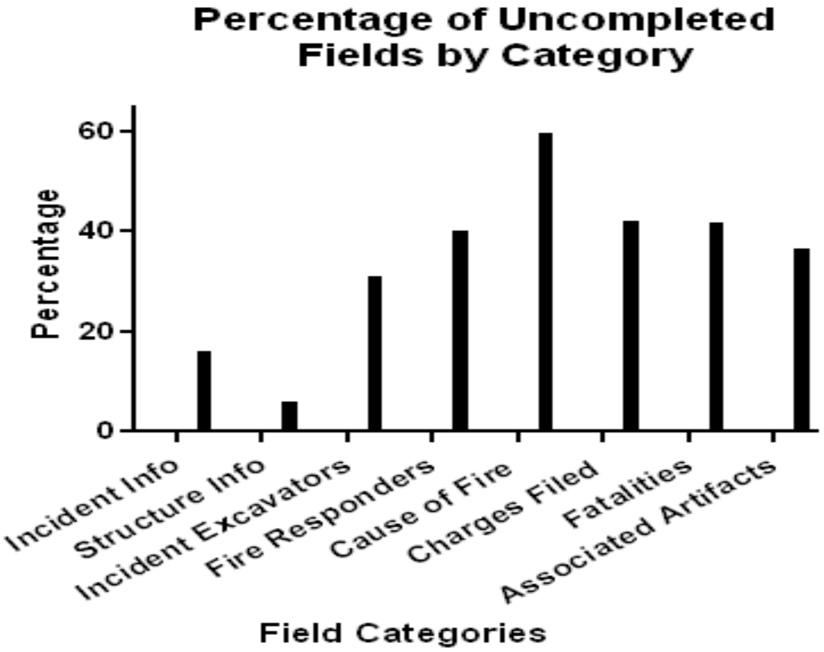


Figure II-4. Percentage of uncompleted fields on data collection forms in each category.

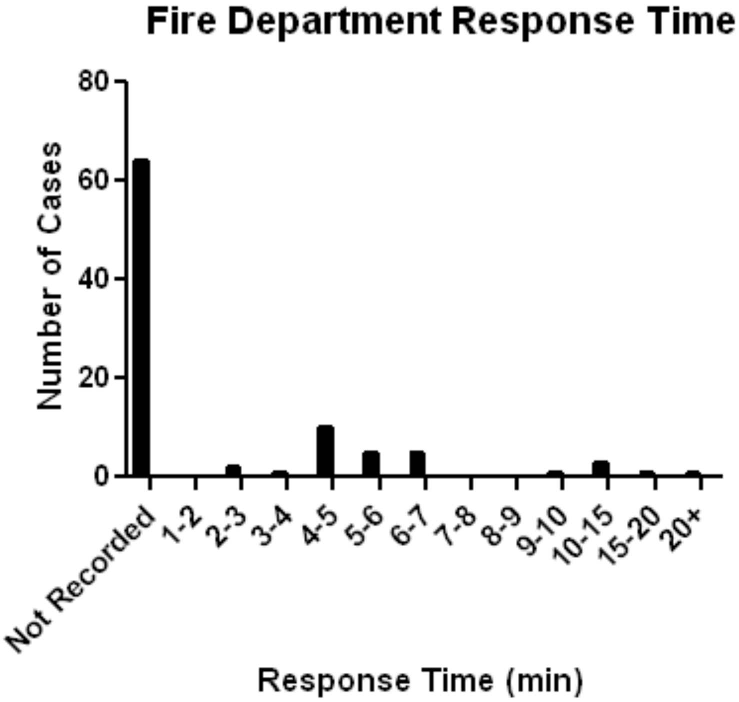


Figure III-5. Time taken by the fire department to reach the fire scene (N = 93)

Table III-1. Time taken by fire department to reach the fire scene (N = 93)

Fire Department Response Time		
Time (min)	Number of Cases	Percentage of Total Cases
Not Recorded	64	68.8%
1-2	0	0
2-3	2	2.2%
3-4	1	1.1%
4-5	10	10.8%
5-6	5	5.4%
6-7	5	5.4%
7-8	0	0
8-9	0	0
9-10	1	1.1%
10-15	3	3.2%
15-20	1	1.1%
20+	1	1.1%

At the majority of the 93 scenes analyzed, only one investigator was present at the scene during the processing and recovery efforts. However, at some scenes, two or three investigators were present, which resulted in 112 records for the number of hours spent at each scene. In more than half of the records analyzed, the length of time that the investigator spent at the scene was not recorded. This information is crucial from both a security and logistics point of view. In the majority of the remaining cases, investigators spent from one to ten hours at the scene (Table II-2 and Figure II-6). Based on this information, the new protocols proposed would not impose a greater time commitment than is currently occurring at most documented fatal fire scenes (see *Fatal Fire Scene Recovery Protocols* below).

Table II-2. Time spent by fire investigators at fire scenes (N= 112)

Time Spent by Fire Investigators at the Scene		
Time Spent (hrs)	Number of Cases	Percentage of Total Cases
Not Recorded	71	63.4%
1-5	10	8.9%
5-10	19	17.0%
10-15	5	4.5%
15-20	4	3.6%
20+	3	2.7%

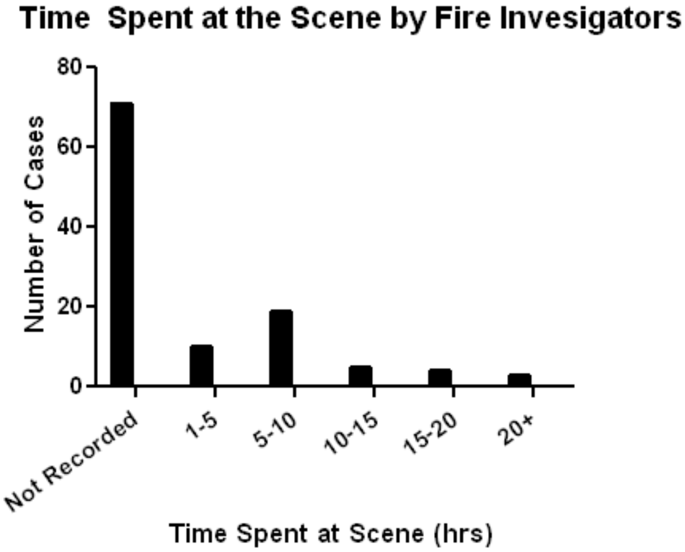


Figure II-6. Time spent at documented fatal fire scenes by investigators (N = 112)

During the course of the investigation, information pertaining to the cause, type, and spread of the fire should be documented. This information will help investigators to recreate the circumstances surrounding the initiation of the fire and the deaths of any individuals found at the scene. In the records analyzed during this study, much of this crucial information was not recorded (Figure II-7). In addition, much of the information pertaining to the type of structure and materials involved in the fire was not recorded (Figure II-8). The lack of structural information combined with the deficiency of fire duration data, gives fire investigators little to work with in identifying the cause and manner of death of fatal fire victims.

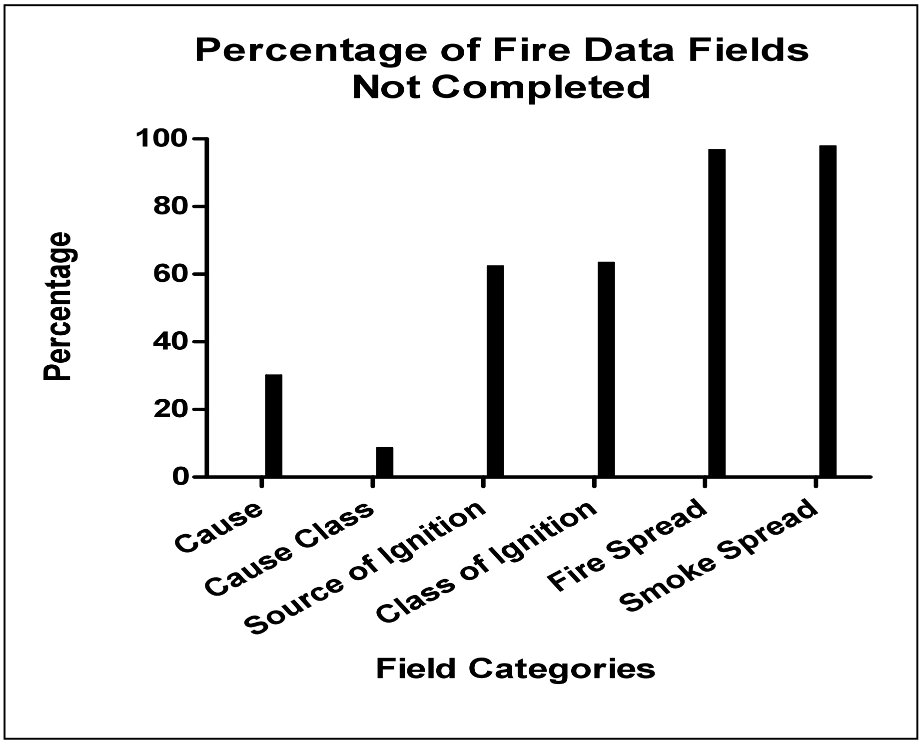


Figure II-7. Percentage of data fields pertaining to the fire itself not completed

As can be seen from this analysis, the current forms and protocols for the collection of data from the fatal fire scene do not result in consistent or complete documentation of the information needed to conduct a proper investigation. The key variables regarding fire and victim investigation, current deficiencies in the recording of variables relating to the fire scene and the victim, and inconsistencies in variable coding affecting data management, sharing, and analysis indentified in this study were used to guide the creation of new fatal fire scene recovery protocols. These new protocols and data collection procedures produce reliable and consistent data collection and sharing between multiple observers, minimize errors in the recording of data, and expedite the data recording process.

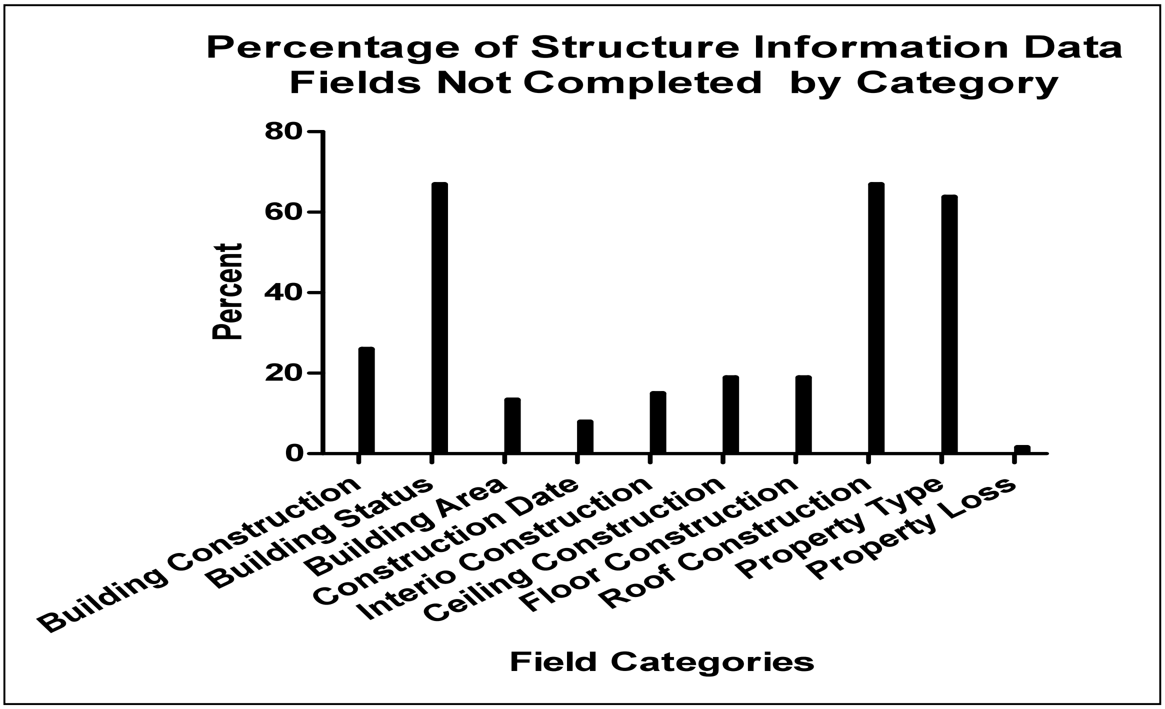


Figure II-8. Percentage of data fields pertaining to the structure at the fire scene not completed

Processing Mock Fatal Fire Scenes

See Appendix II-3 for a photographic outline of the general progression of events for the mock fatal fire scenes. Six mock fatal fire scenes were processed for this project. Below each mock fatal fire exercise is outlined, including protocol and design modifications that were made.

1. Strathroy, Ontario Mock Fatal Fire Scene (February 6-8, 2009)

The first mock fatal fire scene documentation and recovery exercise was conducted February 6-8, 2009 in Strathroy, Ontario. This mock scene served as a preliminary assessment of the utility of data collection forms previously defined and used in Mr. Greg Olsen's (Ontario Fire Marshall's Office) Master's Thesis (Mercyhurst, 2009). It also allowed for the careful notation of fire dynamics and identification of potential issues related to conducting future mock scene recoveries.

Photographic and videographic documentation of the house and the surrounding areas was completed on February 6, 2009. Total station data collection and GPS coordinate data collection were also conducted on this date. On the morning of February 7, 2009, three pigs, two old rifles, and 10 shell cases were placed in the house as evidence. Photographic documentation of the position of the pigs and other physical evidence was completed. Using measuring tapes, a sketch map of the position of the remains in the house was recorded. It was determined that, in the future, a *Berger Laser Distance Measurer* would be used to measure exact dimensions of the house and location of evidence.

In the afternoon of February 7, 2009, the house was ignited by the local fire department. A flare was used to ignite an ottoman couch that was positioned on the first floor, in the stairwell, between the kitchen and a den. The opportunity to watch the complete burn of the house gave the authors a chance to better understand fire dynamics, as well as gain insight into the amount of time it takes particular types of structures to completely burn.

The search for and recovery of evidence at the scene took place on February 8, 2009. Mercyhurst graduate students and faculty, along with several students from Wilfrid Laurier University (Canada) conducted an archaeological excavation of the site in the search for the pig remains and other physical evidence. Once discovered, the pig carcasses were carefully exposed (excavated), and recovered. The forensic archaeologists were able to successfully locate and recover all three pigs, both guns, and several shell cases. In addition, careful notation of context and stratigraphic relationships allowed for the reconstruction of the location of the pigs prior to the house being ignited. In other words, because of the systematic excavation of the areas within the structure, investigators were able to reconstruct the position of each pig prior to the fire, including which floor each was located on as well as their position within the room.

Based on the knowledge gained at the mock fatal fire scene in Strathroy, Ontario, the field data collection forms were revised and used at all subsequent mock fatal fire scenes. *[Note: original data collection forms were compiled by GOO for his Master's Thesis].* One important outcome of the new recovery protocols was the simplification of procedures and reduction of time required for scene processing. It was believed that the refinement and streamlining of data collection forms would both simplify and reduce the total amount of time required to process a fatal fire scene. See Appendix II-4 for data collection forms used at all of the subsequent mock fatal fire scenes.

An introductory letter and questionnaire was created and given to the first responder fire fighters who assisted with the mock scenes. The letter provided a brief introduction to the research project as well as its goals and objectives. The questionnaire, which included questions regarding training and education, served as a baseline for identifying the level of education and training of the fire fighters and investigators, especially with respect to the recovery of human victims from fatal fire scenes. See Appendix II-5 for an example of the introductory letter and fire fighter questionnaire.

2. Malahyde, Ontario Mock Fatal Fire Scene (September 25-27, 2009)

Protocol Modifications

Based on the results from the initial mock fire in Strathroy, Ontario, one protocol modification was tested and implemented in the Malahyde, Ontario fire exercise. This modification affected the scene processing protocols.

Changes in Research Design

A major research design change was introduced that affected the extended times and screening efforts. The protocol was modified for a structure involving a deep basement. Additional screening units and increased screening times were introduced so that sieving efforts could keep pace with the excavation team. Three screens were erected near the structure, with a minimum of three and a maximum of six screeners working non-stop for approximately eight hours. Breaks of approximately half an hour every two hours were programmed and implemented for screening teams members.

Even the addition of more screens and screeners proved insufficient to keep pace with the amount of excavated material generated. The lag between screening and excavation also affected the pace and efficiency of the latter. Within the proposed protocols, screening served to recover evidence missed during excavation, as well as provide an early warning to the excavation team regarding the finding of potentially significant evidence in the sediments from a particular excavation unit. This served to concentrate and increase the level of precaution with which the area was excavated. In the absence of this awareness, due to the delay in screening the sediments from the areas currently being excavated, the excavation team was forced to practice extreme precaution in all areas, forcing the excavators to advance at a slower pace.

At the end of the exercise, some of the planted evidentiary items were still missing, but the area of potential distribution of the evidence had not been completely excavated despite the intense excavation and screening effort programmed for the exercise. In a real situation, given the complexity and extent of the area of the scene, the recovery effort could likely be extended for one additional day. In this case, this was not possible due to time constraints on all parties involved. It remained unclear whether the missing evidentiary elements were missed during excavation and/or screening or that they remained in the non excavated area (approximately one fourth of the total area).

On the other hand, the time and personnel constraints that affected this exercise could easily apply to real situations, in which different factors may prevent work over extended periods of time. Consequently, for research purposes it was decided to reduce the area in which the mock evidentiary items would be planted in future exercises in order to ensure their complete excavation during a two-day period, even if adverse conditions (as in this exercise) were present.

3. Tom Ridge International Airport Property, Erie, PA (October 24-27, 2009)

On October 24, 2009, physical evidence and two pig carcasses were planted in a house scheduled for demolition on. The house was burned on October 27. However, due to a series of unfortunate and uncontrollable events: 1) thermocouple wires were moved just prior to ignition of the house, 2) evidence within the house was moved just prior to the fire, and 3) the structure was determined to be unsafe for excavation purposes. No data was collected during this fire exercise.

4. Franklin Center, PA (November 5-8, 2009) and

5. McDonald, PA Mock Fatal Fire Scene (November 20-22, 2009)

Protocol Modifications

Based on the results from previous successful mock fires, two major protocol modifications were tested and implemented in the Franklin Center and McDonald fire exercises, affecting both 1) research design, and 2) the proposed scene processing protocols themselves.

Changes in Research Design

A major research design change was introduced that affected the areas of distribution of the planted evidence and was related to the extended times and screening efforts recorded during the February and September fire exercises in Canada.

A new recovery strategy was devised to speed screening times, reduce the amount of personnel necessary to process the scene, and increase and speed up the feedback between the screening and excavation teams. This strategy was based on the introduction of a Presorting Team between the Excavation and the Screening Teams. The Presorting Team was able to search, sort and remove irrelevant materials from the sediment before its transfer to the screens.

Modifications in Screening Protocols

Instead of transporting the excavated debris directly to the screens, the debris buckets from apparently sterile areas were first emptied onto tarps, by excavation unit. A second team then rapidly hand-sorted the material. Irrelevant debris and matrix was removed from the screening sample. If any potentially relevant item was found during this search, both the Excavation and Screening Teams could be warned, in a timely manner, to be exhibit precaution in sensitive areas.

With this methodological tweak, only the materials from the areas immediately surrounding detected evidence (such as those around the bodies, weapons, or other evidence) were sent directly to the screen, and the tarp sediments were only screened following detection of an evidentiary item in the surrounding debris.

This strategy proved to be extremely successful, in fact, beyond expectation, at the Franklin Center and McDonald exercises. It served to importantly and effectively reduce the number of screens and screening time, allowing for the processing a large volume of material in a realistic time and significantly increasing detection rates.

In both exercises, evidentiary items were discovered in the presorting of sediments on the tarps from several different locations, which led, through the “early warning” system, to recovering additional evidence in the surrounding debris both *in situ* and at the screens.

When the tarps were added, recovery rates increased from 66% to close to 100% of the total evidence, along with reduced screening time and personnel. Recovery rates were also higher for small clustered elements, especially the closer the evidence was to the body or other major evidence.

Recovery Times

Protocol improvements resulted in reduced recovery times, with more than half of the total structure areas (Figures II-9 and II-10) processed in 1.5 Days (around 8 hours). Fire scenes are more complex than regular crime scenes, and thus should take longer, not shorter to be processed. However, processing a full two story house following these protocols, with the subsequent information gained, should increase processing times by one or two days, not weeks.

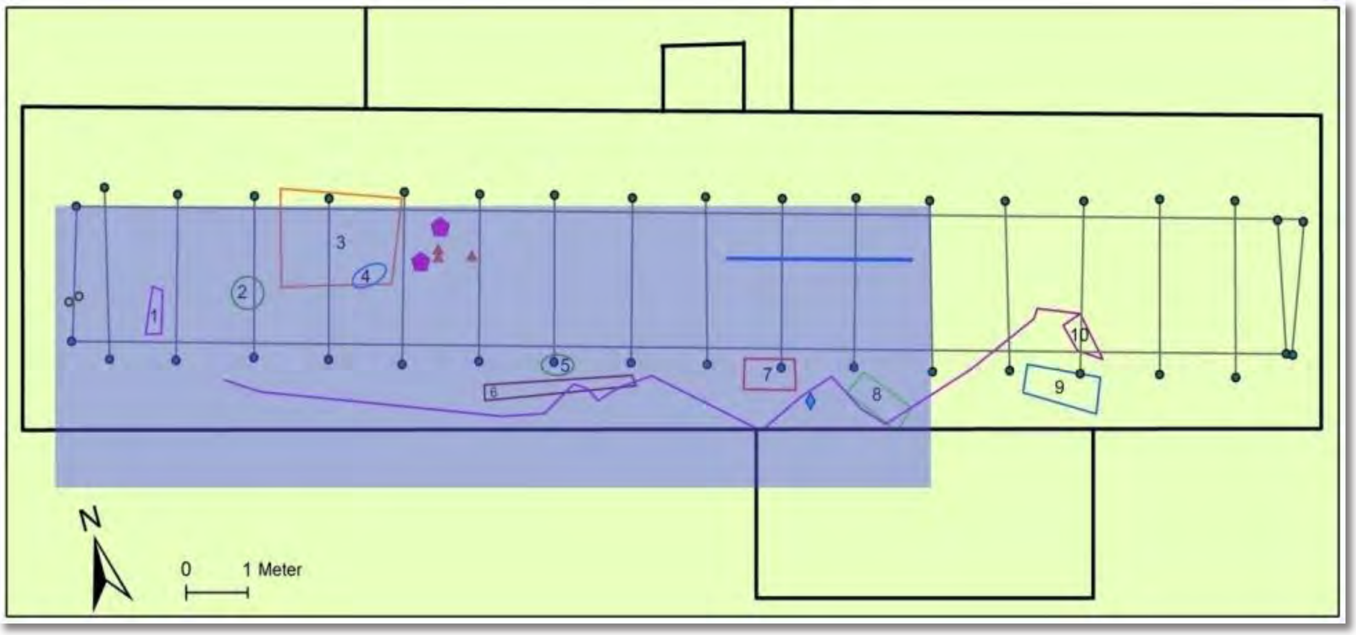


Figure II-9. Survey-grade GPS map of the Franklin Center, PA mock fatal fire scene. The blue shaded rectangle indicates the excavated area processed in 1.5 Days (approximately 8 hours).

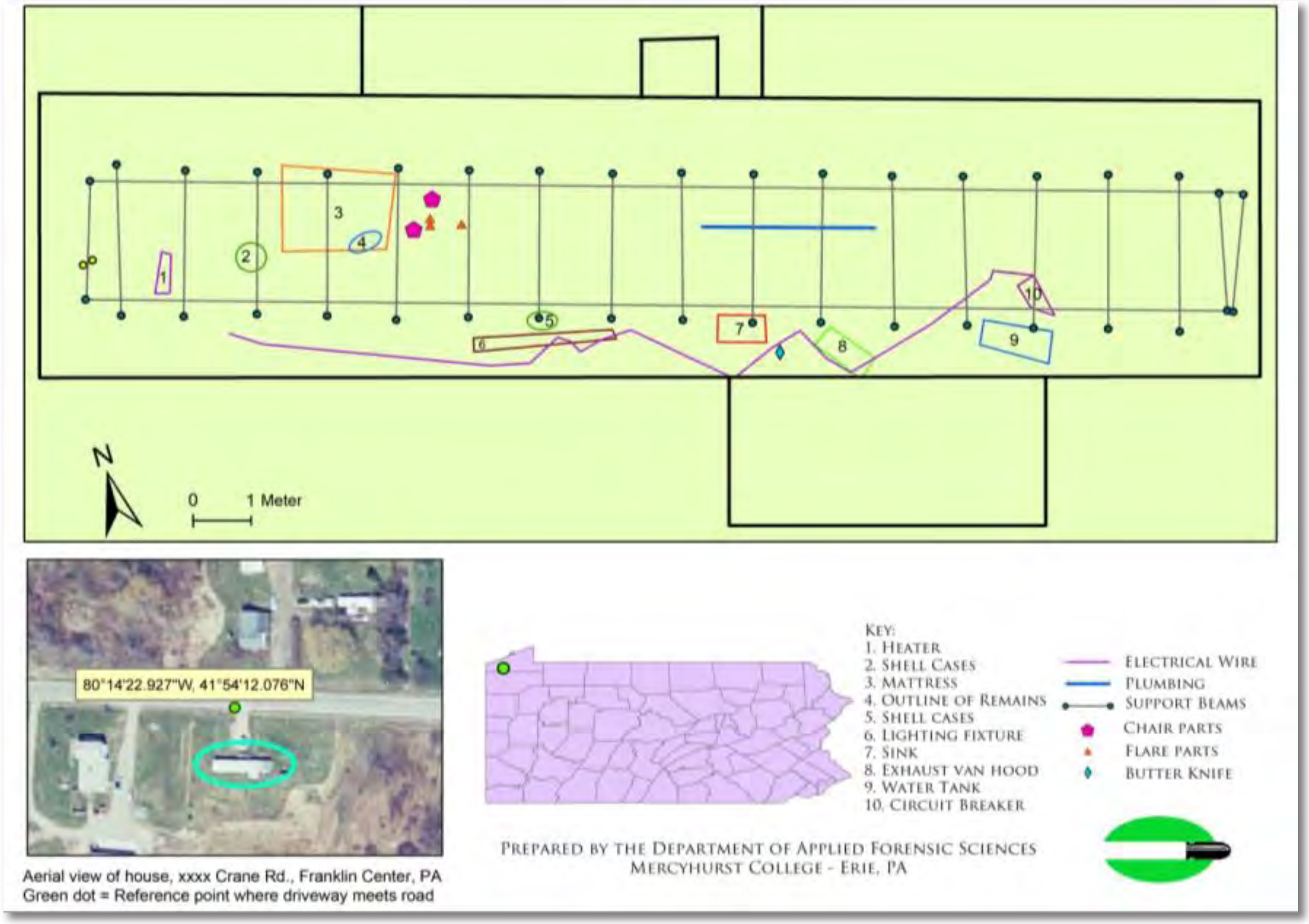


Figure II-10. Presentation figure generated from the R8 data entered into GIS, collected at the mobile home mock fatal fire scene in Franklin Center, PA. Mapping the location of evidence before and after the fire will assist the authors in examining how much evidentiary and regular household items shift from their original locations.

6. Waynesboro, PA Mock Fatal Fire Scene (March 25-28, 2010)

Fire Scene Recovery Protocols

Following the results obtained in the previous exercises, it was not necessary to introduce further modifications in either the protocols or the research design. The additional fire exercise performed rather served as a final test of the already modified protocols, as well as to complete the sample of burned animal remains required for *Component 3* and to record additional thermal data.

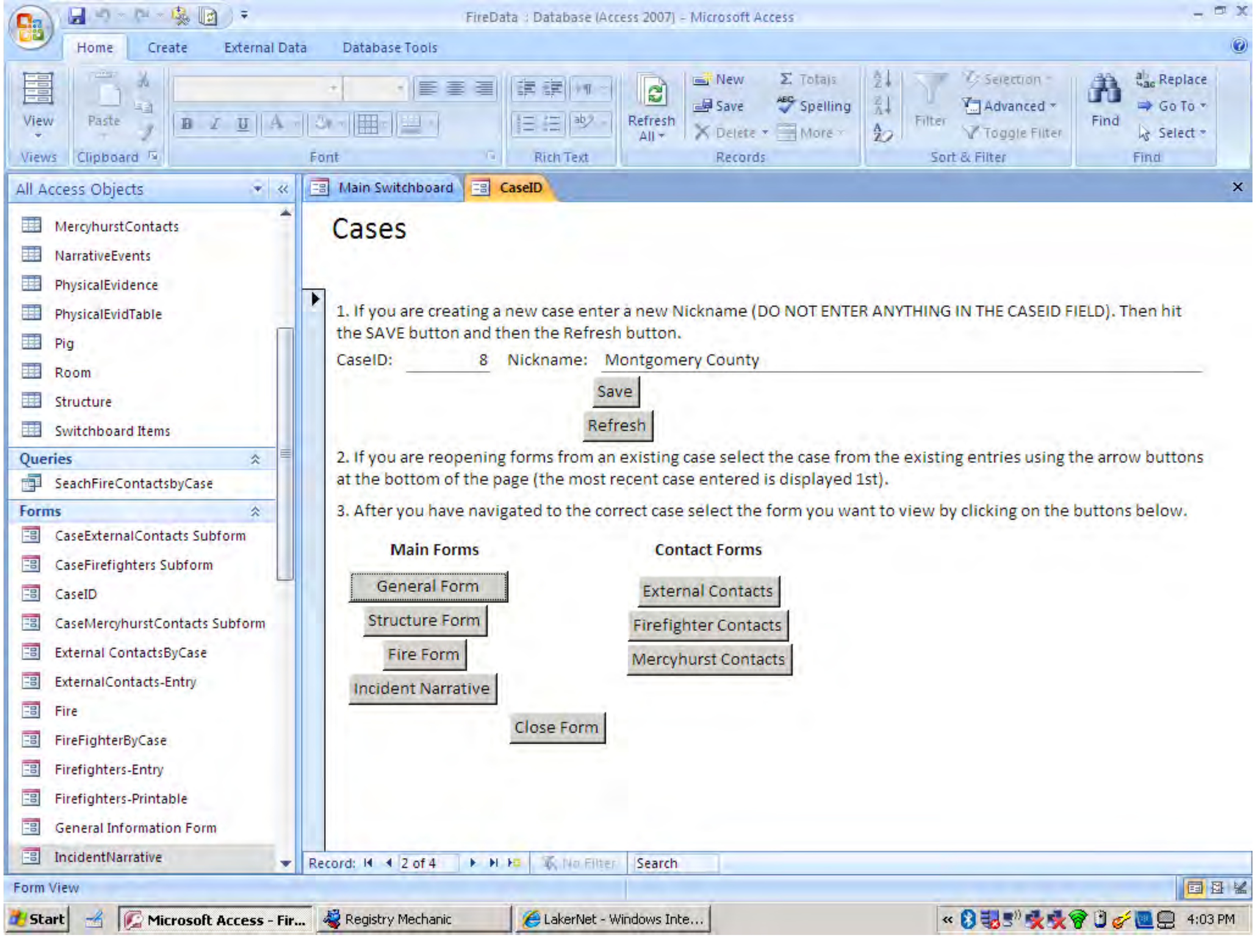
Database and Forms

An important element of these mock fatal fire scene exercises was testing the new databases developed for data recording. These databases are linked and organized around a principal menu form, which allows access to seven secondary forms linked to a set of data tables with the case number as the linking record key (Figure III-9). *Microsoft Access* was selected as the preferred platform, due to its widespread use, availability, ease of programming and translation to other formats. This configuration allowed for easy personalization and improvement by the users.

The sub forms are structured to allow rapid and standardized data collection of information related to the general scene, the structure, the fire and the agencies involved (fire response, law enforcement and external contacts), as well as to record the Incident Narrative describing the progress of scene processing (Figure II-12). The database is intended to provide guidance to the investigator regarding the key information to be recorded. The fields of information contained in the database were selected based on the comprehensive examination of archival case reports as well as information gleaned from the pilot study and subsequent mock fire exercises. It combines information relevant to both the fire and the forensic investigator. They were designed in order to ensure that no relevant information is lost, independent from which of investigator documents the scene in each phase of the investigation. While maintaining a written Incident Narrative form, in which the investigator can document the progress of the investigation at the scene will reduce the written notation in the remaining sub forms. This will help to ensure data integrity and sharing, as well as scene comparisons, by maintaining a uniform data format for all scenes (refer to Appendix II-4 for field data collection forms used at the mock fatal fire scenes).

Recovery Times and Rates

The recovery times and rates obtained in the house exercise were consistent (virtually identical) to those obtained in the previous exercises when the modified protocols were applied. This suggested that reduced, simple scenes such as a mobile home or a partially burned house can be optimally and completely processed in under two days while a more complex two-story house can be completed in approximately three days. These processing times are similar to those expected under the current protocols when a comprehensive investigation is intended. However, in the current protocols virtually no spatial and contextual information is collected and properly documented, and the recovery rates are suboptimal as demonstrated in previous exercises.



Cases

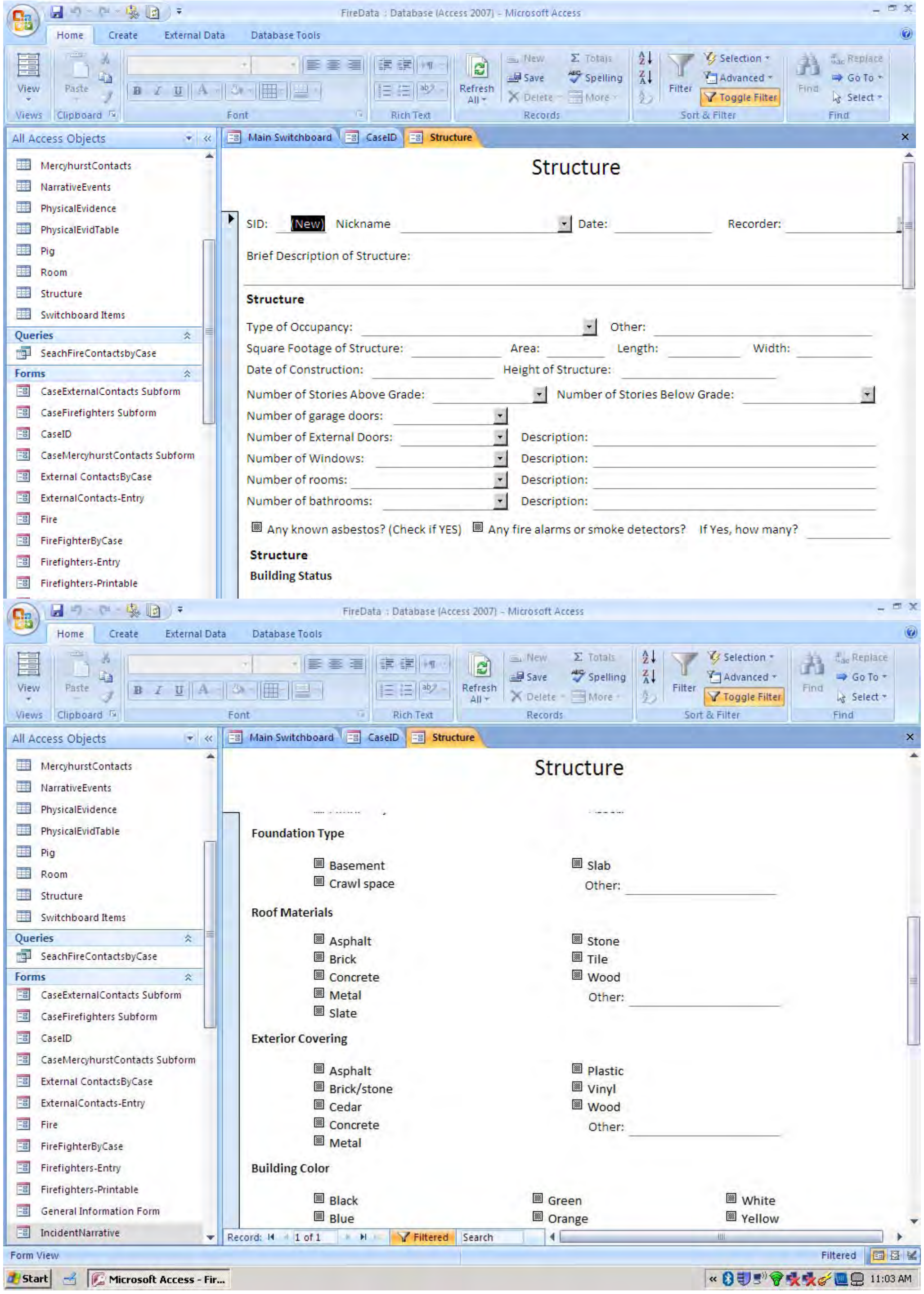
1. If you are creating a new case enter a new Nickname (DO NOT ENTER ANYTHING IN THE CASEID FIELD). Then hit the SAVE button and then the Refresh button.

CaseID: 8 Nickname: Montgomery County

2. If you are reopening forms from an existing case select the case from the existing entries using the arrow buttons at the bottom of the page (the most recent case entered is displayed 1st).

3. After you have navigated to the correct case select the form you want to view by clicking on the buttons below.

Figure II-11. Screenshots of the menu form providing access to the secondary forms for the entry of all information related to the different elements of the fire, the scene, and the participating agencies. The database can be personalized by each agency, automating the entry of common information, like the agency's own address and information, while maintaining a standard, consistent format for the rest of the case data. In its current form, the database is optimized for its use by Mercyhurst College in the fire exercises related to this grant, but a generic form will be provided with the final report.



Structure

SID: (New) Nickname Date: Recorder:

Brief Description of Structure:

Structure

Type of Occupancy: Other:
Square Footage of Structure: Area: Length: Width:
Date of Construction: Height of Structure:
Number of Stories Above Grade: Number of Stories Below Grade:
Number of garage doors:
Number of External Doors: Description:
Number of Windows: Description:
Number of rooms: Description:
Number of bathrooms: Description:

☐ Any known asbestos? (Check if YES) ☐ Any fire alarms or smoke detectors? If Yes, how many?

Structure

Building Status

Structure

Foundation Type

☐ Basement
☐ Crawl space
☐ Slab
Other:

Roof Materials

☐ Asphalt
☐ Brick
☐ Concrete
☐ Metal
☐ Slate
☐ Stone
☐ Tile
☐ Wood
Other:

Exterior Covering

☐ Asphalt
☐ Brick/stone
☐ Cedar
☐ Concrete
☐ Metal
☐ Plastic
☐ Vinyl
☐ Wood
Other:

Building Color

☐ Black
☐ Blue
☐ Green
☐ Orange
☐ White
☐ Yellow

Figure II-12. Two screenshots of the electronic form to guide the investigator in the documentation of the burned structure. The data fields and categories are based on the comprehensive examination of archival records, reported in previous periods. Note the use of list menus and presence/absence click boxes, intended to minimize the need for written notations and, in this way, facilitating data sharing and integrity.

Thermocouple Data

All thermocouple readings indicate a rapid and almost linear increases in the overall temperature in unattended fires, well past flash point, and illustrate the protecting effect of the body tissues on the body surface areas not directly exposed to the fire source (Figure II-13).

Even in the absence of chemical accelerant and in relatively unconfined areas, temperatures above 1000°C (akin if slightly inferior to those in funeral crematory ovens) can be attained in times as short as half an hour in fires with these characteristics (Figures II-13). However, these peak temperatures appear to be short lived, with most of the fire cycle typically taking place under 1000-900ºC. Flash point temperatures can be reached between 10 and 25 minutes, depending on the characteristics of fire and the structure. Even if unattended, most of the high-temperature (above 500ºC) fire cycle was basically completed within around one hour from initial ignition in all cases.

Even when peak temperatures above 1300ºC were observed in some cases, like the two-story house in Montgomery County, PA (see above cautions on the limitations of the thermocouples above 1000ºC), temperatures on the body surfaces away from the fire typically kept at minimum around 100ºC lower than room peak temperatures. Figure II-13 illustrate a typical cycle in which room temperature increases first much faster than body temperatures. Body interior and protected surfaces typically do not even reach boiling temperatures until room temperature rises to around 500-600ºC. Before the flash point temperatures are reached, temperatures of the protected body areas (underneath the body) maintained at least around 100ºC below those of the exposed areas. Temperatures inside the body can follow a similar pattern with respect to temperatures underneath the body, when the body is placed on a piece of furniture (bed or chair) allowing from air circulation under it (Figure II-13a). Apparent sudden high increases in body temperature, apparently not matching those in the areas surrounding the body, appear on occasion but they can be attributed to the snout, rather than the visceral area of the pig, starting to burn once flash point temperature is reached.

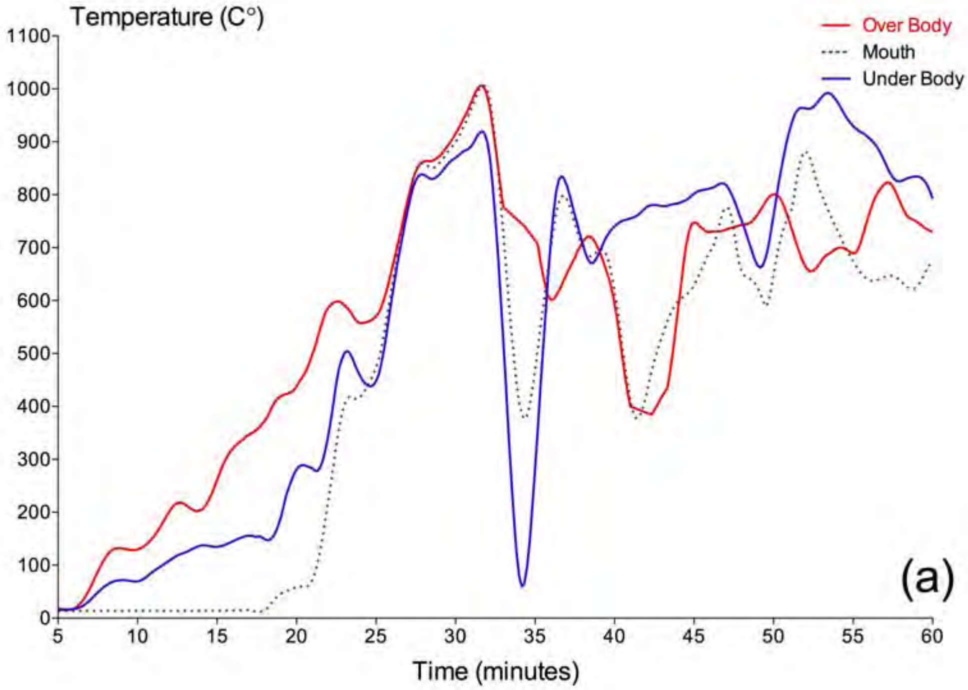
After the flash point, in which the temperatures on all surfaces of the body meet for a short period of time, protected areas keep the same pattern of maintaining a significantly lower temperature (100ºC or more) than the exposed areas. The location of the exposed areas will then vary with the location of the heat source. If the body is placed immediately on the floor, and the latter does not ignite, the area under the body will maintain a lower temperature and thus will suffer a smaller degree of thermal alteration (Figure II-13b). However, if the body is placed on a bed or chair, thus allowing the circulation of air under the body, this relationship can be reversed dramatically, as the furniture becomes the main heat source once that the upper structures are slowing their combustion (Figure II-13a).

Discussion

The range of temperatures observed in the house fires was similar but slightly inferior to the ones in the funerary cremations and, at peak temperature, double the ones applied in the furnace cremations of *Component 3*. However, when average temperatures and cremation times are taken into account, with most of the house fire cycle occurring within around an hour, and temperatures typically below 900ºC for most of the cycle, both the crematory conditions (high temperatures until total consumption of the body) and the laboratory ones (500ºC for two hours, after partial dehydration) seem to represent realistic proxies to real fire conditions (see *Chapters II: Research Component 2* and *Chapter III: Research Component 3* below for additional information on the funerary and the furnace cremations). Based on these results, complete cremations should be in general rather infrequent in house fires, even under the worst circumstances, such as the unattended fires described in this project, and the attribution of missing body areas to total consumption, rather than recovery bias, should be very cautiously proposed.

The temperature ranges and differences between protected and unprotected body areas justify the expectation of clear patterns reflecting body location, positioning and posture, and are consistent with the observations from *Component 2*, in body cremations (funerary) and real fatal fire scene victims.

In particular, the meaningful patterns observed for fire and body temperature distributions and progression, depending on the exact placement of the body, strongly suggest that thermal body alteration patterns can offer significant insight and even strong evidence about these scene factors. For example, the observation in *Component 2* that the body can be prevented from assuming the classic pugilistic posture when placed face down, can serve to infer body position and posture, which can then be compared to scene location and conditions when the scene has been properly documented.



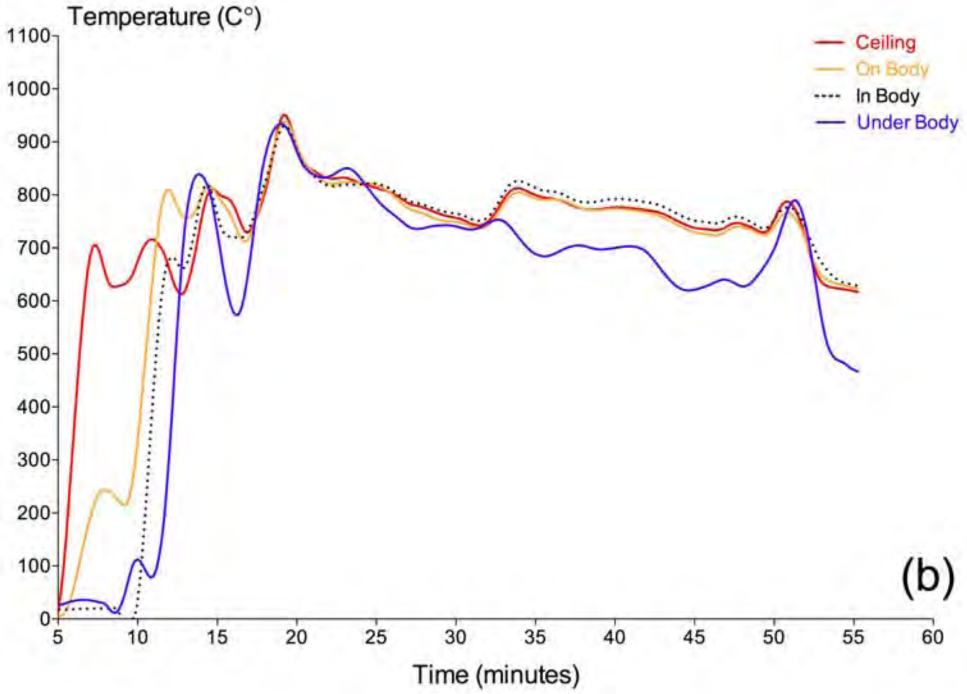


Figure II-13. Illustration of two typical temperature patterns during unattended house fires (a) Temperature readings from a two-story house fire in Montgomery County, PA. Note how after around 35 minutes the temperature under the body raises above than in the upper body surface. In this case the individual was placed over a piece of furniture. This temperature shift would correspond to the moment in which the mattress ignited, becoming the main heat source. This illustrates the protective effect of the body tissues over those areas not directly facing the heat source, in this case the upper surface of the body. (b) Temperature readings at different body surfaces and in the interior of the body. This plot corresponds to the body in a mobile home fire in Montgomery County, PA. Note once again the difference between the temperatures over and under the body. At flash point (around 12 minutes after fire start, approximately indicated by the body temperatures surpassing that at the ceiling) the temperature in the upper surface of the body, directly exposed to the fire, is close to 200°C higher than under the body.

Fatal Fire Scene Processing Protocols

I. Preplanning

Principle. Prior to the occurrence of a fatal fire, a working fatal fire response plan (FFRP) must be constructed and disseminated. The plan should discuss general recovery protocols, agencies involved, and sequence of activities. This plan will help to streamline the process by establishing a chain of command that will negate potential interagency conflicts.

Personnel. Representatives of the following agencies: Coroner/Medical Examiner (C/ME), fire fighters, law enforcement, fire investigator, forensic anthropologist.

Procedure. Construction of a fatal fire response plan that addresses the following issues/topics:

A. Interagency communication and establishment of incident command structure (ICS).
B. The general plan of action: who is called and when.
    1. Fire Fighters as first responders.
    2. C/ME.
    3. Law Enforcement.
    4. Fire/Arson Investigator.
    5. Forensic Anthropologist.
C. Discuss roles and duties of all agencies involved.
    1. Fire Fighters - suppress/extinguish fire and recover survivors.
    2. Police - investigate any fatal fire deaths through interviews and review of scene investigation results.
    3. C/ME - oversee scene management and recovery of human remains; transportation of remains and post mortem examination (victim identification and determination of cause and manner of death).
    4. Fire/Arson Investigators - determine cause and origin of fire at the scene.
    5. Forensic Anthropologists - locate, document, and recover human remains and associated evidence; reconstruct and interpret sequencing of events surrounding the death event.
D. Discuss sequence of activities before, during, and after the scene recovery.
E. Meet on a regular basis to review past recoveries and to review and revise recovery plan.
F. Response and training exercises.

1. Schedule and conduct response and training exercises with some involving mock scenes.

Summary. Preparedness is the main focus in this stage. The roles and duties of each responding organization should be clearly defined. The implementation of an effective recovery plan is necessary to: 1) avoid interagency conflict; 2) promote an effective multidisciplinary effort; and 3) result in a timely and appropriate response.

II. Planning at the Fatal Fire Scene

Principle. Prior to the recovery effort at the scene, it is necessary to re-establish ICS and meet to discuss background information on potential victims, obtain a general impression of the scene, determine the location of remains (if visible) without altering the scene, evaluate the post-fire conditions, and determine whether the scene is safe for recovery teams.

Personnel. Representatives of the following agencies: fire fighters, law enforcement, fire investigator, C/ME, forensic anthropologist, cadaver dog handler.

Procedure. Prior to recovery efforts, a meeting will be held at the scene in which the following activities will be completed:

A. Incident command will be reestablished and reaffirmed.
B. Contact information will be exchanged:
    1. On-site contact (cell phones, walkie-talkies) for each on-site agency representative.
    2. Post-recovery contact numbers and information.
C. Fire fighters will evaluate the scene to ensure safe working conditions:
    1. Fire is extinguished with no potential flare-ups, cool enough for recovery.
    2. Remaining floor and standing structures (walls and chimneys) exhibit adequate integrity.
D. Information concerning potential casualties and their location within the structure will be discussed.
E. General protocols to be used by scene recovery team will be discussed and a detailed recovery plan including sequence of events, personnel involved, and estimated recovery duration will be formulated.
F. Site logistics will be discussed (see Appendix 1 for checklist of materials):
    1. Food and water.
    2. Shelter for rest areas, food and water areas, first aid stations, evidence and scene data collection station.
    3. Accommodations for weather (e.g., blast torpedo heaters in cold weather, tent or awning for shade or rain in summer).
    4. Scene security.

G. How evidence, including human remains, will be handled during recovery and transport (where and by whom) will be established.

Summary. The key to this phase of the recovery is to reestablish lines of communication, to reaffirm the roles and duties of each of the participants, and to construct a recovery plan. A safe and efficient workspace is essential in the recovery process. It is necessary to solidify all of the on-site logistics upon arrival to ensure an effective recovery effort. Understanding the chain of command is essential in the recovery process to avoid interagency conflict.

III. Fatal Fire Scene Recovery Protocols

Phase 1: Organization and overall scene documentation

Principle. Once on the scene, it is necessary to divide into the specific teams, create a proper working environment, and start the documentation of the general scene, including all personnel and specific activities and findings. Documentation takes place at 3 levels: 1) written; 2) photographic/videographic; and 3) mapping. The key to mapping is to obtain an accurate depiction of the scene that is geo-referenced (i.e., its precise location on the Earth).

Personnel.

1. Written Narrative Team
2. Photography Team
3. Videography Team
4. Provenience Team

Procedure.

1.1. Organize site personnel into teams with clearly defined duties (see Appendix 2).

1.2. Logistics

- Set up tents/shelters (a. food; b. water; c. first aid; d. computer and internet; e. miscellaneous supplies)
- Pre-recovery meeting with recovery teams.
    - Reinforce lines of communication and identify team leaders (responsible for communicating with other team leaders through walkie-talkies or cell phones).
    - Discuss overall recovery plan.
    - Question and answer session.

1.3. Written Narrative Team begins Incident Narrative (IN) of recovery (see Appendix 3):

- General description of location, surrounding environment, weather, etc.
- Record of personnel, activities, and timeline of events during recovery.

1.4. Photography Team begins general scene documentation.

- General views of scene from all cardinal directions.
- Detailed shots of the scene and items of interest (from outside of the scene) with scale and north arrow in each picture.

1.5. Videography Team begins general scene documentation.

- Set up video camera at a location where the entire scene can be viewed.
- Videotape (pan) the scene in 360º and surrounding area with sound off.

1.6. Provenience Team begins. Two configurations are possible:

1.6.1. Configuration 1: Combination of electronic Total Station and GPS:

- Establish Datum (in area with good visibility of the scene) by hammering a wooden stake into the ground and spray painting it bright orange (for visibility).
- Set up total station (see Appendices 4 and 5).
- Collect total station points at all corners of the structure and any deviation in shape of the structure to generate an accurate outline depiction of the structure.
- Collect several points around the scene to represent the general topography of the area, especially at any real alterations in elevation (later used to generate detailed contour lines) (See Appendix 6 for details).
- Use GPS to note precise location of at least 4 provenience points in common with total station points including the datum and backsight. More common points are recommended (Appendix 7).

1.6.2. Configuration 2: Survey-grade GPS (Appendix 8).

- Establish site datum with stake as previous configuration.
- Take points at all corners of structure and any major deviations in the shape, as before.
- Take several points around the entire scene to sufficiently document the topography. This will include any deviations in land contour (see Appendix 6 for details).

Summary. This first phase is focused on documenting the scene, ensuring safety of the structure, and beginning the initial search. Mapping the large-scale scene is important for retaining the context and, subsequently, the sequence of events. Two configurations are possible: 1) the total station, which is extremely accurate but not geo-referenced and the GPS, which can be merged with the total station points so long as enough overlapping points are taken; 2) the survey-grade GPS that combines total station accuracy and GPS.

Phase 2: Rapid, Systematic Large Scale Search

Principle. The initial search is used to establish the general area where potential evidence is located within the structure. The idea is to effectively and efficiently search the premises without disturbing potential evidence.

Personnel.

1. Written Narrative Team.
2. Photography Team.
3. Videography Team.
4. Search Team.
5. Forensic Significance Team.

Procedure.

1.1. Written Narrative Team

- Continue Incident Narrative updating personnel duties and timeline of events. Make entries at least every 15 minutes.

1.2.Photography Team

- Document progress of Search Team (general overall photographs).
- Document fire cause/origin evidence at direction of fire investigator with scale and north arrow.

1.3.Videography Team

- Move video camera to establish a good vantage point for documenting Search Team progress.
- Continue videotaping of the search efforts

1.4.Search Team

- Establish search corridors based on boundaries of rooms or create transects of crime scene with crime scene tape (5-10 searchers in width with ca. 20-25 foot wide transects).
- Searchers walk shoulder-to-shoulder maintaining a straight line (enforced by team leader).
    - Remove debris to lowest substrate level and place debris behind searchers. Move around large debris.

- Remove large debris from searched area with heavy equipment (forensic anthropologist to monitor this effort).
- Flag potential evidence (use appropriate flag color for class of evidence).
- Stop large-scale search if human remains or significant evidence is found.

1.5. Forensic Significance Team

- Search for origin of fire/path of fire conducted by Fire Investigator.
- Evaluate flagged evidence noted by Search Team.
- Remove flag if item is not forensically significant.

Summary. The goal of this phase of the recovery is to search the scene rapidly, systematically, and (importantly) carefully. Through the use of this search methodology, areas of the scene that do not contain evidence can be eliminated quickly, and with confidence. When evidence is identified within the fire-altered deposits, its forensic significance is determined rapidly and in real time and does not slow down the recovery. If forensically significant evidence or the body is located, the search can then switch to a recovery operation.

Phase 3: Evidence of Human Remains Found, Rapid Large-Scale Excavation

Principle. Once human remains have been discovered, it is necessary to excavate and remove all of the debris that does not contain evidence of human biological tissue in the immediate vicinity surrounding the victim. This will be done rapidly until forensically significant evidence is encountered. All debris excavated in this phase must be hand sorted and screened.

Personnel.

1. Written Narrative Team.
2. Photography Team.
3. Videography Team.
4. Excavation Team.
5. Screening Team.

Procedure.

1.1. Written Narrative Team
- Continue Incident Narrative. Include general location of evidence/human remains, personnel changes, updated timelines. Update every 15 minutes.

1.2. Photography Team
- Continue photo-documentation of recovery efforts.

1.3. Videography Team
- Move camera to vantage point to document scene excavation.

1.4. Excavation Team
- Begin rapid and systematic excavation by hand or with excavation trowels approximately 10 ft (3m) from areas of interest using proper archaeological techniques (excavate in a top-down fashion using the “cake-cutting” method). Begin from outside and work toward evidence/human remains (see Appendix 9 for details).
- Rapidly move excavated matrix to behind the excavators (to be removed by Screening Team).

1.5. Screening Team
- Collect excavated matrix (behind Excavation Team) and transport to tarps laid outside of the immediate scene.
- Search for evidence by rapidly hand sorting excavated matrix on tarps.

- Stop rapid excavation if forensically significant evidence is found.
- Remove hand sorted material from tarps to a designated area ('screened debris' pile location).

Summary. Once forensically significant evidence or the human remains are identified within the scene, the excavation phase of the recovery can begin. The initial phase of excavation involves clearing areas approximately 10 ft around the evidence that does not contain evidence, rapidly, though still carefully. Burned matrix is excavated using solid archaeological excavation methodologies involving the classic top-down vertical cuts by hand or with trowel, that creates a moving vertical excavation face. The excavated debris is taken off-site and sorted by hand on tarps rather than on screens until evidence is found or excavations are in the immediate proximity of the evidence/body. These simple modifications to existing methodologies result in significant savings in time. If evidence is found, or excavations have commenced to the immediate vicinity of the evidence or body, the excavation moves into the next phase of the recovery.

Phase 4: Fine Detailed Excavation in the Immediate Vicinity of Human Remains

Principle. In the immediate vicinity of evidence, including human remains, the Excavation Team transitions to a slower, more detailed excavation with hands or trowels. This is to ensure that evidence and human remains are located, remain undisturbed, and left *in situ*.

Personnel.

1. Written Narrative Team.
2. Photography Team.
3. Videography Team.
4. Mapping Team.
5. Excavation Team.
6. Screening Team.

Procedure.

1.1. Written Narrative Team

- Continue Incident Narrative making sure to document the time that evidence and human remains are found
- Write brief descriptions of evidence, including description of remains and interesting or unique observations.

1.2. Photography Team

- Continue photographic documentation of the excavation process.
- Photograph any evidence found in the screens
- Photograph evidence located through excavation *in situ* with scale and north arrow from multiple directions.

1.3. Videography Team

- Reposition video camera to document fine detailed excavation. Be sure to set up video camera where all of the excavators can be seen.

1.4. Mapping Team

- Establish grid system (depending on the scene a 1x1 meter, 2x2 meter, etc.) over areas containing evidentiary items, including human remains.

1.5. Excavation Team

- Conduct high resolution excavation (see Appendix 9) starting on outside extents of grid units.

- Place all excavated debris into buckets (for transport to screens).
- Fully expose all evidentiary items, including human remains, but do not disturb their *in situ* location, position, and orientation (flag these items).
- Excavate debris matrix until undisturbed/underlying substrate level is exposed.

1.6. Screening Team

- Collect excavated matrix into buckets.
- Screen all material from buckets on fine ¼ in. mesh screens.
- Record grid unit of any evidence found in screening efforts.
- Package evidence with grid unit, date, time, and screener who found evidence marked on bag.

Summary. This phase of the recovery involves the careful and comprehensive forensic archaeological excavation of the evidence. Debris is removed from around and from above the evidence using exacting excavation methods to reveal the *in situ* position and orientation of the body and any associated evidence. All excavated matrix is removed from the scene and screened through ¼” mesh screens in order not to miss any evidence.

Phase 5: Mapping and Collection of Evidence and Human Remains

***Principle*.** After evidence, including human remains, has been fully exposed, it is necessary to produce a to scale hand-drawn plan view map. Due to the similarly colored surrounding matrix, this map will help visualize the orientation and position of the remains in relation to other evidence.

Personnel.

1. Written Narrative Team.
2. Mapping Team.
3. Provenience Team.
4. Collection Team.

***Procedure*.**

1.1.Written Narrative Team

- Update Incident Narrative including mapping and collection process, and all personnel and their position.
- Note general position and orientation of the remains.
- Note any interesting observations (spatial relationship to surrounding evidence, specific area of the house, etc.).
- Document condition of all items prior to collection (include potential trauma, degree of fragmentation, elements missing, etc.)
- Document time of evidence collections into transport vessels.

1.2. Mapping Team

- Measure specific points from gridlines (northing and eastings) within coordinate grid units to produce a to scale plan-view map.
    - Mapping human remains:
        - Map each visible individual bone. At least proximal and distal ends for long bones and multiple points for irregularly shaped bones.
        - Give each bone a unique number that is recorded on the map.
    - Mapping associated evidence:
        - Piece-plot smaller evidence (assign one point per object).

- Map outline of larger pieces of evidence (enough points to provide accurate representation of the shape, points usually taken at deviations in shape).

1.3. Provenience Team

- Collect same grid points depicted on hand-drawn map with total station or survey-grade for later merging of hand drawn map to GIS generated maps (for details see Appendices 10 and 11).

1.4. Collection Team

- Loose elements or fragile bone still associated with the main portion of the body can be wrapped with plastic wrap to ensure their association and preserve intact elements from further fragmentation.
- The hands, head, and other loose elements should be wrapped in heavy-duty plastic wrap prior to placement in body bags to prevent further fragmentation of skeletal material.
- Place a wooden board in body bag to add stability during transportation.
- Collect large body parts, torso, etc. into body bags with identification written on the outside of the bag
- Collect loose pieces into containers according to area of body (e.g. right hand, left foot, etc.).
- Place items into proper containers with clearly labeled evidence/map number, date and time, and collector's name labeled on the outside of the container. Individual bones should be labeled in pencil with their corresponding map number.

Summary. This final phase of the recovery involves the detailed coordinate mapping of each item of evidence by hand relative to identifiable features at the scene. This is associated mapping of the larger scene with an electronic Total Station and GPS, or just with the survey-grade GPS. Each item of evidence is given a unique field number that is noted on the map and even on the item (and on/in the bag) as it is removed from the scene and placed in its proper receptacle. Individual biological tissue items (burnt bone) are bagged separately. Burned biological tissue (bones and soft tissue) requires wrapping of delicate structures, placing preservative on fragile dental remains, and the placement of solid underlayment within body bags in order to limit further damage during transport.

Phase 6: After Comprehensive Documentation and Collection: Removal and Transport

Principle. After the proper collection and storage, the evidence can be transported to the appropriate channels. The evidence will be taken by law enforcement, while the human remains will go to the c/ME.

Procedure.

1. Transport human remains using an adequately sized vehicle. Larger scenes will require refrigeration trucks to temporarily hold the remains before transportation to the morgue.
    - Remains should never be stacked upon one another.

Summary. The remains and evidence are taken to the appropriate analytical centers in the final phase of the recovery.

Appendix 1. Equipment List

PPE Materials

Tyvek suits (preferably waterproof and flame resistant)
Goggles
Respirators
Latex and nitrile gloves
Leather work gloves

Recovery Equipment

Trowels
Dustpans
Brushes
Shovels
Trash cans
Plastic bins or buckets
Zip lock bags: various sizes
Body bags
Sharpies
Pin Flags
Rebar
Caution tape
Heavy-duty plastic wrap
Tarps
1/4” mesh screens

Documentation Equipment

Electronic Total station
Ruggedized computer
High quality GPS or survey-grade GPS
Digital SLR Cameras
Pens
Clipboards
Data collection forms
Photographic scale
North arrow
Walkie-talkies
Extra batteries for all equipment
Power source for recharging equipment
High quality video recorder

Equipment/Necessities for personnel

3-4 collapsible tents for breaks and changing
Portable bathroom
Bottled water
High energy snacks

Appendix 2. Roles and Responsibilities of Scene Recovery Teams

Principle. Given the scale of the fatal fire scene, it is not practical to have individuals performing multiple tasks. To this end, team members are organized into specific duty teams to expedite the recovery efforts. Often, teams are working concurrently, though certain tasks must be completed before others may begin [see work time chart below].

Procedure. Assign individuals to the following teams:

A. Scene Recovery Manager:
    1. Responsibilities:
        a. Oversees all teams and monitors productivity.
B. Written Narrative Team:
    1.Primary Personnel:
        a. Incident Narrative scribe/note taker.
    2.Responsibilities:
        a. Complete written documentation of scene recovery that is entered into a computer database including:
            1. Details of site location (county, township, nearby towns, etc.).
            2. Names, addresses, and rank of all individuals on the scene.
            3. Scene description (total vs. partial structure burn, etc.).
            4. Description of structure.
            5.Time-stamped, sequential description of all activities and personnel, at least every 15 minutes.
            6. Description of weather conditions.
C. Photography Team
    1. Primary Personnel:
        a. Photographer.
        b. Photographic Log note taker/scribe.
    2. Responsibilities:
        a. General views of the scene from four cardinal directions.
        b. General views of interesting features.
        c. Photograph recovery process.
        d. Photo-document all evidentiary items *in situ*.
        e. Document information about each photograph including, file number, direction, range, flash, and brief description to substantiate provenience data in map production.
D. Videography Team
    1. Primary Personnel:
        a. Videographer.
    2. Responsibilities:
        b. Videodocument general views of the scene.
        c. Videographic documentation of recovery process.
        d. Videotape evidence *in situ.*
        e. Videotape human remains *in situ.*
E. Search Team:
    1. Primary Personnel:
        a. Forensic anthropologists.
        b. Fire/Arson investigators.
    2. Responsibilities:

        - a. Determine an appropriate grid or corridor schematic to divide areas of interest into manageable units.
        - b. Establish grid/corridor.
        - c. Conduct a thorough shoulder-to-shoulder straight line pedestrian search through the scene.
        - d. Flag each piece of suspected evidence without evaluating or disturbing it.

F. Forensic Significance Team:

- 1. Primary Personnel:
    - a. Forensic anthropologist.
    - b. Fire/Arson investigator.
- 2. Responsibilities:
    - a. Follow Search Team and evaluate forensic significance of each flagged item.
    - b. If the item is insignificant to the investigation, remove the flag.
    - c. Ensure each class of evidence is correctly flagged.

G. Provenience Team:

- 1. Primary Personnel:
    - a. Electronic total station operator.
    - b. Prism operator.
    - c. GPS unit operator (if survey-grade GPS is used, Total Station will not be necessary).
- 2. Responsibilities:
    - a. Work simultaneous with Barcode and Photography Teams.
    - b. Utilize electronic total station or survey-grade GPS to record the precise geospatial location of all evidentiary items
    - c. Generate detailed maps showing the distribution and spatial relationships of all evidence.

H. Excavation Team:

- 1. Primary Personnel:
    - a. Forensic anthropologists (number depends on size of incident area)
- 2. Responsibilities:
    - a. Use proper archaeological excavation techniques to excavate, expose and document evidence, including human remains.
    - b. Excavate from the outer extent of the debris pile and work inwards while on hands and knees.
    - c. Retain the provenience of the item.

I. Screening Team:

- 1. Primary Personnel:
    - a. Forensic archaeologists.
    - b. Trained investigative personnel.
    - c. All available participants on-site with no prior obligation.
- 2. Responsibilities:
    - a. Work simultaneously with Excavation Team
    - b. Hand screen materials on tarp or on 1/4” mesh screens.
    - c. Bag evidence with grid location of each piece of evidence.
    - d. Transport buckets from excavation grids to screening area noting the grid unit of each bucket.

J. Mapping Team:

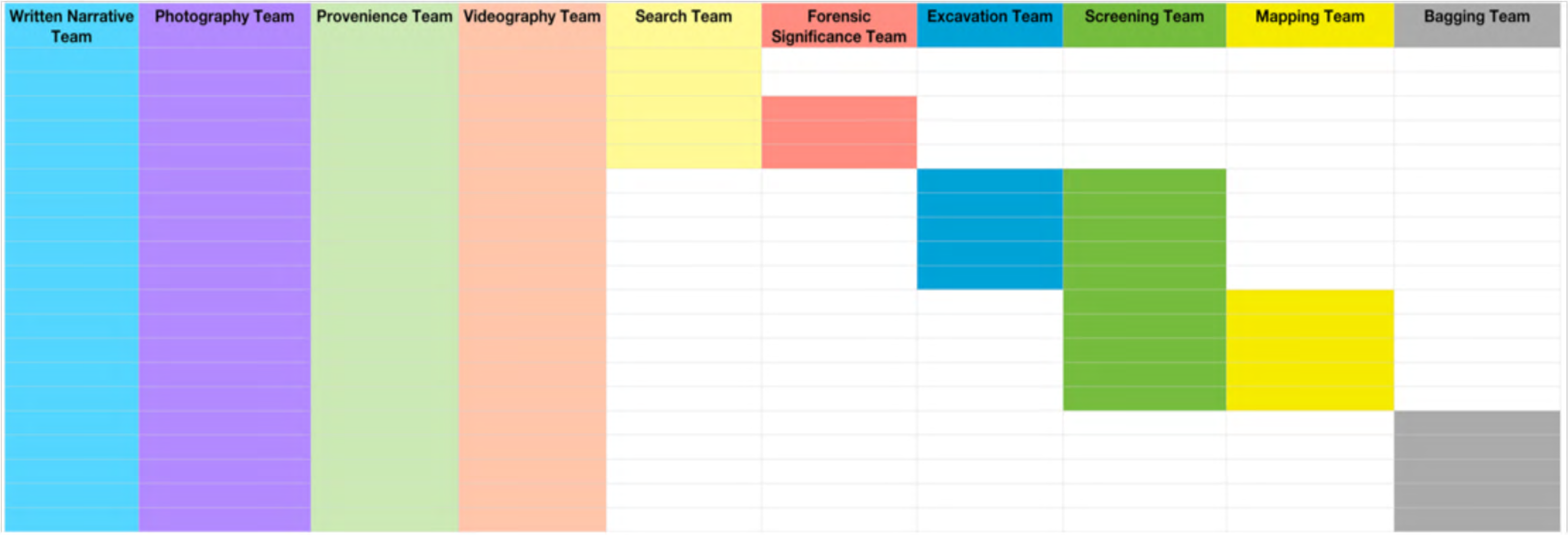
- 1. Primary Personnel (for one unit, several Mapping Teams may work simultaneously):
    - a. Mapper.
    - b. Two mapping assistants to collect coordinate data.
- 2. Responsibilities:

        - a. Create a plan view hand drawn map to scale of all evidence within the structure.

L. Bagging Team:

- 1. Primary Personnel:
    - a. All available participants on-site with no prior obligation.
- 2. Responsibilities:
    - a. Select appropriate collection vessel for specific evidence (plastic bins, paper bags, Ziploc bags, body bags, etc.).
    - b. Carefully bag each piece of evidence documenting (date, grid unit, and initials of collector).

Summary. Separating people into specialized teams allows for a more efficient recovery. As individuals become more comfortable with their roles and duties, their productivity will increase. Job specialization, therefore, is an important aspect of the recovery effort. The teams listed above represent the specific components necessary in the recovery effort and not the total number of people or teams working the entire time. Teams are often working concurrently with one another. Once the function of one team has been fulfilled, those team members will be assigned to a new team. Responsibilities of teams can also be combined; for example, the Barcode Team can also serve as the Forensic Significance Team if sufficient personnel are unavailable.



Work time chart for each team involved in the recovery process. Notice that teams are often working simultaneously during the recovery. Certain teams, however, can only begin after a previous team has completed (e.g. the Search Team must complete their tasks before the Excavation Team can begin). On the other side, the Written Narrative Team, Photography Team, Provenience Team, and the Videography Team are working throughout the whole recovery process.

Appendix 3: Incident Narrative

FORENSIC
ANTHROPOLOGY
AT MERCYHURST COLLEGE

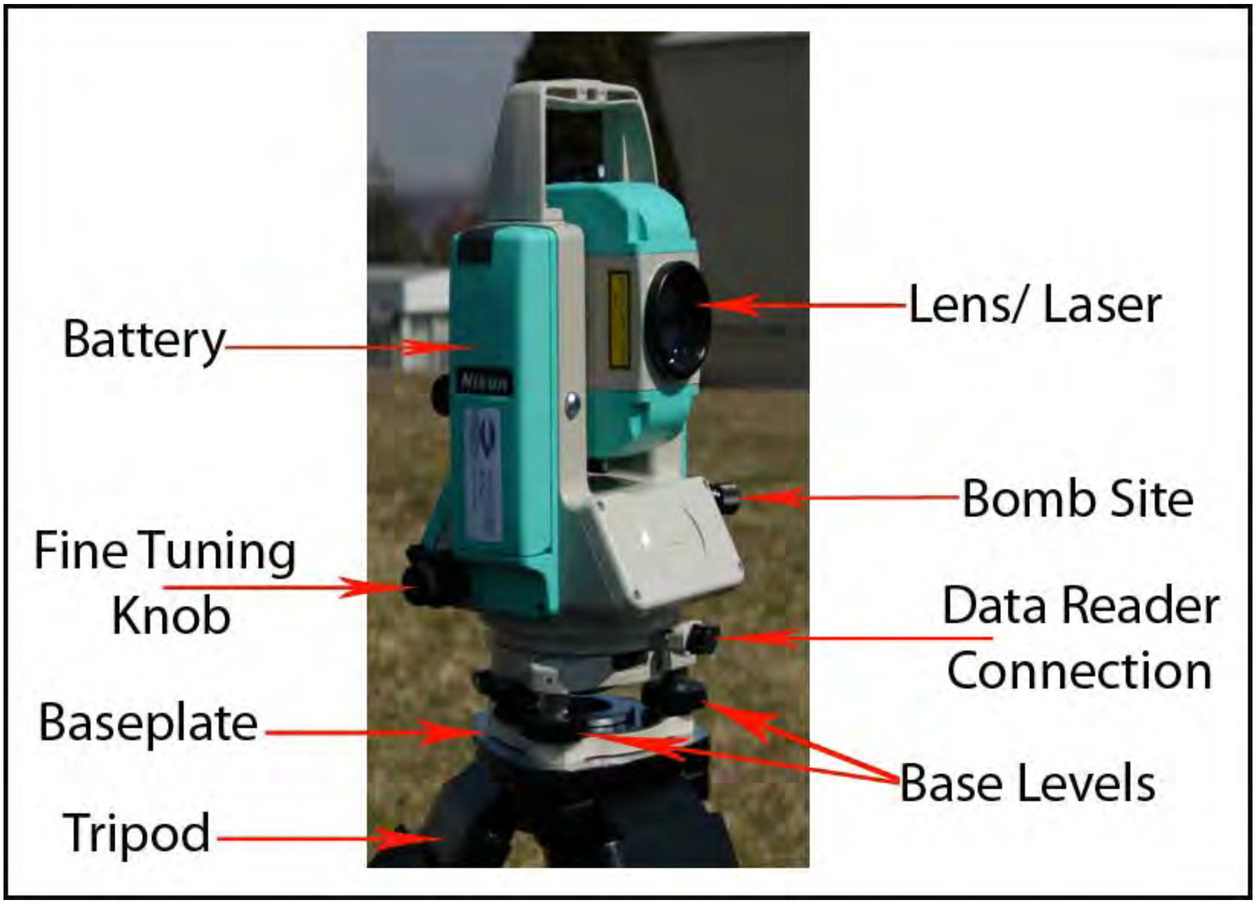
Name of Recorder:________________________________
Location:_____________________________
Case #:_____________________ Agency #:______________________
Date:___________________

Time	Weather	Temp.	Description of proceedings

Appendix 4. Total Station Basics

A total station is an electronic surveying instrument that is used to determine angles and distances from a datum (main reference point on the site) to points of interest. A total station (or TS) records actual positions in a three-dimensional plane (x, y, z or Northing, Easting, and elevation) using an electronic theodolite. A total station is used to impose an x, y, z grid on a site. It allows the user to locate and replicate the position of every point of interest and to create topographic maps of the scene. Information stored in the data reader can later be uploaded into mapping software (i.e., Geographic Informations System or GIS) to add additional details, as well as to analyze the collected data. Because it is efficient and extremely accurate, total station is useful at every outdoor crime scene.

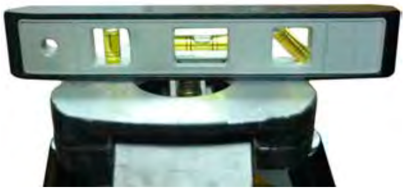
The total station consists of several vital parts. It uses an electronic theodolite (transit), an electronic distance measurer (EDM), a handheld computer and a prism to collect x, y, z coordinate data. The EDM calculates the distance the total station is from a point of interest by sending an infrared beam from the TS unit to the prism. The time it takes for the beam to reach the prism and return to the instrument is then used to calculate the distance. Coordinates calculated using an internal calculator that performs trigonometric functions using angles and distances to relate each point of interest to the established datum.



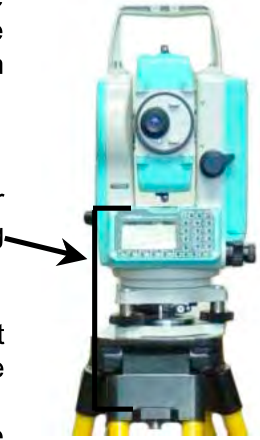
Appendix 5. Total Station Set Up Basics

Choose an approximate location to establish a reference point, or point of origin (datum). This location should ideally be at a somewhat higher elevation that overlooks the entire scene with minimal visual obstructions.

To set up the tripod, place the tripod over the estimated point of origin, adjusting the height of each leg so that the tripod platform is level. Remember, the theodolite is approximately 35 cm (approx. 14 inches) tall and will be placed on top of the tripod so make sure the base is at an appropriate height for the operator to view through the eyepiece.



Level the platform on the tripod using a level. Even if the center of the base is level, the areas of the base above each leg may be slightly askew. Place the level on the base of the tripod on top of the center of each leg and adjust the height accordingly. The tripod is level when the line level is centered for each of the three legs. After the tripod is level, secure the tripod by pressing down on the legs firmly. Verify the tripod is still level. (Approx. 14 inches)



Place the theodolite on the base of the tripod. Once it is centered over the base, secure the theodolite to the base by tightening the mounting screw found under the base.

To level the instrument, begin by adjusting the leveling screws so that the screws are at the same level (as indicated by a line etched into the screw surface). Level the instrument plate bubble using the plate level.

a. Align the level so that its axis is parallel to the line between two of the leveling screws.

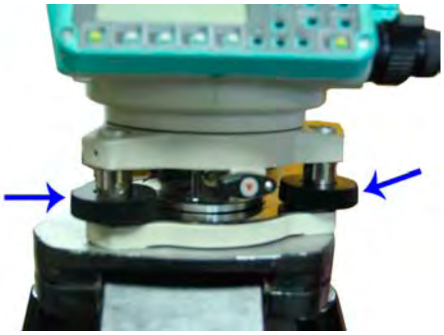
b. Observe the location of the bubble. Move both leveling screws with your thumbs equal amounts in opposite directions. Center the level exactly between the two large lines.

**Left Thumb Rule*: Both thumbs move in or both thumbs move out.

The level follows the direction of the left thumb.

c. Rotate the instrument 90 degrees so that the bubble is aligned over the second screw.

d. Rotate the instrument 90 degrees so that the bubble is aligned over the third screw. Use that screw only to center the bubble exactly. Turn the instrument to its original position (as in a.). Level again if necessary. Continue this process until the bubble stays centered as the instrument is rotated.



To establish a datum, attach a plumb bob to the tripod mounting screw. Center the plumb bob by looking through the optical plummet (viewfinder on the side of the theodolite under the battery) until the cross hair (reticle) is over the top of the plumb bob. Drop the plumb bob lightly to mark the ground. Place a marker where the plumb bob mark is left **(usually a nail)**. Verify that the survey marker is centered by looking through the optical plummet and confirming that the reticle is centered over it.

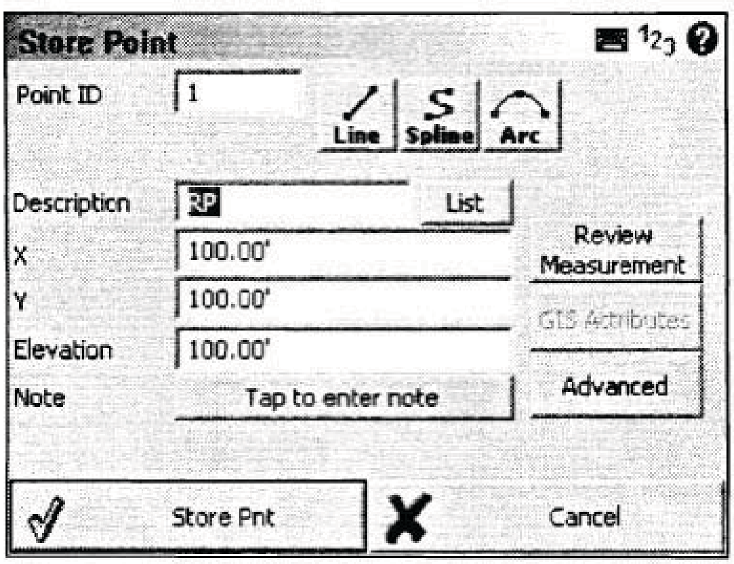
To assemble the prism and rod (and bipod, if desired), attach the prism to the top of the rod and place the tip of the rod's base on the center of the point that will be measured. Usually the height of the rod should stay at 1.5 m. This is the distance from the tip of the rod that is on the point to the center of the prism. The lower the rod, the more accurate the measurement. If the person running the instrument cannot see the prism, the rod should be raised. Position the prism so that it is facing the instrument.

Hold the rod so that the circle bubble is centered. Keep the prism in position until the person running the instrument says, "Okay" or "Good."

To attach the data recorder (i.e., handheld computer) to the tripod, first place the holder onto the legs of the tripod.

Attach the cable to the handheld computer and to the NPL-332. Carefully place the tracker in the holder.

Open Evidence Recorder and begin a new project.



Store Point

Point ID: 1

Description: RP

X: 100.00'

Y: 100.00'

Elevation: 100.00'

Note: Tap to enter note

Establishing your Datum. After connecting to the Total Station, you will see a message asking, **"Would you like to create a new reference point which will be used to occupy the instrument?"** Press **YES**

If you know the GPS coordinates of the datum, input them in the X (latitude) and Y (longitude) field and your points will be georeferenced.

If you do not know the GPS coordinates of your datum, input a large arbitrary number for each, for example 100.00m, 100.00m for X and Y respectfully and 0m for elevation. This will ensure that all of the points you will take will be positive numbers making for easier conversion when merging them with GPS coordinates.

Click: Store Pnt

You will be asked, "Would you like to occupy the reference point you just created?" Press Yes. You have now created your datum and will be prompted to set up your Backsight automatically.

Establishing your Backsight
On the Orientation Setup screen verify:

Occupy Point: **1** (as 1 is your datum)

Instrument Height: measure from the ground to the **+** on the side of the theodolite. Enter measurement in **m**.

Check the Backsight Direction box and verify Backsight Direction as 0°00'00.0" (or true north)

When you have entered all your information Click Observe Backsight Enter your Target Height (height of prism rod.

Place the prism rod assembly directly **NORTH** of the instrument (use a compass) and sight.

Ideally, you want your Backsight to be further than the furthest point of interest or furthest point you will map.

You will now see a summary of your shot.

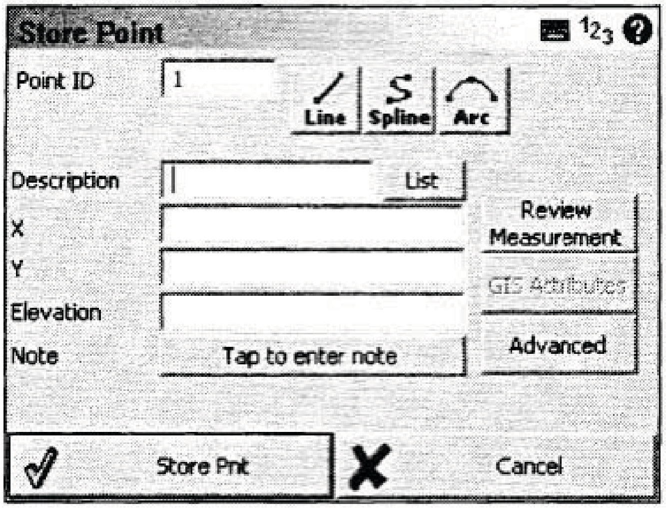
If something does not look right, **Observe** Again!

If everything is OK, Click: **Accept.**

Start Survey.
To record additional points, move the prism rod to the desired location or survey marker. Sight, align, and focus the telescope on the prism. When you are ready, Click: Measure (the sunburst). When the point has been shot, the instrument will beep and the following screen will appear. **Point ID** is the point number that is generated by the program. These will increase sequentially.

Description: Be simple and descriptive. If it is human remains use a code such as HR. Be consistent. This will help with map-making later. You can add a note for additional information concerning a point, such as specific features, etc. Anything that will make map-making easier.

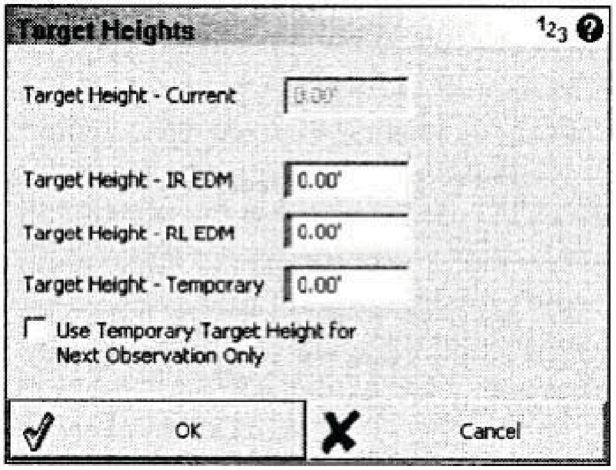
X,Y, Elevation: This information will be measured by the instrument.



Point ID 1

To Change Prism Height

Sometimes it will be necessary to raise or lower the height of the prism to get around objects that might obstruct line of sight between total station and prism. Have the prism operator choose an appropriate height and relay this to the total station operator:



Target Height - Current 0.00'

Target Height - IR EDM 0.00'

Target Height - RL EDM 0.00'

Target Height - Temporary 0.00'

☐ Use Temporary Target Height for Next Observation Only

On the right side of the screen, press the HT button. It will show the current height of the prism (**Target Height - Current**).

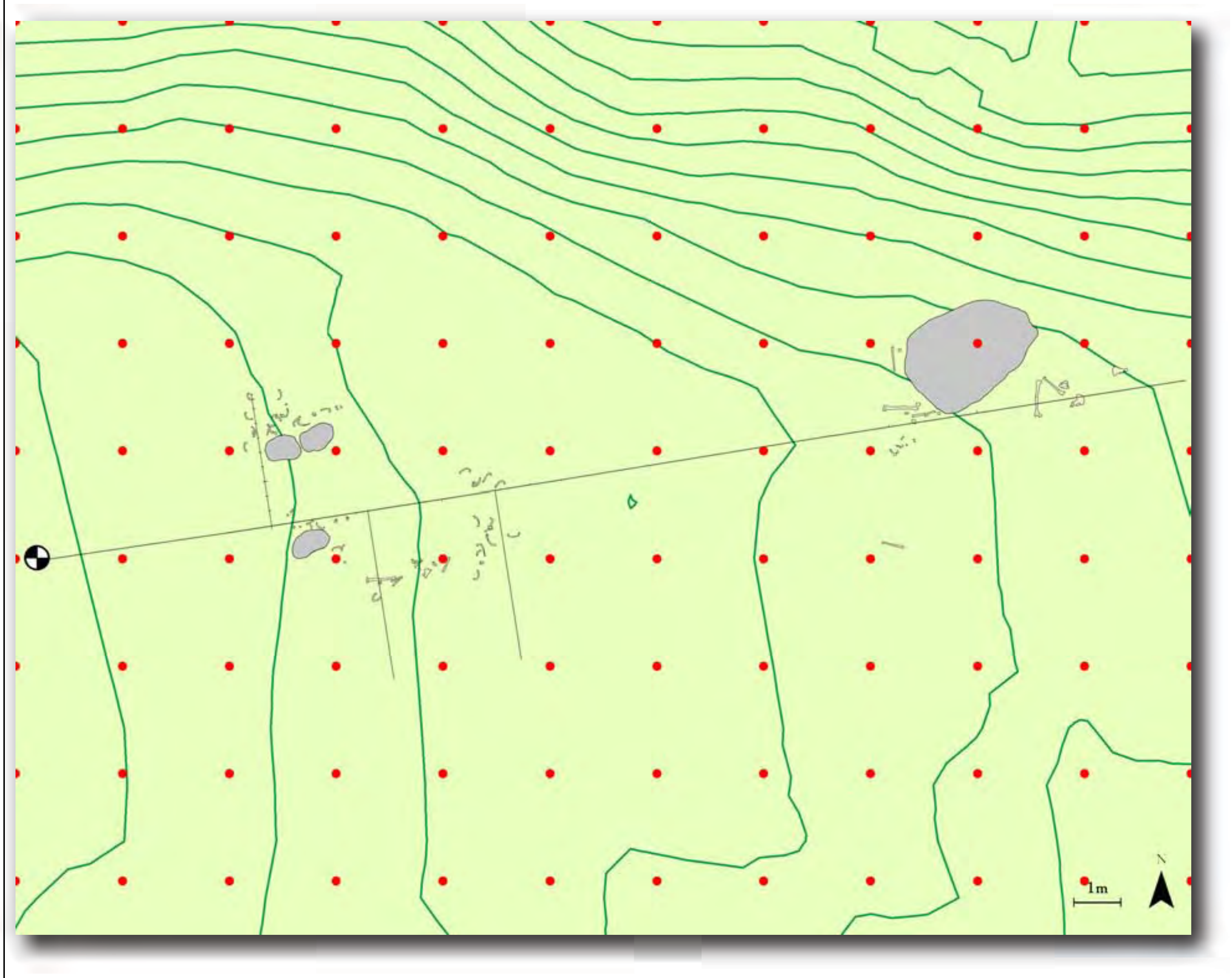
Enter the new height of the prism in the **IR EDM** field. Leave all other fields blank.

If you only need to alter the height for one shot, check the box marked **Use Temporary Target Height for Next Observation Only**. This will automatically revert to the previous height after the point is taken.

Appendix 6. Collection of Provenience Points to Document

Topography Via Contour Lines

The coordinate data collected by the total station or survey-grade GPS can be used to generate contour lines that show the topography of the crime scene and immediate vicinity. To generate accurate contour lines, it is necessary to collect many points. These must be collected in a 360 degree arc surrounding the crime scene in all directions. Take particular care to oversample (collect many points) in areas that show a deviation of contour such as hills. Golden Rule of surveying: you can never take too many points.



Red dots indicated places at which points were taken. Notice an even and consistent spacing of points taken.

Appendix 7. How to Geo-reference a site

Provenience data needs to be geo-referenced. Geo-referencing refers to the recordation of an item's precise location on the planet specific to a site in 3 dimensions. Geo-referencing a site allows for a means to return to a specific area of interest for further investigation. This is accomplished with the use of a Global Positioning System device (of GPS). If a survey-grade GPS is utilized, this will have been completed. If a total station is used, a traditional GPS will have to take at least four points in common with the total station points in order to create a link file.

It is important that the appropriate datum and coordinate system are used in conjunction with geo-referencing. All coordinate systems are based on a datum because they are based on approximations of the earth's shape. North America has two specific datums (North American Datum, or NAD), the NAD1927 and an updated NAD1983. Using the NAD1983, each state has a specific coordinate systems designed for accurate mapping, which are known as the State Plane systems. It is recommended that the appropriate 'State Plane' system is utilized using the NAD1983 datum. The appropriate State Plane system can achieve accuracy of 1:10,000 of an inch. There are many resources on the Internet illustrating the State Plane divisions, one in particular, "http://www.ems-i.com/smshelp/General_Tools/Coordinates/StatePlane_system.htm" is particularly useful in determining which State Plane system to use. Collecting data in one coordinate system, such as the NAD1927, and comparing it to data collected in NAD1983 can produce errors as great as 200 meters in the N-S direction, and 70 meters in the E-W direction. This is known as the NAD Shift and acts as a reminder to be cognizant of the coordinate systems being employed.

Once an appropriate coordinate system and datum have been selected, coordinate data can be imported in to any Geographic Information Systems (GIS) program. A GIS is any computer software designed for the collection, management, analysis, and display of spatial data. Using layers in a GIS can be thought of like laying transparencies on top of one another. Each layer will have a common feature. In the GIS model, this common feature is geographic location. ArcGIS (ESRI 2010) is recommended though free alternatives, such as GRASS, are available (http://grass.fbk.eu/).

Appendix 8. Survey-Grade Global Positioning System Basics

The Trimble R8 (left), used in this research, is a survey-grade GNSS (global navigation satellite system) that combines total station accuracy with high-resolution GPS accuracy. The R8 connects to an RTK (real time kinematics) network of established GPS points (base stations) to constantly update corrections for more accurate estimations of the R8's location (Figure 1). The system requires at least 4 satellites to be visible and a direct connection to the RTK network via cell-phone or wi-fi modem. With this connection, the R8 is capable of georeferencing, or assigning precise coordinate points on the earth's surface, at sub-centimeter accuracy. This effectively eliminates the need for a traditional GPS and total station.

The R8 has the ability to work in relatively thick forest canopies more accurately than traditional GPS units; however, it cannot work indoors, in extremely dense canopied areas, or near large standing objects such as large buildings. This is due to multi-path signal errors and interference from 'sight' of satellites. Multi-path errors occur when a GPS unit is near a large object. Correction signals sent from a satellite can bounce off of large objects to the receiver. This causes confusion within the receiver because it has two signals telling it that it is in two different places (one is the actual position, and the other is the position where it was reflected from).

RTK network coverage in Pennsylvania.

Number of Bases: 144

Cursor Lat/Long:
43.50075244, -81.14501953

Three Nearest Bases

NYFD	189.42 km
UPTC	241.17 km
NYSM	243.95 km

Appendix 9. Correct Archaeological Excavation Technique

Use the modified cake-cutting method of excavation of sediments at all archaeological sites. The trowel is held perpendicular to the debris pile and the excavation cutting motion is from the top of the debris pile straight down through all layers to base level, through a stratigraphic level starting from the outside of the debris pile working inwards. A straight line of excavation is maintained perpendicular to direction of excavation progress. Debris can be collected in a dustpan and transferred to a bucket to be collected for screening.

Appendix 10. Data collection during the mapping process

In the field, different classes of evidence must be considered because different agencies will require different types of information to be collected and depicted on the final map. To be sure to provide this information, it is best to separate items to be included on the map into different classes that, in turn, can be displayed on different layers. In the case of a suspected fatal fire scene, classes of items may include: human remains, physical evidence related to the death event (guns, shell cases, flares, gas starter trail, knives, etc.), electrical components (outlets, junction boxes, circuit breaker and associated electrical wire), house features (outline of house, structural demarcation of individual rooms, major appliances, gas lines, bed, bath tub, etc.), personal effects (see Appendix 2 for an example of differentiating evidence into different layers).

Using this categorized layer system, all of the data collected in the field can remain in a one location while individual components of the scene can be separated and analyzed (for instance, a map of the human remains distributed within the house structure or a map of only electrical components and house features). A map showing all of the features of the scene will be cluttered and difficult to interpret. The ability to utilize layers allows for clear and concise separate maps to be produced.

Appendix 11. Map Production

Inset, or base, maps can be anything conveying extra information about the scene. These can be topographic maps, satellite and aerial photography, or maps of a state. These maps will contribute additional information that may be pertinent to the scene. Topographic maps are widely available. In Pennsylvania, spatial information is free via http://www.pasda.psu.edu. Aerial photographs are often mathematically correct to account for the curvature of the earth. These orthophotographs are geo-referenced for ease of integration with spatial information collected at the site.

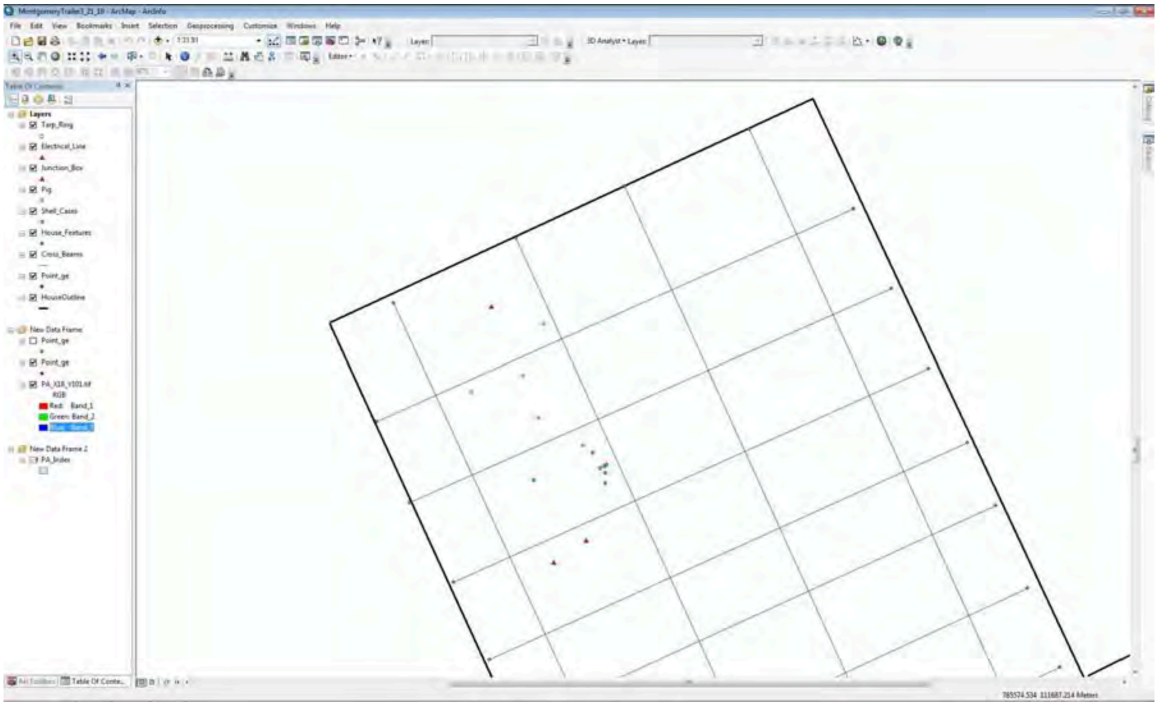
The points and lines for each layer should be a noticeably different color. This will help to easily differentiate between features. All maps should include a relevant scale, north arrow, legend or key, map preparer/agency, date, and citation for any inset maps not collected by the agency (aerial maps, topography maps, etc.).

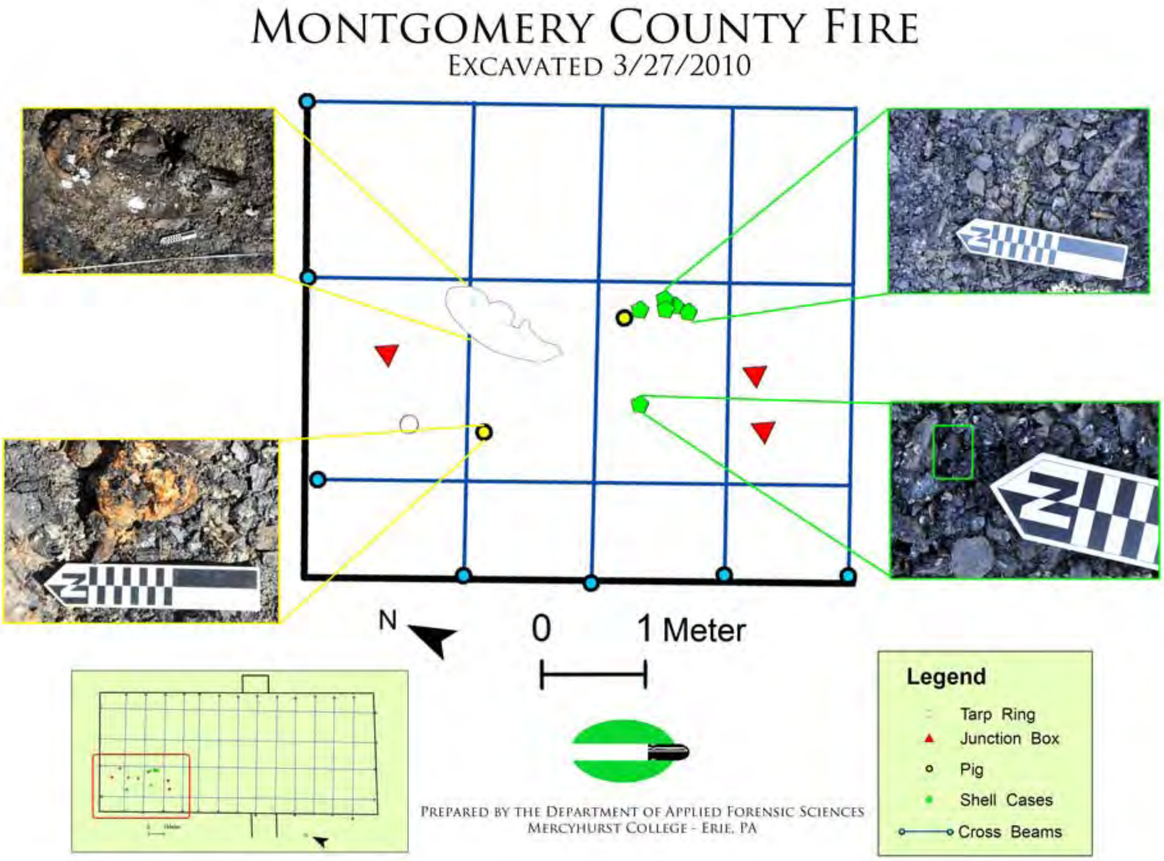
Maps, like standard forensic photography, should first show the big picture and then refine the focus to areas of interest. This will include inset maps showing location in the state, aerial photograph of the area of interest, outline of house, and specific areas of interest, such as rooms or concentrations of artifacts. Each of these can be referenced to the last to maintain the integrity of the relative positions on the planet (Appendix 3). This process of starting broad and then narrowing the focus will help orient the viewers of the map who are likely not familiar with the scene.

Produce *Photoshop* version of hand drawn map to be combined with TS map.

Due to the nature of a house fire, the likeness of objects will be masked by charring from the fire. Through this, photographs might not supply the best depiction of the artifacts. To resolve this issue, accurate hand drawn maps can be produced in the field systematically and quickly. These maps can be integrated with total station or R8 maps through taking a series of like points. Through these points, the hand drawn map can be scaled and referenced to the electronic map, thus geo-referencing the hand drawn map itself.

The hand drawn map must be scanned and then imported into a photo-processing program such as Photoshop. Here, the images can be separated from the grid paper to present a clear depiction of the scene and improve the overall aesthetics.


MontgomeryTrailer3_21_10 - ArcMap - ArcInfo
File Edit View Bookmarks Insert Selection Geoprocessing Customize Windows Help
Table Of Contents
Layers
Tarp_Ring
Electrical_Line
Junction_Box
Pig
Shell_Cases
House_Features
Cross_Beams
Point_ge
HouseOutline
New Data Frame
Point_ge
Point_ge
PA_X18_Y101.tif
RGB
Red: Band_1
Green: Band_2
Blue: Band_3
New Data Frame 2
PA_Index
3D Analyst
Editor


MONTGOMERY COUNTY FIRE
EXCAVATED 3/27/2010
N
0
1 Meter
Legend
Tarp Ring
Junction Box
Pig
Shell Cases
Cross Beams
PREPARED BY THE DEPARTMENT OF APPLIED FORENSIC SCIENCES
MERCYHURST COLLEGE - ERIE, PA

Processing Actual Fatal Fire Scenes

As previously stated, a primary consultant (GOO) was involved in the investigation and recovery of human remains from 16 fatal fires in Ontario, beginning in 2008 through the end of 2009. In five of these cases the destruction of the scene by fire had progressed to the point that archaeological methodologies were required and utilized. Below are two summaries of scenes excavated using the developed protocols. Two case studies are presented below which utilized the newly developed protocols. They were selected in order to serve as a comparison with previously defined protocols as well as to show the range in variation of fatal fire scenes in real life conditions.

Structure Fire

The fire scene was located in the outskirts of a large city in Ontario. The building consisted of a one-story home where the entire structure was lost with substantial debris located in the basement of the home (Figures II-14).

Figure II-14. Aerial view of the scene showing complete destruction of the home.

There was extensive debris created from a gaseous explosion. There were four deceased individuals found inside the structure. An additional individual (referred to as *Person 1* for the purpose of this description) was located on the front lawn. *Person 1* was removed prior to the processing of the scene. Preliminary information indicated that *Person 1* killed the four other individuals (referred to as *Persons 2 - 5* for the purposes of this description) and set fire to the home with a volatile, ignitable liquid (Figure II-15).

Figure II-15. Gas can found at scene.

Person 2 was located by the first recovery crew prior to the arrival of the fire investigator (GOO). *Person 2* was located in the basement area on top of the debris from the main floor, hidden within the ceiling and roof debris. Stratigraphic information lead to the conclusion that this individual was initially located on the main floor prior to the fire and consequently fell into the basement with the collapse of the main floor.

The second individual discovered in the debris was *Person 3* who was located in the northwest corner of the basement. *Person 3* was situated on the remains of a mattress with total flash over having taken place in the one area of origin. The fire debris situated on top of and underneath the deceased indicated that they had been located on the main floor bedroom prior to the fire. The deceased fell into the basement during the collapse of the main floor.

The third deceased individual found within the structure (*Person 4)* was located the following day approximately five to six feet from *Person 2* on top of the wooden basement sub-floor and under approximately 3.5 to 4.0 feet of debris.

Even with the use of a cadaver dog, the final deceased eluded the search team. Due to the large amount of fire debris and the urgency in locating and removing the final victim, a backhoe was brought in to assist.

Once the appropriate fire debris samples were collected, a grid system was placed over top of the fire debris in fluorescent paint (Figure II-16). A backhoe, beginning in the southeast corner of the basement, systematically removed fire debris from the first grid unit.

The debris in this initial square was removed in 6-inch increments. The systematic removal of debris was continued until reaching a few inches above the wooden basement sub-floor. The second grid unit excavated was located directly north of the first unit searched. The fifth and final victim, *Person 5* found in this unit, approximately 1.5 to 2.0 feet above the surface on the wooden sub-floor..

Figure II-16. Excavation units made with florescent spray paint.

Person 5 displayed signs of more severe fire trauma than the previous four victims located within the structure and was basically “melded” to the wooden sub-floor. The mid-thorax, pelvis and right femur exhibited significant fire trauma and fragmentation. The victim and the surrounding debris including flooring were removed together and transported to the morgue for further processing in a more controlled environment. An electric saw was used to cut through the wood beneath the victim and the remains placed into a body bag for removal (Figure II-17).

Figure II-17. *Person 5* in situ (left) and after removal from the house (right), prior to placement into a body bag.

The remaining grid units were excavated in a similar fashion with fire debris associated with the already recovered bodies removed and screened for additional evidence and human remains. The implementation of the grid-style search and the subsequent systematic excavation of this scene yielded the recovery of the all individuals involved along with the recovery of crucial evidence associated to the perpetration of the crime.

The excavators at this scene were aware that a firearm had been used in this suspected quadruple homicide. Even though the actual weapon had been discovered early in the investigation, the only link to the victim was a spent .22 caliber casing found in the clothing of the youngest deceased (*Person 5*) (Figure II-18).

Figure II-18. Spent .22 caliber casing found in the clothing of the youngest deceased.

All debris and materials were removed from the structure down to the basement sub-floor (Figure II-19). In summary, the systematic and methodological search employed at this scene assisted the investigators in finding a previously unlocated victim, and importantly, *in situ* (*Person 5*) which also assisting in documenting the context and association of a shell casing fround near the victim.

Figure II-19. Basement of structure after excavation was completed.

Vehicle Fire

The vehicle fire illustrated here involves the homicide of a four-year-old female, a 22-year-old female and a 44-year-old female. The deceased were placed inside a passenger van which was then set on fire (Figures II-20 and II-21). Following fire suppression, the investigator at the scene (GOO) excavated the vehicle using archaeological techniques by instituting an internal grid system within the vehicle. Debris was removed in a top-down manner according to the proposed protocols (Figure II-22).

Figure II-20. Overall view of the scene and the vehicle.

Figure II-21. Mid-range view of the vehicle from the left side.

Figure II-22. Interior view of the vehicle. Two individuals lying across each other in the mid section of the vehicle. The third individual is on the backseat of the vehicle.

The four-year-old victim was located in the rear portion of the vehicle interior on top of a bench seat. The careful excavation and screening of the fire debris surrounding this back seat yielded several tooth enamel crowns of deciduous teeth (milk teeth) of a young individual. The resulting analysis of the crowns by a forensic odontologist placed the deceased in an age range consistent with the missing four-year-old female.

Excavation continued until all debris and human tissue were removed from the vehicle (Figure II-23). The systematic and methodological search and excavation conducted within the van yielded a firearm (Figure II-24), shell casings, and a near complete assemblage of remains of three individuals. Figure II-25 represents the map that was produced for this scene using the proposed protocols.

Figure II-23. Interior view of vehicle following excavation in which all debris, evidence, and human remains were removed.

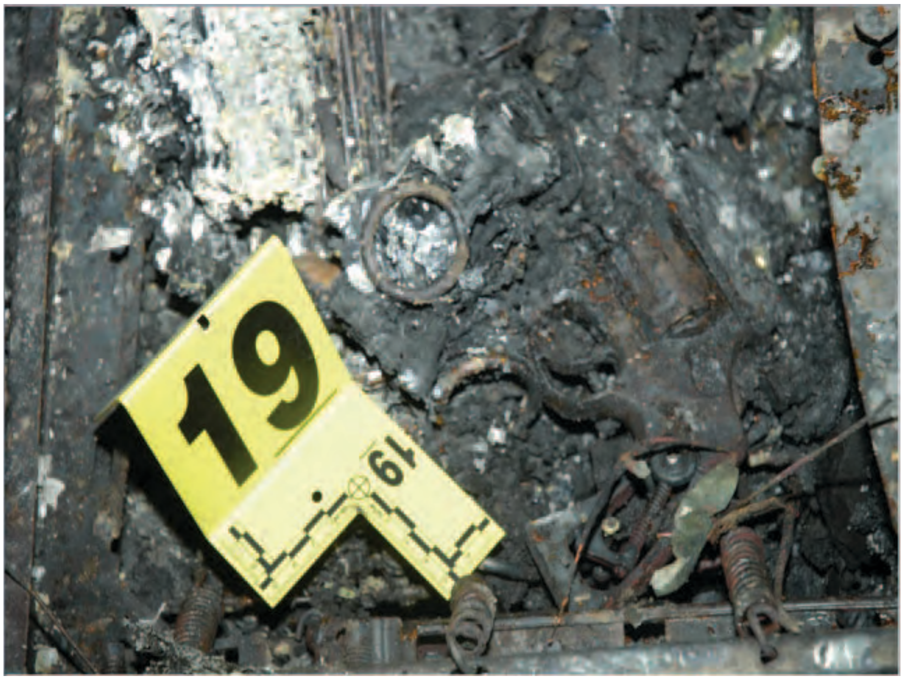


Figure II-24. Firearm located within the vehicle during excavation

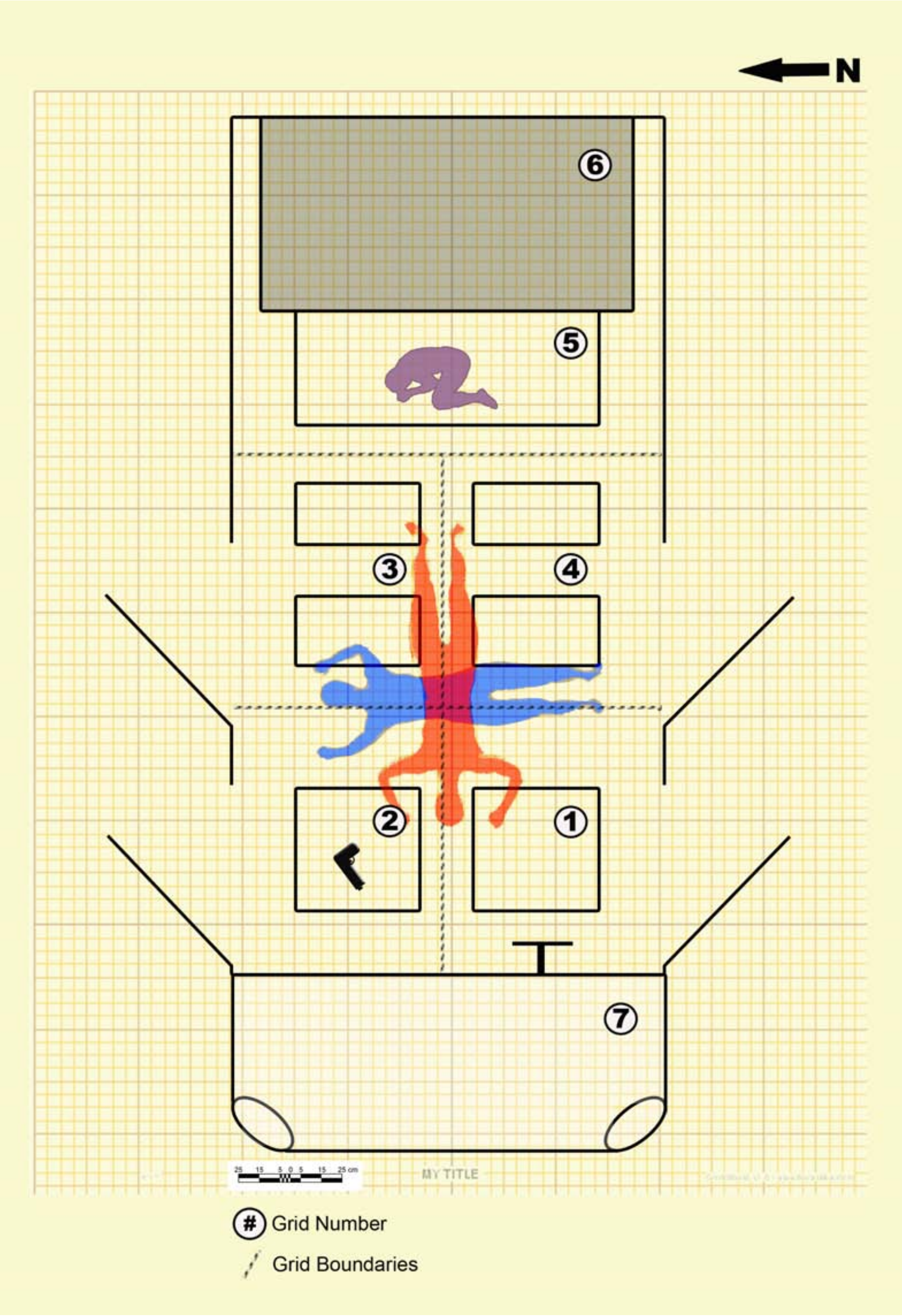


Figure II-25. Map produced from the vehicle fire. Note the location of the two adult individuals in the middle of the vehicle and the child located on the backseat. Also note the location of the recovered firearm.

Discussion

The two cases presented above provide compelling evidence for justifying the utility of employing archaeological methodologies at fatal fire scenes. Without the use of an effective and efficient systematic approach to processing the fatal fire scene a tremendous amount of physical and contextual evidence would be lost. In both cases presented, crucial physical evidence was located within the structures in situ (thus establishing context and association), as well as, a nearly complete inventory of all human remains.

CHAPTER III

Research Component 2: Analysis and Interpretation of Heat Altered Bone

Materials and Methods

There is a lack of understanding of how bodies burn naturally. Interpretations of heat-induced bone trauma are often based on misconceptions such as that the limbs can be completely consumed by the fire or skulls explode as a result of the high temperatures. But the reality is that little was previously known regarding the normal patterns of heat alteration that could be expected in a human body subject to the temperature conditions of a fatal fire, other than generic references to the pugilistic posture. Identification of these patterns would be key in detecting and identifying suspicious body alterations potentially related to perimortem trauma or body manipulation, which would appear as outliers or departures from these normal patterns.

Thus, one of the key objectives of the project was identifying and describing normal burn patterns to be expected in burned bodies when the fire is the only source of alteration. This is to say, when bone trauma or body manipulation, including treatment of the body with accelerants, are not present. This component of the research was aimed at these objectives, and intended to: 1) study and document normal burn patterns in fully fleshed human remains cremated under controlled conditions (in a crematorium), 2) assess the validity of these burn patterns when applied to real situations, by comparison with real forensic cases and 3) examining the typical temperature ranges and regimes that can be expected in common fire scenes. These goals were accomplished through comparison of normal burn patterns documented in a crematory setting with those observed in forensic cases, incorporating scene information and documentation. Archival fire documentation and temperature readings at different locations and body areas obtained from fire exercises, served to further assess the correctness of the extrapolation of crematory conditions to those found in real case scenes, as well as the potential effects on the burn patterns of typical area exposures, tissue protection and anisotropic conditions of the heat distribution.

Data for this component were gathered from three main sources: 1) existing documentation, including the extensive written documentation of dozens of cases charted for burn patterns over the past 23 years by SAS, and archival information collected from Ontario, Canada fatal fire scenes, 2) graphic documentation and analysis of the burn process exhibited by fully fleshed human bodies, incinerated under controlled temperature conditions in modern crematoria, and 3) the analysis of current forensic cases processed at the New York Office of the Chief Medical Examiner (OCME).

Burn Pattern Charting of Forensic Cases

The main goal of this study was charting and analyzing the burn patterns in a sample of human remains recovered at real fatal fire scenes, in order to assess the validity of the ideal patterns observed in the crematory exercises and past forensic cases, as well as the ability to identify abnormal fire or death conditions in real situations, as departures from these inferred general patterns.

The sample data for this study were collected and processed during the Summers of 2009 and 2010 at OCME, by one of the key project consultants (Christopher W. Rainwater MS, Forensic Anthropologist and Director of Photography at OCME), assisted by a Mercyhurst research assistant (Christina Fojas MS), who interned at OCME for this purpose. Appropriate OCME fatal fire cases numbers were first identified based on cause and manner of death, as well as case report keywords ("burn victim," "fatal fire," burning," etc.), at OCME's casework database for the period from 2005 through July 2009. The resulting list was then narrowed down to 74 forensic cases, for which all the appropriate written and photographic documentation had been recorded.

Research Design

A subsample of 25 of these cases was initially analyzed and employed to fine tune and validate the digitization and analysis protocols. The burn patterns documented in the photographic evidence were charted and digitized to produce standard homunculi/diagram sheets akin to those employed by forensic pathologists to illustrate autopsy findings. Two of these diagrams were produced for each body, in anterior and posterior orientations. The different body areas (i.e. burn patterns) were color and numerically coded according to the categories described in Figure III-1 (grey square).

Once that each homunculus was charted on paper, it was scanned and stored as an individual *jpeg* graphic file. Figure III-1 depicts an example of the resulting homunculi.

In order to allow their quantitative analysis, the *jpeg* images were then used to create and store shapefiles of the body outline and burn patterns in a GIS database (ArcGIS), containing also all relevant contextual information, including circumstances and manner of death (personal information was coded to avoid posterior identification of the victim). This was attained by first creating two polygons (anterior and posterior body outline views) in ArcCatalog, to serve as a master body outline shapefile (template). The master outline could then be used for all cases, since the outlines of the polygons were identical, only requiring renaming them according to the coded case number (i.e., B060502BodyOutline or B060502Body), and exporting each case individually as its own shapefile. One new shapefile was created in each case, corresponding to the burn pattern information, and also named accordingly (for example, B060502Burns). In this way, the burn shapefiles could be accurately traced for each individual, and later combined in a single master homunculus to precisely map burn intensity and surface areas by body region.

Both shapefiles were then dragged into the ArcMap workspace. For each case, the body outline and burn pattern shapefiles were kept in the ArcMap table of contents, along with the jpeg of the charted body.

The polygons of the burn patterns were then traced on the workspace *jpeg* of each charted body. The burn patterns were numerically coded into five levels of heat alteration (1 = no burning/minimal burning, 2 = charred tissue, 3 = charred tissue with burned bone visible, 4 = charred tissue with calcined bone visible, 5 = bone fragmentary or missing). The vector data were converted to raster data and added together using an *ArcGIS* Desktop Extension, from which surface areas for each heat alteration level were calculated for each individual case. The value of the polygon in the attribute table was set to correspond to the appropriate of the four burning degrees. Similarly, the attribute values of the body outline polygons were edited to express the overall extent of the burning area.

Finally, a new polygon/feature was created for each case by merging its two shapefiles (body outline and burn pattern) with ArcToolbox. The order in which the shapefiles are merged is important, as the burn pattern polygons must be visible over the body outline (i.e., the burn shapefile must be placed on top of the body shapefile, and not the opposite). The final merged polygon was then converted into a raster, changing the field to case ID. These rasters were imported as IMG files into the Raster Math Plus analytical module of the ArcMap 3D Analyst extension, and merged together to obtain a composite figure.

The figure obtained in this way illustrates those areas of the body that are more severely altered by heat (Figure III-2), as well as the extent of this modification (more frequent charred tissue, burned bone exposure, etc). As the image (and its attached numerical area and burn intensity estimates) was obtained from a series of individuals showing different degrees and orientations of exposure to heat, the burn patterns estimated in this way are actually independent of the specific area of fire exposure. For example, although individuals in whom only the upper body had been exposed to fire are common in the sample, the knee area still appears as a "hot spot" (almost white in the diagram) of high heat alteration, displaying a clear pattern even with the limited size of the initial pilot sample (Figure III-2).

Once that the digitization and coding protocols had been tested and refined with the pilot sample, the remaining individuals were treated in the same way. At this step, the initial sample of 80 individuals was reduced to 74 upon discovering that 6 of the cases lacked satisfactory photographic evidence or were missing elements in a manner preventing appropriate charting of the body according to the protocol. These 74 cases comprised accidents (including vehicular accidents, n = 45), homicides (n = 18), suicides (n = 6), and undetermined (n = 5) manners of death, and both indoor and outdoor crime scenes.

The final product illustrates those areas of the body that are more significantly altered by heat (Figure III-3), as well as the extent of this modification (more frequent charred tissue, burned bone exposure, etc).

It was initially hypothesized that the extent of the relative area (percent of total area) presenting any sign of heat alteration would be indicative of exposure times and temperatures reached, and thus should also be correlated with the overall degree of tissue alteration. In other words, as the fire progresses both the body area affected and the degree of alteration of the more exposed areas will gradually increase. Of course, once the whole surface of the body is affected, only the degree of alteration can increase.

In this way, if the proposed model is correct, a pattern would be expected in which: 1) the subsample comprising those individuals in which the whole body surface is affected would display both higher degrees of alteration (i.e. individuals with more severe overall burning), and a wider range of alteration levels (depending on the time and intensity of exposure in each particular case after the whole body surface was already affected), and 2) the remaining individuals, with less than 100% of body surface area presenting signs of heat alteration, should display a clear pattern indicating the early progression of heat alteration, characterized by a coupled increase of the area affected and the degree of alteration reached.

Confirming the validity of this simple model was key for the present study for different reasons. First, the existence of a clear relationship between the extension and the degree of heat alteration would provide a solid objective baseline to rank the data points according to their heat exposure times and intensity, even when the sample is comprised of victims from real forensic cases in which these factors were unknown. In this way, the extent of body surface area would allow to order the victims by increased degree of exposure, and thus to document and illustrate the sequence of appearance of new affected areas as exposure increases. The degree of alteration would serve the same purpose in those individuals with 100% of their body surface area showing heat alteration.

Secondly, the identification of these patterns would allow identifying unusual cases not representing the normal burning sequence (see below).

Last, but not least, the ability to detect the expected patterns would be indicative of the appropriateness of the variables employed to describe heat alteration patterns, and therefore of the validity of the method.

In order to test these hypotheses, individuals were first ranked based on degree of burning. In the ranking system employed, individuals displaying level 5 alterations (bone fragmented or missing) would always rank higher than individuals showing only level 4 or lower alterations. Individuals with level 4 alterations would rank above individuals lacking this level, and so forth. The relative area of heat alteration was used to rank individuals within levels (i.e. within level 5, individuals would rank higher the larger the area showing alterations at this level). Figure III-3 (left) displays the result of plotting these ranks against the total surface area showing heat alteration.

Next, parametric linear methods were employed to test the correlation between the extension and severity of the burn patterns in those individuals displaying heat alteration in less than 100% of the body. As explained above, both factors are expected to be independent in individuals whose whole surface has already been altered, as in that case the severity of the burns will depend mostly on exposition times. Outliers in burn severity (i.e. the dependent variable) from this baseline were expected to represent abnormal patterns in which the severity of the burns does not seem to correspond with the exposure times expressed by the extension of the altered area. The circumstances and manner of death of these outliers was then compared to those of the individuals in the baseline, in order to assess whether they actually represented a subsample of individuals deceased in atypical circumstances.

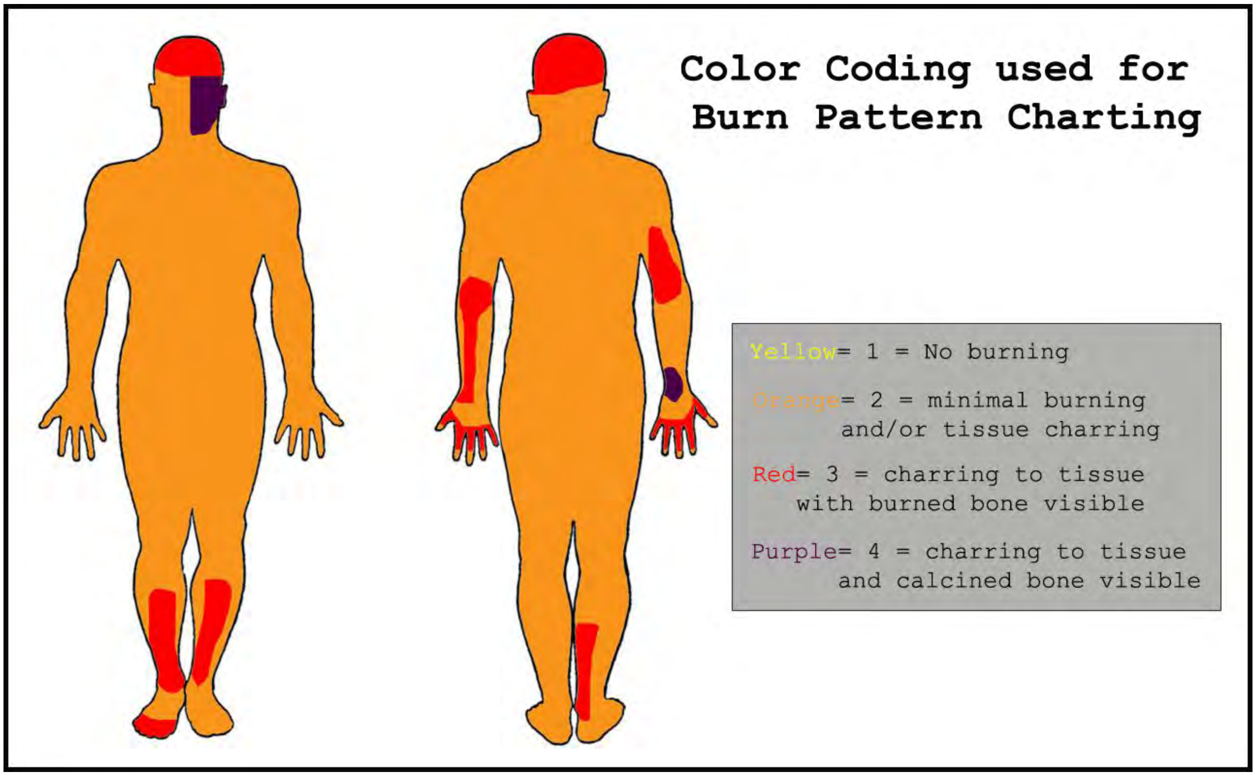


Figure III-1. Example of finalized homunculus for a single individual, describing the color system utilized to code the severity of the heat alteration.

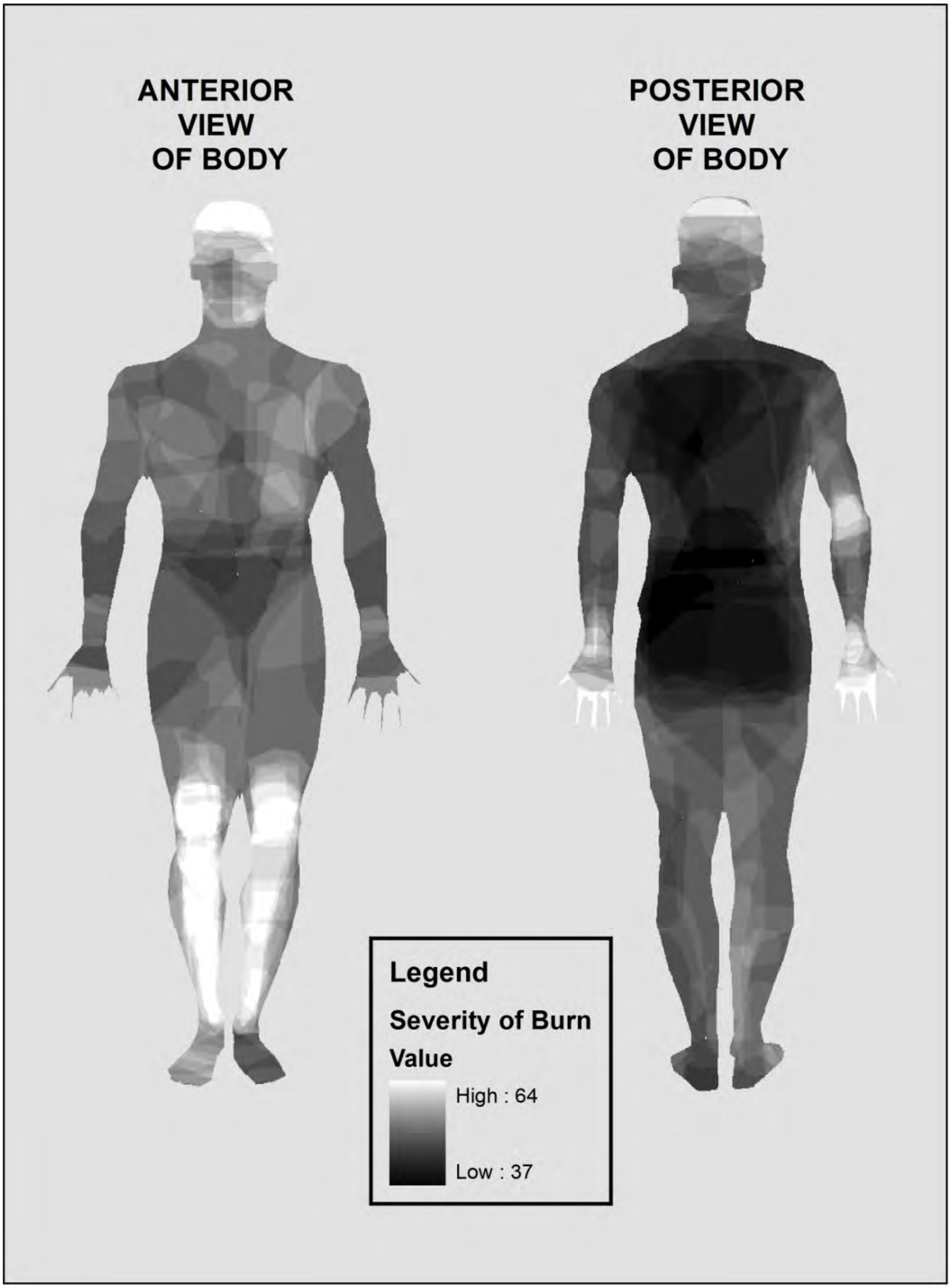


Figure III-2. Composite image from the raster images of the 25 individuals in the pilot sample. Lighter areas indicate higher thermal damage frequencies and degree.

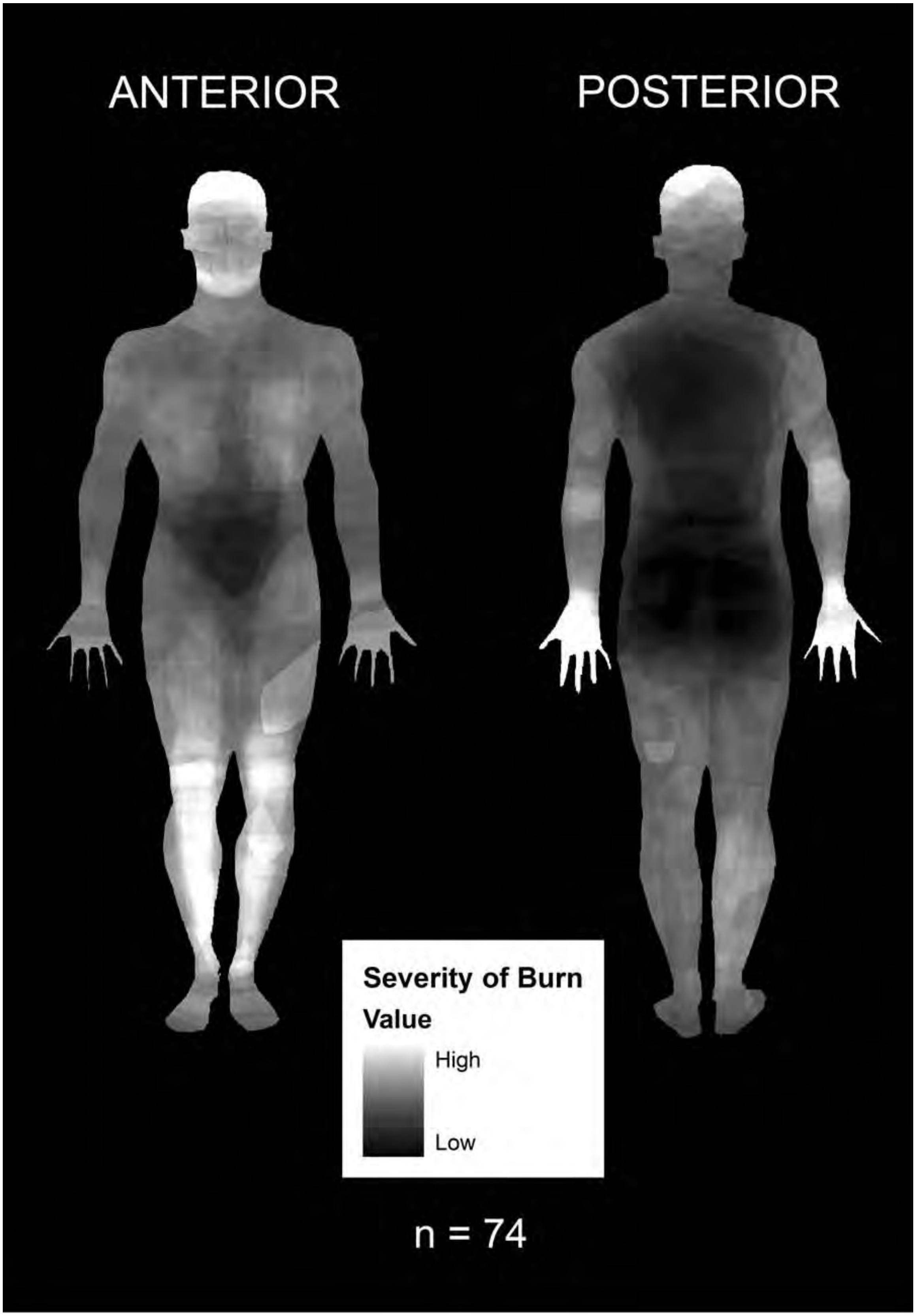


Figure III-3. Final composite image of the overall burning pattern for all individuals in the OCME sample. Note the higher consistency and clarity of the overall pattern, although still consistent with the patterns displayed in the initial pilot sample.

Documentation of Cremations

Criminals often use fire in an attempt to conceal their crime and hinder the analysis of both the scene and the victims' remains. In order to identify and effectively investigate fatal fire scenes, it is essential to be able to detect and demonstrate that a particular injury to the body cannot be attributed to normal heat alteration derived from exposure to fire but to inflicted perimortem (related to death) trauma. Unfortunately, there is currently a glaring lack of data and understanding of the burn patterns expected from a normal cremation of the human body. In addition, contradictory information has been presented in regard to what is considered "normal" fire alteration of the human body. The information gap includes specific burn sequences of soft tissue and patterns of hard tissue modification (e.g., fracturing, calcination, and disarticulation), and derives from the ethical and technical difficulties of designing and developing specific laboratory studies on this subject. This deficiency severely hinders the investigative and prosecutorial efforts to detect and solve the number of cases involving deliberate burning of victims to hide evidence. Therefore, advancement in this subject must rely on the research that focuses on the documentation of regular funerary (human) cremations that comply with typical professional funerary standards.

One of the three main research components (*Research Component 3*) of this project was to conduct a series of observational studies of patterns and sequences of burning human remains during a typical cremation in a state-approved commercial crematory retort. A number of variables can be controlled in these laboratory settings including temperature and duration of the fire within the retort, and original body position. Non-invasive procedures were to be used to document and interpret the common (typical) patterns of alteration to all portions of the human body as they relate to position and orientation of the body and duration of exposure to heat and fire. These typical modification patterns are then compared to atypical patterns observed on victims of fatal fires in forensic cases. The differences in patterns can be used in the recognition and interpretation of perimortem trauma such as blunt force trauma, ballistic trauma, and other forms of intentional body manipulation or modification inflicted on the individual prior to the postmortem fire episode.

Research Design

This component of the research project is based on previous research conducted by one of the principal investigators (SAS), who documented all fatal fire victims (and individual bones) brought to the Regional Forensic Center, Memphis, Tennessee, from 1992 to 2004 (Symes et al. 1996, 1999a-b). Symes's preliminary findings during that period of time have been presented in the form of a skeletal homunculus (Figure III-4) in which color-coded burn patterns were noted for each skeletal element (Symes et al. 2008).

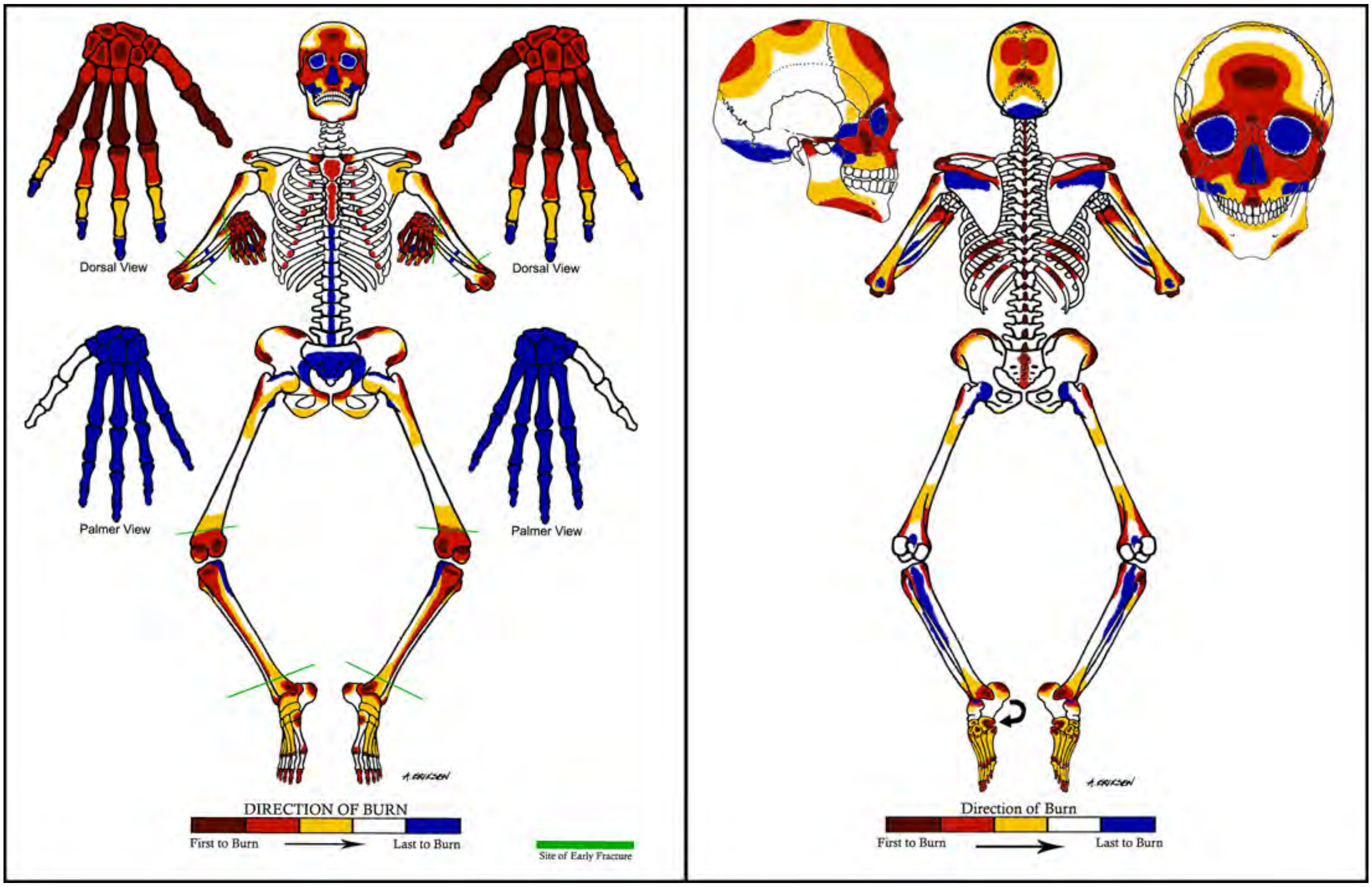


Figure III-4. Taken from Sumes et al (2008). (Left) Anterior view of a homunculus depicting a general sequence of burn pattern from each skeletal element from the first element to burn to last element to burn. (Right) Posterior view of a homunculus depicting the same general burn pattern observed in actual cases observed by Symes.

For the completion of this portion of the project, an attempt was made to simulate flashover temperatures and atmospheres reached in a burning house or car by incinerating fully fleshed complete bodies in a crematory retort of a modern crematorium under controlled temperatures. A variety of different research designs were initially explored for this purpose, including turning off the gas and fire at different intervals during the burn, removing the remains from the retort on a large tray at various times during the cremation process, and videotaping with an ultra-high speed video camera above the remains or through a side window of a retort. However, due to a number of technical considerations related to retort construction and design (e.g., exposure of equipment to high temperatures, visibility issues, etc.) and the reluctance of funeral home personnel to alter burn methodology, it was determined that the most efficient, realistic, and economic research design consisted of video recording and photographing the cremation process at randomly chosen intervals from the exterior of the retort without changing the temperature or removing the remains from the oven. Given these considerations, as well as the time required to acquire family permissions for research and project time constraints, the analysis of a total of eight cremations are included in this report. Results of the analysis of these cremations, however, have significantly enhanced our understanding of typical burn patterns of humans.

The deceased individuals, from which data was collected in the study, were handled in accordance with all of the corresponding state cremation laws and remained anonymous during all stages of cremation investigation, analysis, and professional scientific presentation of results. Additionally, the remains were handled with the utmost respect and were not modified or disfigured in any way. Permission of the individuals' families was obtained prior to observance of the cremations.

Research Methodology

A total of eight cremations were studied over the course of this research project. The first two cremations were observed from start to finish and served to refine the final research design. Comprehensive documentation was completed for six subsequent cremations and provides the basis for the analysis and results described here. Each cremation was documented by photography, videography, and detailed written notes. Prior to the start of each cremation, the body was photographed and video-recorded to document the precise position and condition of the individual in the retort. Each individual was given a unique cremation number. In addition, information was collected on the chronological age and approximate weight of the individual, existing pathological conditions and individualizing characteristics. Visible pathological conditions and individualizing characteristics were noted so that burn patterns in areas of anomalies would not be confused with an "atypical" burn pattern. No perimortem trauma was present on any individual included in this study.

Following collection of data prior to the cremation, the crematoria personnel placed the individual in the retort. The individuals were either placed on their backs in the prone position in the middle of the retort (7 cases), or were placed face down in the middle of the retort (1 case). They were either placed head first (4 cases) or feet first (2 case). Gas jets were turned on and the fire started. The gas fueled the cremation process for a certain amount of time (determined by the until the body tissues caught on fire. The cremation process continued until all soft tissue was removed and the osteological remains exhibited characteristics of fully calcined remains (no longer containing organic components) as determined by crematoria personnel.

During this process, a Sony HDD digital video camera was mounted on a tripod and filmed portions of the cremation process through the open door of one end of the retort. The filming was not continuous because the door to the retort needed to be closed at times in order for the burn sequence to commence naturally. In addition to the videocamera, a Nikon D700 digital camera was used to take individual still images of the cremation process.

Detailed notes were taken during the cremation process and again while viewing the video of the cremation. Standardized data collection forms related to the burn patterns were created after initial data collection efforts (see Appendix III-1). The documentation forms include the time and temperature of the retort at the start of the burn, the duration of the cremation, and the gross burn patterns observed throughout the body, including the specific timing and sequence of changes observed for each area of the body. Patterns on the skin, the first bone to become exposed, the first bone to become calcined, and the first bone to detach from the body were noted individually on the forms.

Results

Burn Pattern Charting of Forensic Cases

The clarity of the results obtained in the preliminary analyses of the pilot sample were already surprisingly good, and unexpected given the small sample size (n=25). As predicted in the research model, the pilot sample already demonstrated that the overall degree and patterning of heat alteration, as expressed in different body areas, can be more accurately predicted from tissue thickness than from the extent of fire exposure, especially in relation to the sequence in which the different body areas exposed to heat will attain a certain degree of alteration. In this way, alterations in this sequence can be seen as suspicious, regardless of the overall degree of heat exposure. The alteration patterns obtained in this preliminary analysis from fleshed bodies were also already strikingly similar (actually, virtually identical) to those previously reported by one of the principal investigators (Symes et al., 2009) for burned bone (Figure III-4 above).

This result was important in order to validate the analytical method, but also served to validate some of the implicit assumptions of the analytical model through their comparison with the results for the total sample. As explained above, one of the assumptions of the model was that, as the composite image and related estimates are obtained from a series of individuals showing random types of exposure to heat, the burn patterns estimated in this way should actually not be affected by the presence of some atypical individuals in the sample. In other words, the heat alteration patterns would add to each other, while atypical patterns, due to their heterogeneity and dependence of very specific circumstances, would have a weak effect on the final composite pattern, which would therefore be a general one, applicable to normal situations and largely independent of the specific composition of the sample. For this to be true, the clarity and definition of the obtained pattern should increase with sample size, as the larger the sample becomes, the smaller the distortion of the final image by the addition of an individual atypical case (i.e., cases in which thermal damage is not the only alteration to the body, thus presenting an atypical burn pattern). We can draw a parallel with the effect of outliers on the estimate of the arithmetic mean: the larger the sample, the smaller the effect of an outlier on the final mean estimate. In this way, increased sample sizes should result in an increase in pattern definition, rather than in blurrier patterns, obscured by the presence of more atypical cases.

This hypothesis was confirmed with the addition of the remaining individuals (n=74). As anticipated, while the results of the pilot study of 25 individuals began to show distinctive "hot spot" areas of high heat alteration, tripling the sample size rendered consistent but significantly clearer and more refined results, further confirming the validity of the model (see Figures III-2 an III-3 above).

As predicted by Symes and colleagues (2008), the obtained overall degree and pattern of heat alteration, as expressed in different body regions, can be most accurately predicted from tissue thickness, particularly in relation to the sequence in which the areas exposed to heat will attain a certain degree of alteration. Areas covered by thin layers of soft tissue, and those exposed in pugilistic posture, matching the observations in the crematory exercises of this project (see above) display higher degrees of alteration earlier than more protected areas.

In this sense, it is interesting to note how some areas like the dorsal surface of the elbows, while showing high degrees (frequency and early timing) of alteration, as would be expected from their exposure in the pugilistic posture, this degree appears to be slightly lower than in areas like the knees and lower leg. This may be related to the crematory observation of the pugilistic posture being impeded when the victim is facing down, which can impede arm flexion. The obtained patterns are also consistent with observations like the distal hand phalanges burning before the hand attains the pugilistic posture, so that they would not be protected by the closed fist, as had been previously hypothesized.

Regarding the quantitative analysis, as predicted by the model, the individuals with lower degrees of alteration showed a very clear pattern of increased alteration with area affected. When approximately the lower third of the distribution of the degree of alteration is considered (26 out of 74 individuals) the extent of the area affected explains approximately 98% of the variance of the severity of heat alteration ($p<0.01$, Figure III-5, right). This extremely strong correlation indicates that these individuals provide a very accurate representation of the progression of the normal burn pattern as exposure increases. Although the sample sizes or males and females are too unbalanced (with only eight females available) to allow for reliable testing of this hypothesis at this moment, both males and females appear to fall very closely within the same line, without strong differences due to the different body compositions of both sexes. No sexual differences were found either in the area or degree of alteration in the pooled sample. Also as predicted by the model, after approximately 80% of the body shows heat alteration, the degrees of alteration are higher and very variable (upper right quadrant of Figure III-5, left).

The shadowed area in Figure III-5 (left) would represent degrees of alteration not explained by the extent of body area altered (i.e. by time and intensity of exposure). At wit, individuals falling in this area are expected to represent unusual cases in which part of the body was shielded from the heat source, the later was very localized, accelerants were present on some body areas, perimortem trauma prevented the adoption of the normal pugilistic posture, resulting in the atypical exposure of areas more sensitive to heat alteration, etc. In the present sample, the individuals falling in this area are in all cases characterized by the presence of level 3 lesions (charred tissue with burned bone visible) or above, while less than 80% of the body area is affected by any visible degree of heat alteration. This strongly suggest that, as a rule of thumb, the concurrence of these two characteristics would be indicative of some of the unusual circumstances described above, and therefore would recommend a closer examination of scene and body. In this study, a closer examination of the cases meeting these proposed criteria for the detection of unusual burning patterns revealed that they include cases such as a homicide in which the victim's legs were bound by a ligature, a vehicular accident in which the victim sustained extensive blunt force injuries, and different accidents with evidence of substantial clothing on the body.

Figure III-6 displays the differences between the total composite pattern and those of accidents, suicide and homicide cases. The accident profile is virtually identical to the total one (normal pattern), while those for homicides and suicides clearly depart from the former ones. In this way, deviations from this sequence can be marked as suspicious, regardless of the overall degree of heat exposure.

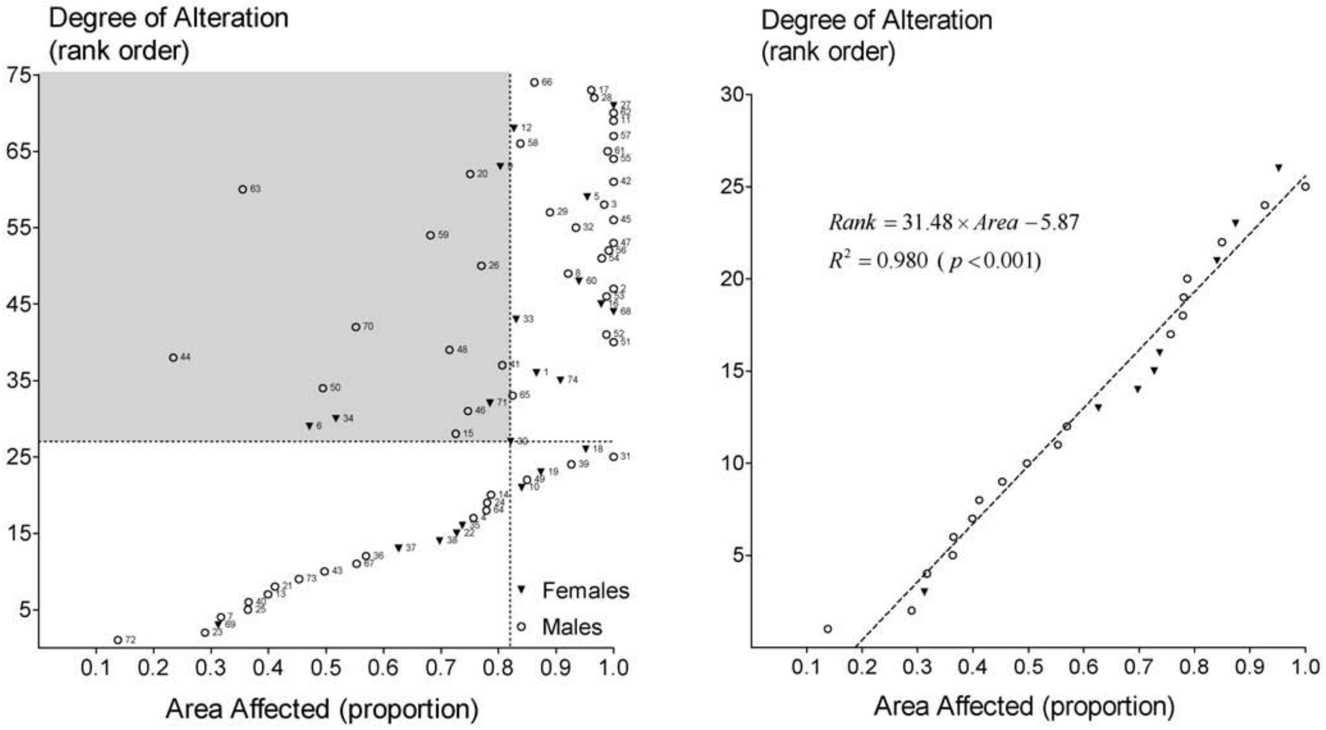


Figure III-5. Left: Comparison of the degree and extent of heat alteration. Note the individuals grouped on a tight line in the inferior third of the graph, under the horizontal dotted line. In these cases the extent of the area showing any signs of heat alteration would be reflecting heat exposure: The longer and more intensely the body is exposed to the heat source, the higher the area affected and the larger the degree of alteration. They therefore represent the normal progression of heat alteration as exposure increases. In the individuals on the upper right quadrant, forming a vertical line, exposure has progressed to a point where close to the whole body surface has been affected, and therefore only the degree of alteration can increase. The shadowed area represents the parameters within which a body can be considered to present an abnormal burn pattern based on these variables. Individuals in this area show a much higher alteration than expected from the extent of the altered area. All these individuals show a level 3 (charred tissue with burned bone visible) or above, while less of 80% of their body surface presents signs of heat alteration (see the text for further discussion.) Right: A more detailed look at the series of individuals displaying lower degrees of alteration (under the horizontal dotted line in the left diagram.) Note the extremely high correlation between the degree and extent of heat alteration, explaining 98% of the variance.

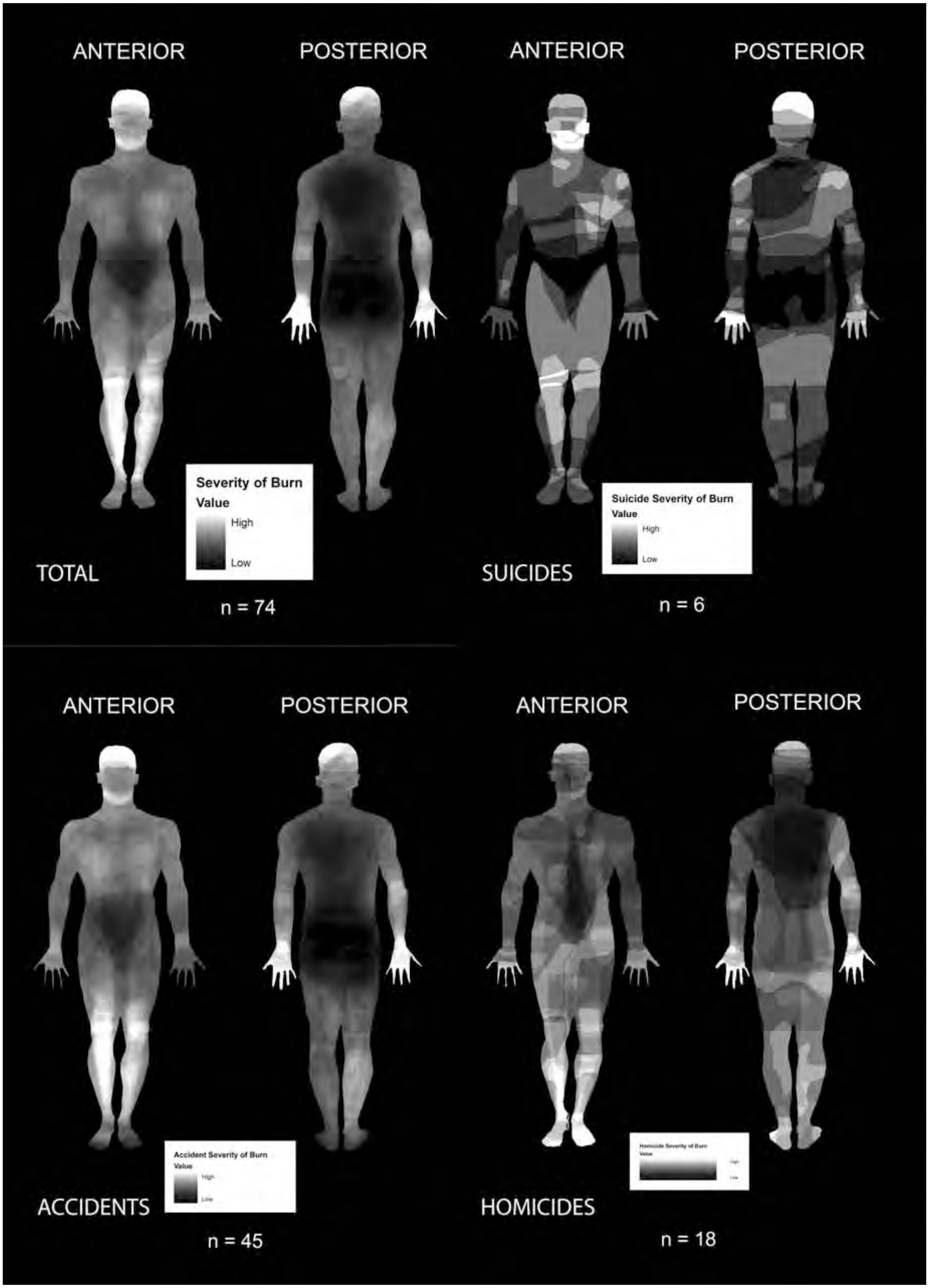


Figure III-6. Composite pattern images for different manners of death. Note how the suicide and homicide patterns depart from the total (normal) and accident ones.

Documentation of Cremations

Modification Patterns in Individuals Lying Face-Up

The following descriptions of the burn sequences are based only on those individuals who were cremated in the face-up or prone position. The phases described below provide a relative sequence of modifications to the human body; variations in body form, mass, state of health, and other factors of the individuals resulted in quite variable specific timing of the events in the sequence. The alterations are discussed in terms of sequence of changes in the appendicular skeleton and to some degree, the axial skeleton. The changes observed in the cranium are discussed separately as they often were occurring concurrently with those occurring in the appendicular skeleton.

Phase 1. Modification of External Skin.

In the majority of cases, blistering and splitting of the skin was noted before any other changes to the body occurred (Figure III-7). Splitting occurred due to the shrinking of the skin from the heat and is not indicative of trauma or any other abnormality. Blistering was expressed as circular or ovoid patterns with charred edges.

Figure III-7. General view of lower portions of body during cremation process. Note blistering (white circle) and splitting (white rectangle) of the skin of the legs and thighs seen early in the body modification process.

Phase 2. Flexure of limb units into the Pugilistic Posture.

The typical description of a fatal fire victim is that the individual has assumed the 'pugilistic posture,' meaning that the major muscle masses in the limbs have lost moisture and begun the process of shrinkage. The denser muscle masses, typically those that flex the limb joints, will exert more pull than other muscle masses. This flexure has been described in the fingers, wrist, elbow and shoulder joint in the upper limb. In the lower limb, this is described in the knee and hip joints and the plantar muscles of the foot. It is also common in the neck region. All of these patterns except neck flexure were noted in the individuals in this study who were placed on their backs and their limbs unimpeded from contact with the sides of the retort.

Phase 2a. Flexure of hands and fingers.

In this study, the hands and fingers flexed before any other limb joint of the body. This was generally associated with significant fire alteration of first digit (thumb), which, in turn, often was followed by disassociation of the digit from the hand. This disassociation occurred regardless of body position in terms of face up or face down (Figure III-8).

Figure III-8. Superior view of upper distal limbs showing flexion of wrist and fingers of both hands during cremation process.

Phase 2b. Flexure of the elbow in the upper limb

Pugilistic posture of the upper limb, in form of bending at the elbow, occurred at the same time or slightly after the hands and fingers flexed, and began approximately one minute after the start of the cremation for individuals lying in the prone position. In the individuals who were placed on their stomachs, with arms to the sides of their body, flexure at the elbow was not observed.

Phase 2c. Flexure of the knees and feet

The lower limb exhibited flexure into the classic pugilistic posture (knees bent) later than the upper limb did. This is likely due to the greater amount of muscle associated with the lower limb. However, as with the upper limb, the individuals who were placed face down in the retort, did not exhibit flexure at the hip joint.

Burn Sequences and Patterns in the Appendicular Skeleton

See Table III-1 below for an approximate sequence of alteration to human remains during cremation for the appendicular and thorax.

Phase 3. Retraction of the Muscles from the Bones.

As the muscles of the thigh and upper arm were exposed to heat, moisture was lost and the muscles shrank and eventually pulled off and away from the underlying bones (Figure III-9). This was especially pronounced at the distal ends of the bones at the elbow, wrist, knee, and ankle. Therefore, the distal femora and humeri became charred and calcined much earlier than the proximal ends of these bones.

Figure III-9. General view of human forelimb showing retracted muscle exposing forelimb elements. Also note warping and longitudinal and transverse fractures exhibited by the bones (ulna) and disarticulation of the distal radius.

Phase 4. Disassociation of the hands

The hands, excluding the thumbs, were the next area of the body to disassociate (Figure III-10). This happened after the distal radius and ulna were exposed, and always before the feet detached. Of the hand bones, the metacarpals and phalanges were the first to bones to be exposed and then the dorsal surface exhibited charring (black) and then calcination (white).

Figure III-10. General view of the left hand during the cremation process, showing calcination of the distal phalanges of the left hand following disassociation and detachment from the forelimb.

Phase 5. Disassociation of the feet

Generally, the next major alteration of the body to be noted was detachment of the foot from the distal tibia, which earlier exhibited significant fracturing. Of the foot bones, the plantar surface of the calcaneus generally burned first and exhibited charring and then calcination. The dorsal surfaces of the metatarsals and phalanges were also differentially burned black and later calcined.

Phase 6. Longitudinal and transverse fractures of exposed bones

As the muscle retracted, bones were exposed to heat, which resulted in a loss of moisture and destruction of organic content. As a result, the bones warped and exhibited longitudinal and transverse fractures (see Figure III-9).

Phase 8. Disarticulation of the patella

Concurrently with the burning of the foot, the patella was modified relatively early in the burn sequence as there is only skin as overlying tissue. However, it seemed that the strong tendons attaching the patella to the lower limb elements kept it in place for an extended period of time. When the patella did become detached, it generally fell to the lateral side of the leg due to the bent-kneed position of leg in the pugilistic posture. Additionally, when the patella disassociated from the leg, it did so before the bone calcined. If it did not disassociate, it remained in a clump of tissue with the distal femur and proximal tibia after they fractured.

Phase 9. Internal aspects of thorax exposed

The first noted changes to the thorax were the removal of soft tissue and skin around the bones, exposure of the ribs to fire and heat resulting in external charring and calcination. Shortly thereafter, a window appeared in the thorax, around the same time of the disarticulation of the patella, beginning at approximately a half hour to an hour after the start of burning (Figure III-11). This window resulted from the burning and then fracturing of the ribs in association with the reduction and destruction of the internal organs.

Phase 10a. Midshaft fracturing of upper limb long bones, followed by burning of internal bone structures

The humeri, radii and ulnae fractured at the midshaft in some, but not all, instances. The intact bone burns initially on the outside until the bone calcines and eventually portions of the shaft become detached and fall away. When that happens, often the bone will ignite internally and burn from the inside to the outside of the bone.

Figure III-11. Superior view of axial portion of body showing ventral aspect of torso during cremation. Note calcined and fractured ventral portions of the ribs, charred internal organs and bone fragments collapsed into opening and on top of organs.

Phase 10b. Disassociation of distal portions of long bones (humeri and femora), followed by burning of internal bone structures

In most cases, following warping and appearance of significant fractures in the distal portions of the long bones, the distal humeri and femora fractured from the rest of the bone shaft (likely, from the weight of the manus and podia), and fell to the retort floor.

The distal femora were found to fracture after the longitudinal fractures in the shaft, which generally occurred after the abdominal window became visible. The distal end of the fractured femoral shaft then tends to exhibit a frayed appearance (Figure III-12). The distal tibiae were also exhibited significant fractures, but the fibulae often remained intact.

Figure III-12. General view of the right femur during cremation. The bone exhibits distal fraying morphology after the distal end has fractured off, and it is burning from the inside to the outside of the bone.

Burn Sequences and Patterns in the Skull

See Table II-2 below for an approximate sequence of alteration to human remains during cremation of the cranium.

Phase 1. Mandible

The inferior and lateral aspects of the body of the mandible were noted to burn and become calcined even before all of the facial skin had burned off completely.

Phase 2. The Cranium

Details of the burn pattern of the skull were highly dependent upon the original placement of the body in the retort. When the body was placed feet first into the retort, the cranium was positioned towards the open end of the retort, which was not as hot as the remainder of the retort. The parietal bones exhibited fire alteration earlier than the frontal bone. The cranium fractured as it heated. Fractures were seen throughout both parietals and the occipital as the cranium heated, but they did not occur in the facial bones (e.g., frontal, maxillae, zygomatics) until complete calcination of those bones occurred. The facial bones, with the exception of the maxillae and the superior frontal, were the last bones to calcinate.

Table III-1. Approximate sequence of alteration to human remains during cremation for the appendicular and thorax

Sequence of Cremation: Appendicular Skeleton and Thorax (face up individuals)
Skin blistering on the hands, arms, and legs
Skin splitting on hands, arms, and legs
Charring, calcination, and disarticulation of distal hand phalanges
Pugilistic posture of hands/ Disarticulation of the 1st metacarpal (thumb)
Pugilistic posture of the upper limb
Muscle shrinkage in thigh and upper arm
Exposure, charring, and calcination of distal femora and humerii
Exposure of the radii and ulnae/Calcination of the metacarpals and hand phalanges
Disarticulation of the hands
Disarticulation of the feet and fracturing of distal tibiae
Disarticulation of patellae/ Window in the abdomen
Longitudinal and transverse fractures of femora and humerii
Possible fracturing of humerii, radii, and ulnae
Possible calcination of patellae
Fracture of distal femora
Sternal rib end fraying
Complete consumption of all soft tissue
Complete calcination (cremation) of individual

Table III-2. Approximate sequence of alteration to human remains during cremation for the cranium

Sequence of Cremation: Cranium (face up individuals)
Inferior and lateral aspects of mandible body calcine
Facial skin burns off
Parietals exposed
Frontal exposed
Occipital exposed
Fractures in parietals and occipital
Calcination of facial bones
Fracturing of facial bones
Complete disarticulation of cranium

Burn Modification Patterns in Individuals Lying Face-Down

All of the heat alteration patterns noted above were observed in individuals (as mentioned previously) who were placed in the retort in the prone (face-up) position. The patterns were fairly consistent and uniform from individual to individual. However, when the body was placed face down in one cremation, the burn pattern noted was dissimilar to the pattern noted in the prone individuals.

The general sequence of changes noted for this individual:

1. The lower legs flex at the knee and assume the typical pugilistic posture that the arms had assumed in the previous burns.
2. The feet disassociate before the leg is finished moving into final pugilistic posture.
3. The lower leg continues to flex at the knee, even to the point of pulling the tibia and fibula up and toward the back. The tibiae and fibulae flex over the posterior of the femora (Figure III-13) with the distal tibia and fibula close to the proximal femora and pelvis.
4. The medial and inferior edge of the scapulae were flexed dorsally to the point that the inferior border of the scapula was facing away from the body.
5. Additionally, the distal phalanges of the hands were the first bones to become exposed, following removal of skin and became detached prior to any other bone being affected.

6. The spinous processes of the vertebrae, vertebral ends of the ribs, medial borders of the scapulae, and the occipitals were the first bones to calcinate after the patellae became disassociated (Figure III-14). Due to the early calcination, the ribs fractured at the vertebral end. Some cervical vertebrae rotated, leaving them posterior side up on the floor of the retort. No abdominal window or rib end fraying was observed when the body was face down.
7. The sternal end of the ribs, anterior iliac crests, and sternum were the last regions of the body to burn.

Figure III-13. Superior view of body oriented face-down, during the cremation process showing the backward flexion of the lower leg to the point that the distal tibia is positioned over the proximal femur. Note the disassociated left foot on the floor of the retort.

Figure III-14. General view of body during cremation process (superior view). Note the calcination of the vertebral spinous processes, vertebral ends of ribs, and medial border of the scapulae.

It is interesting to note that the foramen magnum and surrounding inferior occipital region burned prior to the throat. The occipital was among the first bones of the cranium to calcinate and the parietals quickly followed (Figure III-15). The frontal and facial bones began charring at approximately the same time as the calcination of the occipital. The cranium fragmented into disassociated pieces soon after being completely exposed (Figure III-16).

Figure III-15. Superior view of skull during cremation process. Note fracturing of the cranial bones.

Figure III-16. General view of cranial remains during cremation process. Note the complete fracturing and disassociation of individual pieces of the cranium after calcination.

Discussion

In Symes *et al.* (2008), a detailed discussion of burning and fracture patterns of human bones of fire victims was presented. The authors indicated that the first bones to exhibit heat alteration included:

- the dorsal aspect of the metacarpals
- the elbow joint (distal humerus and the proximal radius and ulna)
- the shoulder joint (acromion process of the scapula and the antero-proximal end of the humerus)
- the sternal end of the clavicle
- sternal end of ribs 1-8
- the posterior surface of the lower ribs inferior to the scapula
- all vertebral spinous processes, the knee joints (distal femur, patella, and proximal tibia and fibula)

- the ankle joints (distal tibia and fibula, posterior calcaneus and talus, and the medial cuneiform and proximal first metatarsal)
- the distal metatarsals and foot phalanges
- the lateral aspects of the mandible and frontal bone, the nasals, and the zygomatic bones.

Additionally, they indicate that the last places to burn include:

- the palmar surface of the hand, with the exception of the thumb
- the midshaft of the radius and ulna
- the olecranon fossa of the humerus
- the posterior aspect of the scapula inferior to the scapular spine
- the anterior bodies of the thoracic and lumbar vertebrae
- the pelvic inlet (the anterior sacrum, medial surfaces of the ischium)
- the femoral head, the posterior surface of the distal femur and proximal tibia
- the mandibular condyles, and several of the cranial bones including the frontal, maxilla and occipital

Although most of these observations were confirmed in the present controlled study, deviations from this pattern observed in real-case experiences suggests that the sequence of fire alteration to bones is dependent upon body and limb positioning and orientation prior to burning. Additionally, the weight and composition of fat and muscle of the individual and prior pathological conditions must be considered when assessing a burn pattern in a fatal fire victim, as they may play a role in the relative thermal damage to different skeletal elements. The relative potential contribution of each of these factors should be addressed by future research.

In agreement with Symes *et al.* (2008), the lateral sides of the ascending rami of the mandible were exposed and burned early in the study cremations. This area was generally calcined before other bone surfaces of the cranium and mandible were even initially exposed. Areas of minimal protection (i.e., those areas lacking thicker layers of overlying muscle tissue) showed the first evidence of burning including the dorsal surfaces of the metacarpals, the “elbow” joint, the sternal end of the clavicle, sternal ends of ribs 1-8, the “knee” joint, and posterior surfaces of the ribs. The burning pattern of the long bones was generally consistent with the conclusions of Symes *et al.* (2008), in which they suggest that the fire modified the outside of the bone before the inside of the bone unless the shaft was fractured. After the bone had fractured, the inside medullary cavity of the bone was observed burning on a number of occasions. Additionally, the progression from unaltered bone to calcined bone described in Symes et al. 208 was noted during the observations of cremations. In agreement with Mayne Correia (1997), the general progression of changes in the bodies was as follows: first charred, black in appearance with internal organs remaining; then partial cremation, in which soft tissue remained; and finally, complete cremation, in which only bone fragments remain. Longitudinal, transverse, step, and curved transverse fractures were noted in the present study, which also corroborates the observations in Symes *et al.* (2008).

In contrast to Symes *et al.* (2008), no evidence was found for the "shoulder" joint being one of the first areas to burn. Also noted in the controlled cremation study was the fact that the distal phalanges were altered by fire early in the process and often detached before the hand flexed into the characteristic pugilistic posture. Accordingly, the distal phalanges were not observed curling into the palm. The nasals and zygomatics were among the last bones to burn in the cremations, but this pattern is most likely due to the head being further away from the flames and heat in the retort.

In the current study, pathological conditions caused atypical burn patterns in the bodies.

1. In one cremation, a prosthetic device on the proximal end of the left humerus was quickly exposed during the cremation due to the left shoulder joint burning earlier than the unaffected right shoulder joint without a prosthetic.
2. In another cremation, the individual possessed a metal mandible, which became exposed in its entirety sooner than the mandibles in all other cremations.
3. In still another cremation, the individual exhibited pronounced spinal kyphosis. During early stages of heat alteration, the torso twisted laterally to the right during flexure into the pugilistic posture (Figure III-17).

The body position, tissue shielding, and color change in thermally altered bone were observed during the cremations in accordance with a normal burn pattern. When these factors differ from the observed instances, the body may have an atypical burn pattern. Perimortem trauma was not observed in the cremations and therefore it was not possible to conclude how trauma will influence the normal burn pattern.

Figure III-17. uperior view of individual during cremation process. Note altered puglistic posture due primarily to the individual's spinal kyphosis.

CHAPTER IV

Research Component 3: Heat Alterations in Traumatized Bone

Materials and Methods

Once normal, expected heat-induced bone trauma and damage due to recovery (including bone loss or destruction at the scene) have been identified and controlled for, the remaining question is whether the same diagnostic traits used to detect, assess and identify forensically significant perimortem trauma in non-burned bone (including the identification of inflicting tool class characteristics), are still present and effective after fire alteration. Ultimately, the question can be posed as whether the *absence* of certain class characteristics in a trauma feature means that the tool typically producing those characteristics can be ruled out as the inflicting weapon or, on the contrary, exposure to fire is actually expected to significantly alter or even destroy them. This component of the research addresses this question for sharp trauma, through the documentation and analysis of saw marks in human bone and an animal model (*Sus scrofa* limbs), before and after burning in near-real and laboratory conditions. Additionally, the study evaluates the validity of the use of animal models for this kind of research, through the comparison of results obtained from animal and human limbs.

Data for this component were collected from three sources: 1) *Data Source A*, a sample of human bones previously subjected to sharp force trauma under experimental conditions in a previous research project conducted by the first investigator (SAS) with funding from the NIJ (*Award #2005-IJ-CX-K016)*, aimed at the study of saw mark analysis in fresh bone and its accuracy in Daubert-type analyses (Symes *et al.* 2005a, 2006); 2) *Data Source B*, a sample of animal bones (pig) generated during the mock scene exercises in *Research Component 1* and subjected to the exact same treatment as applied to the human sample; and 3) *Data Source C*, a second animal sample (pig) that was generated by applying the same trauma-induced treatment as the other two samples, and then burned under controlled conditions in the laboratory.

This study relied on an opportunistic experimental design, intended to take advantage of these existing resources (*Data Sources A* and *B*) through the generation of *Data Source C*, which serves to link the two existing samples through two pair-wise sample comparisons via a simple but powerful statistical design. Both the *Data Source A* sample of human remains and *Data Source C* sample of animal bones received the exact same treatment, serving to compare the effects of fire on perimortem trauma class characteristics in human and animal remains.

In the second comparative study, *Data Source B* and *C* samples, both animal (pig) remains, were burned under different conditions, after receiving the same pre-burning treatment (i.e., controlled vs. mock scene field burning). The results were then compared.

This component of the research provides a baseline for the forensic analysis of sharp trauma in burned bone, particularly in terms of the interpretation of the presence/absence of diagnostic traits relative to general tool class characteristic. Additionally, the comparison of results from identical experiments in human and animal remains served to assess the validity for future research of observations based on animal models.

Sample Preparation

Research Component 3 is comprised of three *Data Sources: A, B,* and *C*. *Data Source A* is comprised of cut bone sections of human long bones that were burned in a furnace. *Data Sources B* and *C* are two samples of cut bone sections of domestic pig (*Sus scrofa*) long bones. *Data Source B* was burned in the mock fire scenes and *Data Source C* was burned in a furnace under controlled laboratory conditions. All animal remains employed in this research were obtained from commercial food sources and were not euthanized for the purpose of the study.

Data Source A

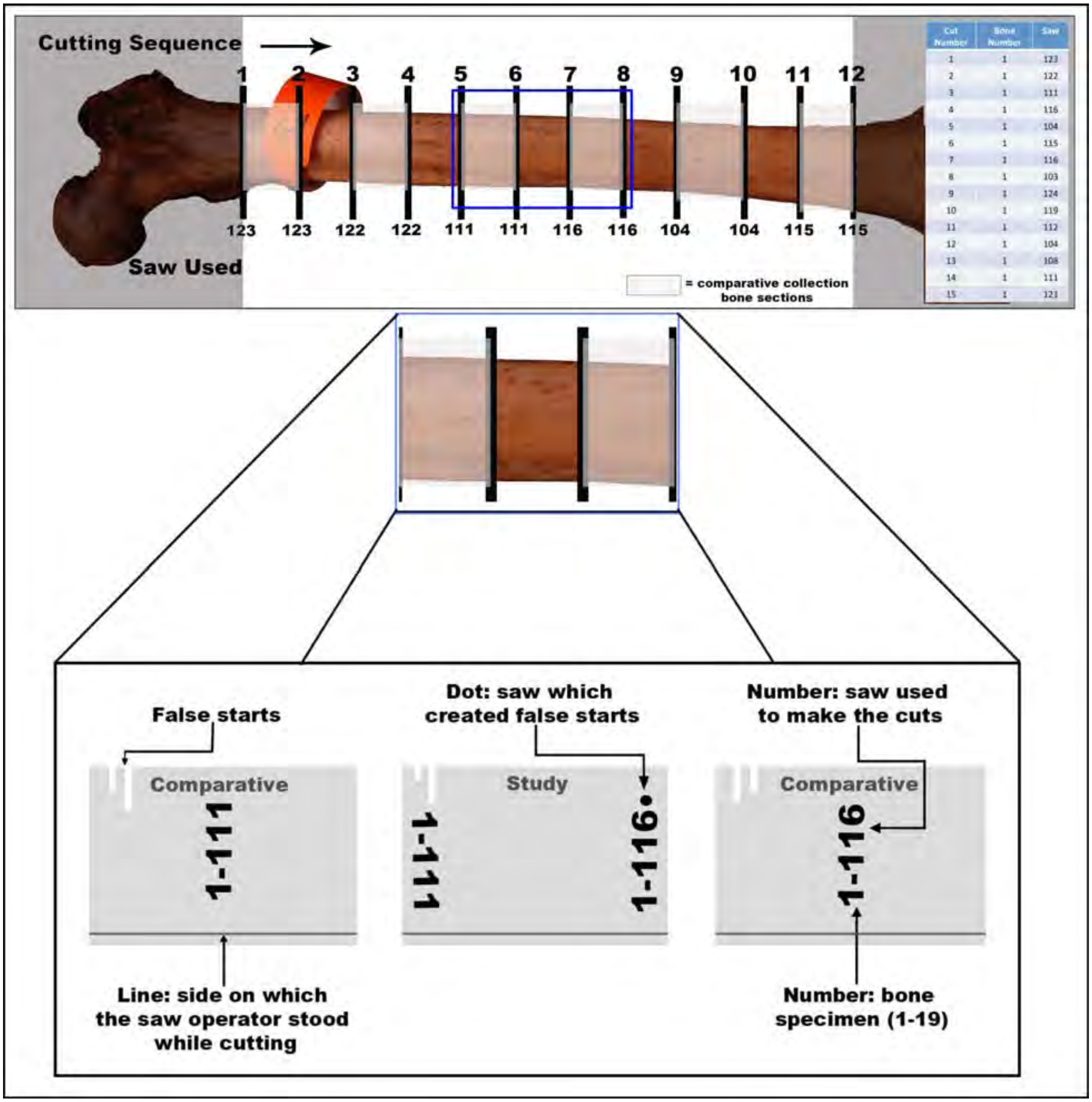
Data Source A is a sample comprised of human bones that were used in a previous National Institute of Justice-funded research grant (*Award #2005-IJ-CX-K016*). At the time this research project was carried out, 19 human long bones (humeri and femora) from six individuals were obtained from the director, Dr. Jonathan Kalmey, of the Lake Erie College of Osteopathic Medicine (LECOM) Willed Body Program in Erie, PA

The bones were originally fixed in a preservative solution of 33.3% glycerin, 27.8% phenol, 5.6% formaldehyde (37%), and 33.3% methanol. Each long bone was processed in an aqueous solution of commercial laundry detergent and approximately 4 ounces of bleach per gallon, at close to boiling point temperature. Each bone was denuded of soft tissues and left to dry at room temperature. A unique number from 1 to 19 was assigned to each of the long bones.

A random sequence of cuts was then generated using the 19 long bones and 27 different saws (labeled 100-126). Fifteen saws were randomly selected to inflict cuts into each of the 19 long bone in order to eliminate potential sample biases. Meaning that a sequence of 15 cuts was generated for each bone (Table IV-1). Cutting proceeded either from the distal to the proximal end of each bone, or more commonly, from the distal to proximal end in order to use the entirety of the bone (Figure IV-1). Each cut bone section was then labeled with pencil and further processed in nearly boiling water, detergent, and small amount of bleach to further remove any grease or preservative solution. After drying, the bone sections were labeled with ink and stored into plastic containers with individual compartments.

Table IV-1. An example of the 15 randomly generated cuts that were produced for *Bone 1* of *Data Source A.* Note that not all 15 cuts were made for each long bone. The sequence was followed until the complete long bone had been cut into as many bone sections as possible.

Cut Number	Bone Number	Saw Selected
1	1	123
2	1	122
3	1	111
4	1	116
5	1	104
6	1	115
7	1	116
8	1	103
9	1	124
10	1	119
11	1	112
12	1	104
13	1	108
14	1	111
15	1	121



Cut Number	Bone Number	Saw
1	1	123
2	1	122
3	1	111
4	1	116
5	1	104
6	1	115
7	1	116
8	1	103
9	1	124
10	1	119
11	1	112
12	1	104
13	1	108
14	1	111
15	1	121

Figure IV-1. An example of the cutting sequence and preparation of the bone sections for *Data Source A.* Only bone sections labelled "study" in the diagram and only bone sections with cuts created by *Saws 101* and *104* were used for analysis in *Data Source A.* The other bones sections labelled "Comparative" were used to compile a Collection Sample that was not used for any analyses.

One hundered twenty-one bone sections (242 cut surfaces) were produced for the study sample of the previous sawmark analysis research grant. In order to control for differences based on saw characteristics, only those bone sections cut with *Saw 101* and *Saw 104* were used in the current project. The analysis comprised 11 bone sections cut with *Saw 101* and five sections cut with *Saw 104*. *Saw 104* was selected in order to increase the sample size of *Data Source A*, due to its similarity in characteristics to *Saw 101* (Table IV-2).

Table IV-2. General characteristics of *Saw 101* and *Saw 104*. Bone sections cut with *Saw 104* were selected for analysis in order to increase the sample size for *Data Source A*.

Saw No.	*Hand/Power*	*TPI*	*PPI*	*Set Type*	*Tooth Type*	*Direction of Cut*	*Blade Name*
101	Hand	11	12	Alternating	Cut	Push/Pull	Utility saw
104	Hand	11	12	Alternating	Cut	Push/Pull	Finish blade

Data Source B

Data Source B is a sample of pig (*Sus scrofa*) long bones that was produced to assess the effects of fire on saw marks under realistic conditions (see *Processing Mock Fatal Fire Scenes* in *Chapter II*: *Research Component 1* of this report). These pig carcasses were obtained from farmers in the Erie, PA and Waynesboro, PA areas. The two pig carcasses used for the Franklin, PA mock fatal fire scene along with the two used for the McDonald, PA mock fatal fire scene were obtained from The Walters Meat Company in Erie, PA. The complete pig carcass that was burned at the mock fatal fire scene in Waynesboro, PA was purchased from a local farmer in that area. Eight additional pig limbs were inflicted with saw marks and burned in the trailer fire in Waynesboro. The eight limbs were obtained from Gourley Farms in Sugar Grove, PA.

Franklin Center, PA Fire

The sample from the Franklin Center mock fire scene consisted of eight limbs from two juvenile pigs obtained from Walters Meat Company in Erie, PA. The limbs were cut using *Saw 101.* The cuts were made starting at the proximal end of the bone and proceeding to distal end (see Appendix IV-1 for a detailed list of the cuts made). After the cuts were made, the limbs were removed from the pig torso and placed in the trailer. Documentation of the condition, position, and location of the limbs were recorded prior to the fire being set.

McDonald, PA Fire

The sample from the McDonald mock fatal fire scene also consisted of two juvenile pigs obtained from Walters Meat Market Company. In the Mercyhurst College Wet Preparation Laboratory, these limbs were cut with *Saw 101* in the same fashion as the limbs for the Franklin Center fire but were not removed from the torso of the pig (see Appendix IV-2 for a detailed list of the cuts made). The pigs were then transported to McDonald, PA and placed in the house. Documentation of the condition, position, and location of each pig was recorded prior to the fire being set in the home.

Waynesboro, PA Fire

The pig sample used in the Waynesboro mock fatal fire scene consisted of eight pig limbs purchased from Gourley Farms in Sugar Grove, PA. In the laboratory, these limbs were also cut with *Saw 101* starting from the proximal end of the limb and continuing to distal end of the bone (labeled *Pigs 1* and *2*; see Appendix IV-3 for a detailed list of the cuts made). The pig limbs were then transported to Waynesboro, PA and placed on the floor of a bedroom in a mobile home. The position, condition, and location of the limbs were recorded prior to the fire.

Two additional pigs were obtained for the mock fatal fire scene in the Waynesboro. *Pig 3* was placed in the master bedroom where cuts were made to its limbs while in the structure of the home. *Pig 4* was placed on the second floor of the house, where the cuts were made (see Appendix IV-3 for a list of the cuts made to *Pigs 3* and *4*). The position, condition, and location of all four pigs were documented prior to the fires being set. The saw marks on the fourth pig (*Pig 4*), however, were not analyzed since this site could not be processed due to unexpected problems during the fire response training exercise.

After the cuts were made, all of the pig specimens were burned at the mock fire scenes and were subsequently recovered by the individuals that processed each scene. The pigs and pig limbs were packed in plastic storage containers and cushioned with foam after which they were transported to Mercyhurst College for processing and analysis.

All burned limbs were processed in the Mercyhurst College Wet Preparation Laboratory. Scalpels and scissors were used to remove the large pieces of tissue and the remaining bones with residual tissue were placed in pots of nearly boiling water, detergent, and a small amount of bleach. Scalpels, scissors, tweezers, and bamboo sticks were used to remove all residual tissue from the bones. After the bones were left to dry, each cut bone section was placed in an individual plastic bag labeled with a unique number. Each bone section number began with 1, 2, or 3, indicating the fire from which the section was recovered (1 = Franklin Center, PA; 2 = McDonald, PA; 3 = Waynesboro, PA), followed by a dash and sequential number. Further, the first cut surface of each bone section was labeled "A" and for those sections with a second complete cut, the second cut surface was labeled "B". The first cut surface (A) was determined based on the more proximal side of the bone sections in reference to the complete long bone. The second cut surface (B) was identified based on the more distal end of the bone section. In order to differentiate between surfaces "A" and "B", distinguishing characteristics on each cut surface were described in documentation forms and directly on the plastic storage bag (see Appendix IV-4 for a list of *Data Source B* bone sections used for analysis).

Data Source C

Data Source C is a sample comprised of 24 pig limbs purchased from Providence Pastures Farm in Corry, PA. These limbs were treated in the same manner as *Data Source A.* First the majority of the tissue was removed with a knife. To fix the pig limbs, a custom-made preservative solution was diluted by adding two parts of water to one part preservative solution (identical to the fixing solution in *Data Source A*). This was done taking special precautions, wearing appropriate gloves and a respirator with cartridges suitable for filtering volatile organic compounds. This mixture was poured into four airtight plastic containers into which the 24 limbs were placed. The containers were then stored in a chemical closet in order to preserve the bones and remove some of their water content. After approximately two months, the bones were carefully removed from the plastic containers and processed in nearly boiling water, detergent, and a small amount of bleach at the Mercyhurst College Wet Preparation Laboratory.

After the bones were cleaned and dry, cuts were made in each of them using *Saw 101*. One end of each long bone (most commonly the proximal end) was placed securely in a vice while cuts were made. This was done in order to stabilize the bone while making the cuts. Complete cuts and false starts were made in the bone shafts. An attempt was made to make at least three complete cuts and five false starts per long bone (Appendix IV-5). All the resulting bone sections were placed in individual plastic bags labeled with a bone number, ranging from 1 to 59 (one number for each bone) *(Note that there is no bone section numbered 60, as one of the bones was over-processed and not used in the study).* Researchers noted that many of the teeth of *Saw 101* had broken off because the saw had been extensively utilized in the previous research project as well as in the production of *Data Source B*. As a consequence the same identical saw was purchased for the production of *Data Source C*. The second *Saw 101* was used to make cuts on bones 20 to 50. Although the bone sections from *Data Source A* were processed for a second time after the saw cuts were made (see *Data Source A* section above), many of the bone sections from *Data Source C* were already processed to a suitable condition and were therefore not processed a second time after being cut. Individual bone sections were labeled with a unique number, beginning with the bone number (1-59) and the sequential section number, with the most proximal section being number 1. For example, bone 5 was a left ulna with five complete cuts. The most proximal section was labeled 5-1, the second most proximal cut section was labeled 5-2, and so on. Further, the most proximal cut surface on each bone section was labeled "A" and the more distal cut surface on each bone section was labeled "B" on bone sections.

Analysis

Data Sources A and C

Data Sources A and *C* were burned in a furnace in order to compare the effects of heat on saw marks between humans and pigs and to test the validity of using porcine specimens for trauma research. It is for this reason that these two data sources were analyzed for the presence and absence of select sawmark characteristics (see below). The minimum kerf width was also recorded before and after burn for later analysis pertaining to bone shrinkage after burning (see *Analysis of Kerf Width Dimensions* section below). As the differences in density and, thus, strength between human and animal bone are one of the key factors that might affect the comparisons between human bone and animal proxies, the differences between wet, dry and ash weight were approximated and compared in both samples, as the "golden standard" for bone densitometry (see *Comparing Organic Compositions* section below) (Ebbesen et al. 1999, p. 714).

All 16 bone sections from *Data Source A* listed in Table IV-3 were analyzed for presence or absence of sawmark characteristics (See *Trait Coding* section below). A random sample of bone sections was generated for *Data Source C*. The first randomly chosen 30 bone sections were selected for this analysis. Five random groups of six bone sections were pulled from their labeled bags in order to create five rounds of analysis, burning and subsequent post-burn analysis for *Data Source C* (Table IV-4).

Table IV-3. List of bone sections analysed for *Data Source A* including which saw was used to make the cuts. Note that bone sections cut with *Saw 104* are highlighted in grey.

Bone	Section	Saw Used to Cut
4	110-101	101
4	101-120	101
4	108-101	101
4	101-106	101
12	101-109	101
17	103-101	101
17	101-121	101
18	111-101	101
18	101-118	101
18	108-101	101
18	101-109	101
12	119-104	104
12	104-116	104
15	104-117	104
17	121-104	104
17	104-111	104

Table IV-4. List of bone sections randomly generated for analysis from *Data Source C* broken down into five rounds of six bone sections.

Round	Section Number
1	40-3
	6-3
	37-3
	49-2
	55-2
	20-4
2	4-3
	48-3
	16-3
	38-2
	17-2
	27-3
3	25-3
	5-4
	16-2
	30-2
	36-3
	40-2
4	47-2
	14-2
	43-2
	49-3
	48-4
	23-2
5	21-3
	46-2
	23-4
	29-3
	26-3
	9-2

Data Source B

Data Source B was analyzed in the same manner as *Data Sources A* and *C*, with the exception of the pre-burn analysis. Cuts created for *Data Source B* were not analyzed before they were burned because the cuts were created in fresh limbs with adherent soft tissues. The results of the *Data Source B* analysis were compared with those of *Data Source C* in order to determine the validity of using laboratory-controlled furnace burns in comparison to the realistic mock fire scenes.

After the bone sections were processed free of any remaining adherent soft tissue, a research assistant systematic did a macro- and microscopic analysis to identify all bone sections and bone fragments that contained saw marks (see section above). There was a great deal of variation in the range and degree each bone section had been altered by the fire. Some bones and cut marks in this case were greatly shielded by the soft tissues surrounding them and the fire significantly altered others. These results are what we would expect to find in a real fatal fire scene in which some bones are going to display more significant heat alteration than others (Figure IV-2). A total of 174 bone sections with saw marks were collected from the mock fatal fire scenes. Of those 174 bones sections, 30 were randomly selected for trait coding analysis for *Data Source B* (Table IV-5).

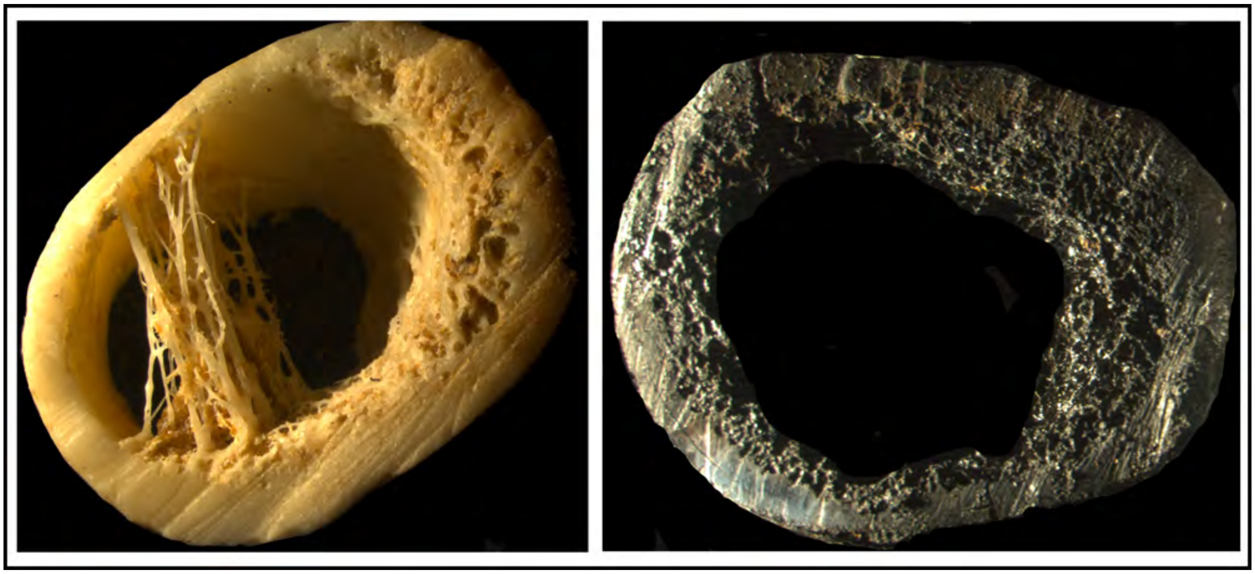


Figure IV-2. Two bone sections recovered from mock scenes (Data Source B). Note the degree/range of heat alteration. The bone section on the left is only slightly heat altered while the section on the right is charred and even calcined in some areas.

Table IV-5. DS-B bone sections randomly selected

Data Source B Bone Sections	
2-008A	3-045B
2-021A	1-004A
2-015A	3-019A
3-085A	3-010A
3-049B	3-090A
3-079A	3-055B
3-033A	2-026A
3-045A	3-063A
3-038A	3-037A
3-092A	3-081A
2-006B	3-057A
2-010A	2-024B
3-028A	2-027A
3-071A	1-005A
3-047B	3-030B

Description of Coded Traits

Originally nineteen traits were selected for use in *Research Component 3.* See Table IV-6 for a complete list of the original traits. The nineteen traits were based on previous research by one of the principal investigators (SAS) during a previous National Institute of Justice funded grant (*Award #2005-IJ-CX-K016*) (Symes et al 2005a, 2006). After the initial pilot sample was coded for the presence or absence of traits for *Data Source C*, it was decided to reduce the number of traits being coded to nine traits (Table IV-7). This decision was made due to the fact that these nine characteristics or traits were the ones seen in the highest frequency during the pilot study. The authors wanted to ensure that enough traits would be identified as present given the samples sizes.

Table IV-6. List of original nineteen traits that were selected for use in *Research Component 3*.

Original Traits						
Consistency of cut	Energy transfer	Polish	False starts	Exit chipping	Curved kerf floor contour	Break-away notch
Cut surface drift	Material waste	Tooth imprint/floor dip	Kerf flare	Entrance shaving	Pull out striae	
Break-away spur	Bone islands	Blade drift	Harmonics	Flat kerf floor contour	Tooth hop	

Table IV-7. List of coded traits used for *Data Sources A, B, and C*.

Modified Coded Traits				
Break-away spur	Tooth hop	False starts	Exit chipping	Tooth imprint/ floor dip
Break-away notch	Pull out striae	Kerf flare	Blade drift	

Definition of Traits

Below are the nine traits that were used for this study, which were defined previously by Symes et al (*Award No.2005-IJ-CX-K016*). Each definition and description has an accompanying photograph (or photographs) depicting the trait.

Kerf Flare: If kerf flaring occurs on one end of the kerf floor, it indicates the 'handle-end' of the blade. It expresses the increased movement of the flexible blade as it continually enters the kerf. The opposite end of the kerf floor does not exhibit a flare due to stability from the kerf (Figure IV-3).

Figure IV-3. (Left) Example of kerf flare taken from Symes et al 2008. (Right) Example of kerf flare seen in pig bone from the current project.

Exit Chipping: occurs at the end of the cutting stroke or on the side of the stroke emphasized by the individual sawing. As a general rule, the largest chips of bone are removed on the cutting stroke as the blade exits the bone (Figure IV-4).

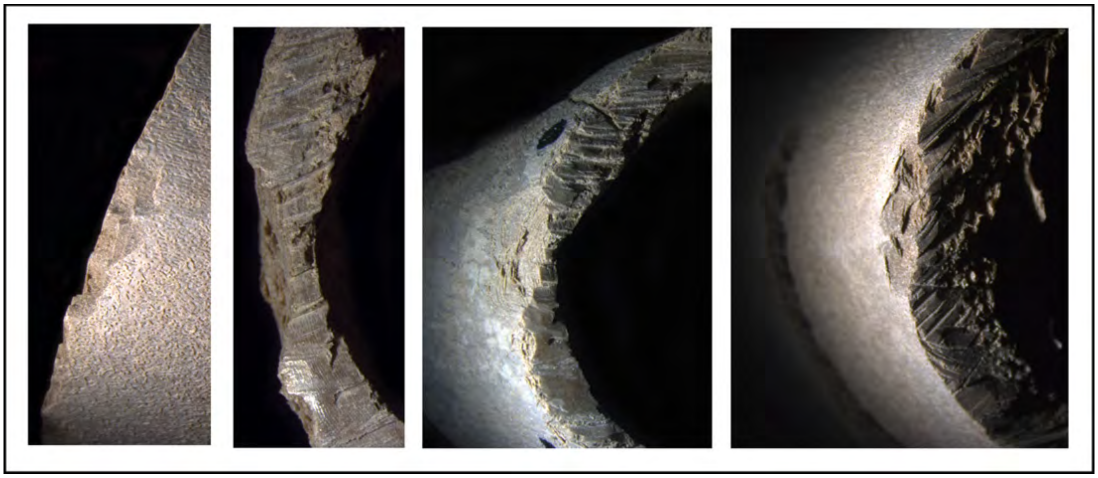


Figure IV-4. Four examples of exit chipping. Photographs taken of burned bone sections from *Data Source C.*

Break-away Spur: is a projection of uncut bone at the terminal end of the cut after the force of the sawing motion breaks the remaining uncut tissue. This commonly occurs on the stable end of the bone. The size of the spur often depends on the amount force applied across the bone while sawing, which also results in a fracture of that bone (Figure IV-5).

Figure IV-5. Three examples of break-away spurs. Photographs taken of bone sections created for previous NIJ funded research grant.

Break-away Notch: is the mirror image of a break-away spur that forms on the other side of the cut bone (Figure IV-6).

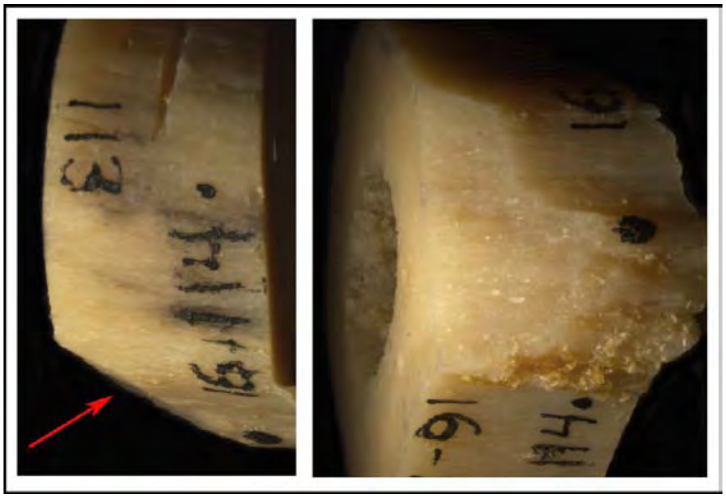


Figure IV-6. Examples of break-away notches. Photographs taken of bone sections created for previous NIJ funded research grant.

Blade Drift: refers to the pattern of teeth drifting across a kerf floor. Every tooth that enters the kerf in the bone creates a directional change in the blade. Blade drift is most evident in shallow cuts produced by alternating set saws (Figure IV-7).

Figure IV-7. (Left) An example of blade drift from bone section 12:119-104 from Data Source A. (Right) An example of blade drift from bone section 17:121-104 from Data Source A. Notice how the drift across the bone surface will eventually lead to the creation of bone islands.

Tooth Hop: refers to striae across the face of the bone that generally progress in a linear pattern. With close observation, the residual kerfs (striations) occasionally show patterned hopping or predictable waves. Tooth hopping is created as teeth begin to enter the kerf and each successive tooth strikes bone, which produces movement of the whole blade (Figure IV-8).

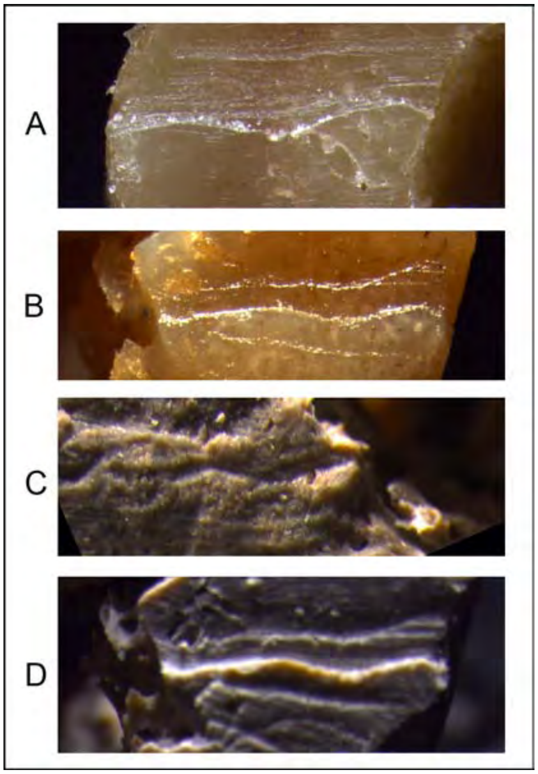


Figure IV-8. A and B: Examples of tooth hop visible in the cut surface of bone sections prior (A,B) and after exposure to heat (C, D). Note the dry appearance of bones sections C and D. The elimination of a shiny surface allowed for easier recognition in many cases.

Pull Out Striae: involves the presence of perpendicular striae on the cut surface of the bone. When the saw is withdrawn from the kerf in mid-stroke, the blade creates striations on the cut surface (Figure IV-9).

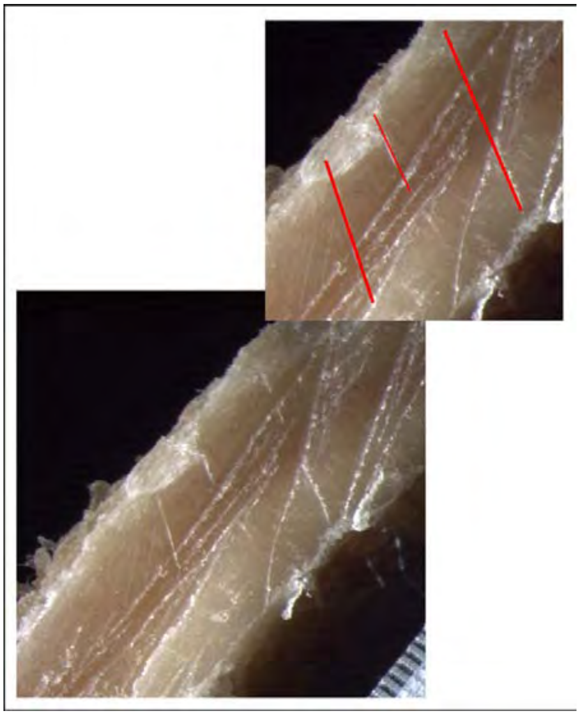


Figure IV-9. An example of pull out striae seen in the cut surface of one of the bone sections.

Tooth Imprint/ Floor Dip: when the floor of the kerf is examined on end, the seemingly flat-bottomed kerf may actually be notched or wavy. Tooth imprints and floor dip are residual imprints from tooth points in the kerf floor created after a saw is interrupted in the cutting stroke (Figure IV-10).

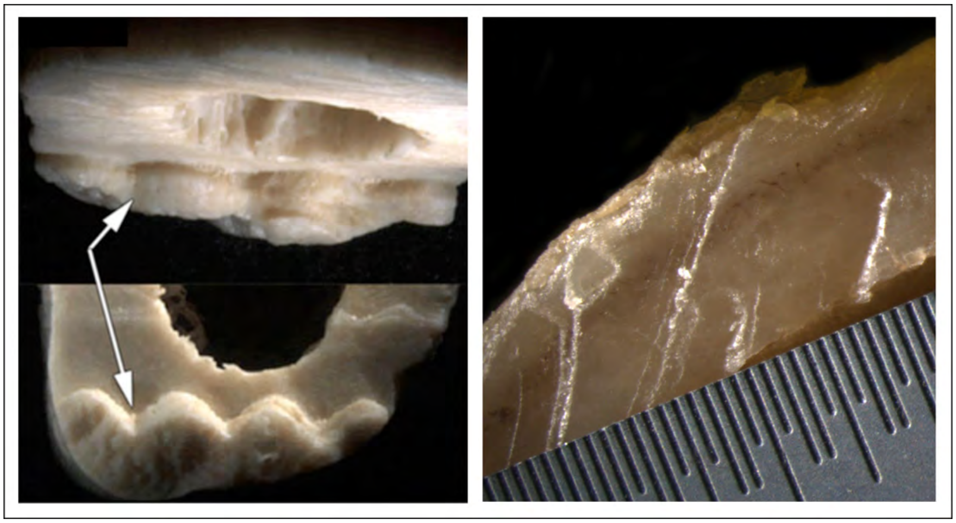


Figure IV-10. (Left) An example of tooth imprint from Symes et al (2008). (Right) An example of tooth imprint as seen in one of the bone sections analyzed in *Research Component 3*.

False Starts: cuts that do not completely separate bone into two halves. A false start is composed of two initial corners on the surface of the bone, two walls, two floor corners, and a floor (Figure IV-11).

Figure IV-11. Examples of false starts. Photographs taken of bone sections created for previous NIJ funded research grant.

Coding the Presence and Absence of Traits

For the purposes of documentation and later comparison overall photographs of each bone section were taken before and after was burned for *Data Source A* and *C* (described as 'pre-burn' and 'post-burn'). Photographs were also taken of the bones sections from *Data Source B* after they were processed free of any remaining soft tissue (post-burn). All photographs were taken using a *Leica MZ16 A* stereomicroscope and saved as *TIFF* files. Figure IV-12 depicts before and after images for bone sections analyzed as a part of *Data Sources A* and *C*.

The analysis of each bone section consisted of indicating the absence or presence of each trait by assigning either a "0" to indicate the absence of a trait or a "1" to indicate the presence of a trait or feature. The *Leica MZ16 A* stereomicroscope was used for microscopic analysis of the presence and absence of all traits. Table IV-8 (below) highlights the traits that were coded and briefly describes how each trait contributes to sawmark analysis in bone. All data were recorded in an *Excel* spreadsheet. It should be noted that the entire sample had the presence of false starts, since they were purposefully created when the cut marks were being inflicted on the bones. While the presence of the false starts was recorded as already described, the number of false starts observed was also recorded for each bone section. Analysis included comparing the number of false starts observed prior to burning with the number of false starts observed after the bone sections were exposed to heat.

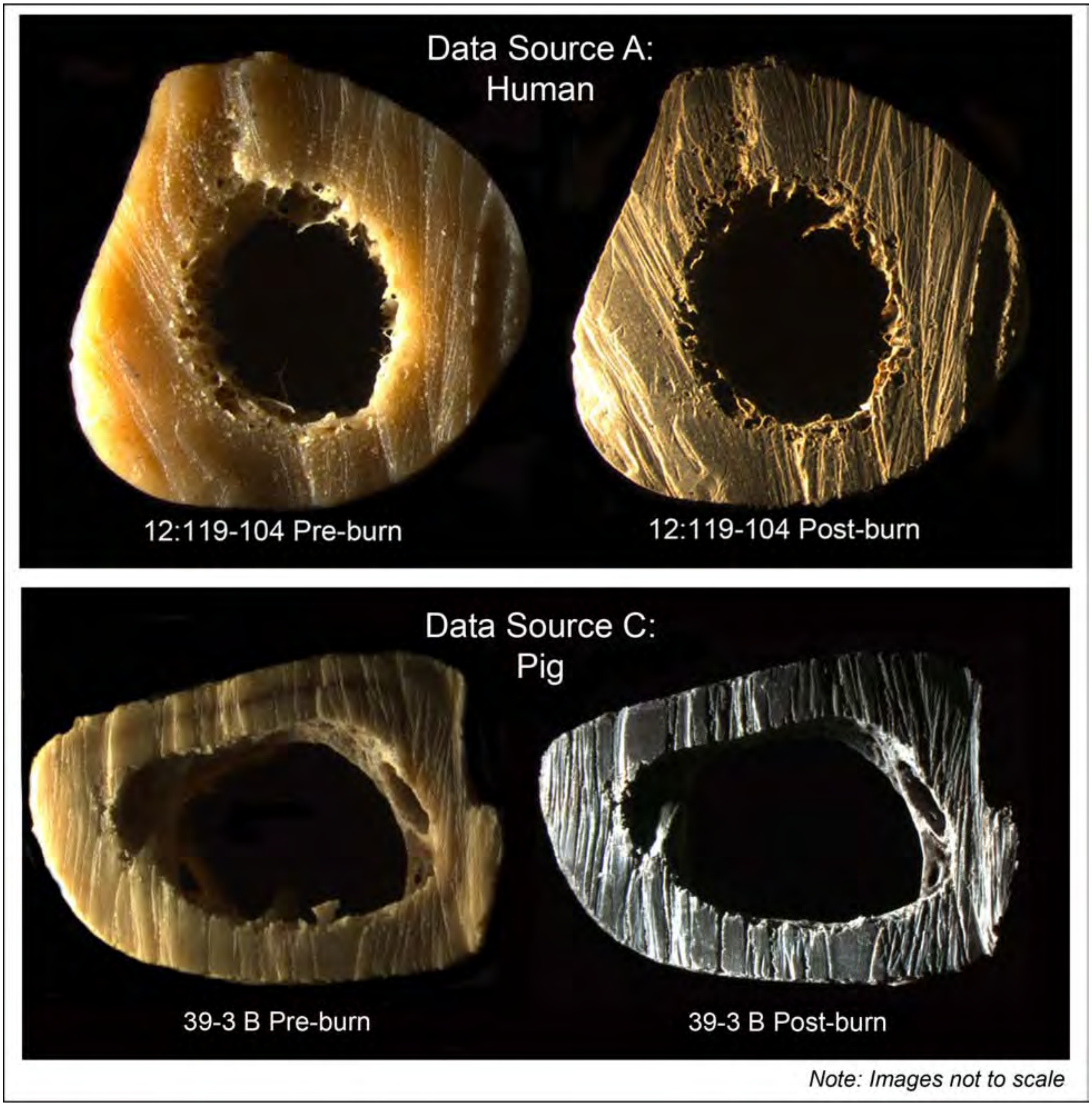


Figure IV-12. Examples of both human and pig bone sections before burning in the furnace and after. Note in both the human bone (above) and the pig bone (below) the striations appear to be more visible after heat alteration.

Once all bone sections were obtained, cleaned and photographed, they were examined microscopically, using a *Leica MZ16 A* stereomicroscope and *ImagePro 5.1* software. Each bone section was first illuminated with oblique lighting and photographed under the stereomicroscope with its bone section number, as previously stated above. Following this, each trait was scored for presence or absence. Photographs with a 1/100 of an inch scale were taken of the kerf width when it was present. These images were later used to compare minimum kerf width before and after burning for each bone sections analyzed from Data Sources A and C (see section *Analysis of Kerf Width Dimensions* below).

Table IV-8. Description of coded traits and how each effects sawmark analysis in bone.

Trait	Code	What each trait tells us or contributes to
Kerf Flare	Absent=0 / Present=1	Indicates handle end of the kerf
Exit Chipping	Absent=0 / Present=1	Direction of blade progress; occur at the end of the cutting stroke; large chips as a rule indicate the side where the blade exits the bone
Tooth Hop	Absent=0 / Present=1	Measuring from peak to peak or dip to dip of each wave indicates the distance between teeth of the saw; Can occur with a variety of saws; accurately indicates spacing of saw teeth
Break-away Spur	Absent=0 / Present=1	Size of the spur often depends on the amount force applied across the bone; for example weight of a handheld circular power saw or chain saw often produces a large break-away spur
Pull Out Striae	Absent=0 / Present=1	Estimations of tooth distance (every other tooth in alternate set); with raker set may represent the distance of three teeth
Tooth Imprint/ Floor Dip	Absent=0 / Present=1	Consecutive tooth imprint features can be measured in false starts and break-away spurs to represent the distance between teeth, indicate the set (shape) of the blade and indicate the shape of the individual tooth.
Blade Drift	Absent=0 / Present=1	There are certain drift actions that all blades with alternating set teeth follow since saw teeth are set to produce a cut wider than the saw blade.
False Start	Absent=0/ Present=1	May traits are exhibited in false starts. Features in false starts may indicate size, shape, and set of a blade. The size and number of false starts may help indicate saw power.

Comparing Organic Composition

In order to test the validity of using pig specimens in trauma research, and controlling for potential sources of error derived from the physical characteristics of each type of bone, the organic to inorganic composition of pig bones (*Data Source C*) was compared with that of human bones (*Data Source A*). The relative percentages of water and organic content were assessed through the differences between wet weight (initial mass), approximate dry weight (after incubation for one hour at 60º), and approximate ash mass (two hours at 500º) through controlled furnace burns. These furnace burns also served to approximate heat alteration in an actual fire scene. Two trial rounds were conducted with *Data Source C* in order to establish protocols that would be most effective in estimating approximate water and organic content for the remaining rounds of bone sections.

First, six crucibles with lids were labeled numbers 1 through 6 with a permanent marker and weighed on a digital scale equipped with a draft shield. Each bone section from *Data Source C* Round 1 was placed in the corresponding crucible and weighed on the digital scale. The mass of each bone was recorded as the wet mass. The bone sections were individually placed into uncovered crucibles, which were then distributed in two rows in a *Barnstead International Type 30400* Thermolyne Furnace. The furnace was then turned on and its thermostat was set to ramp up to 60 degrees Celsius. It should be noted that while the furnace was set to heat to 60 degrees Celsius, the temperature increased above this point, up to 78 degrees. As a result, the thermostat was decreased to 50 degrees and the temperature remained ultimately the same. Due to the fact that the temperature remained below 80 degrees (temperature of denaturation of organic collagen), it is assumed that the organic bone matrix would have been unaffected and only water would have evaporated.

The bone sections were left in the furnace for approximately 30 minutes, after which masses were measured at 10- to 25-minute intervals for just over three hours, until it was decided that there were no further significant decreases in mass. This indicated that most water content had evaporated until any further small fluctuations (e.g. 0.01 g) were one order of magnitude inferior to the initial water losses, serving to set the dehydration phase to one hour for the remaining of the sample. It should be noted that, in order to control for water gains derived for the absorption of ambient humidity, in the first seven weightings all crucibles were stored in a desiccator while one bone section was weighed at a time. For subsequent weightings, it was decided that lids would be placed on the crucibles when the oven door was opened, and one crucible would be removed from the oven at a time to be weighed. This expedited the weighing process and reduced the amount of time the bone sections were removed from heat, while no significant differences in water losses were observed between the dessicator and lid trials. Figure IV-13 depicts the weight loses and times during the dehydration phase of the pilot sample.

After most water content had evaporated, the dry mass of each bone section was measured, and the furnace temperature was set to ramp up to 500 degrees Celsius after the bone sections were returned to the furnace. The bone sections were left in the furnace for approximately 90 minutes in order to burn most of the organic content and reach a calcined stage, as evidenced by the light grey coloring (Figure IV-14). After this period of time, the furnace was turned off and the ash mass of each section was measured with the digital scale. A cooling period was allowed between burning at 500 degrees Celsius and weighing the bone sections.

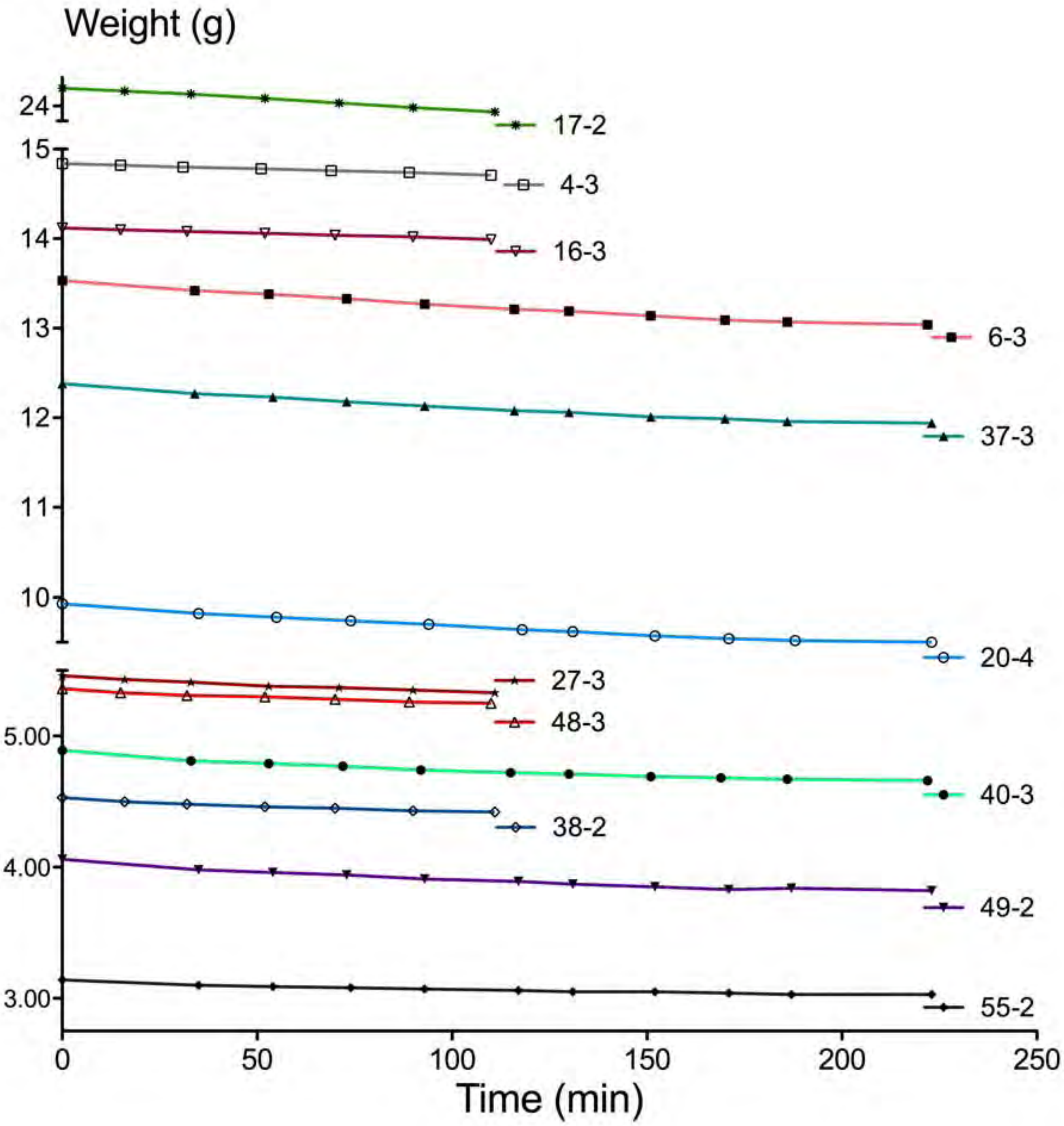


Figure IV-13. Weight changes at 60º Celsius for the subsample (pilot) of *Data Source C* utilized to determine time and temperature protocols. Note how more than 50% of water loss occurred during the first hour, with the higher loss during the first 30 minutes.

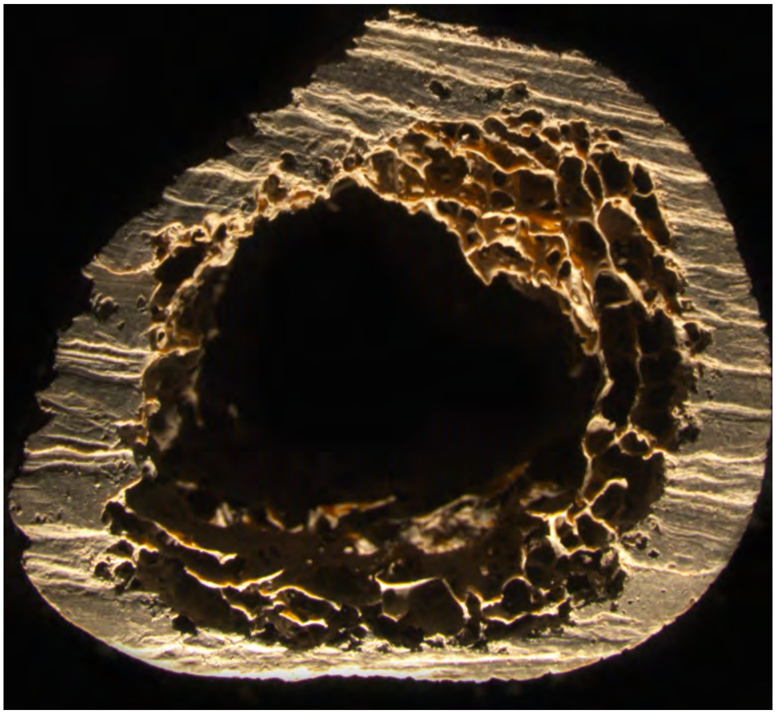


Figure IV-14. An example of a bone section from *Data Source A* after burning. Note the grey color indicating that the bone is calcined.

The second trial round consisted of carrying out essentially the same procedure on the second group (or round) of *Data Source C* with minimal changes in the times at which masses were measured. The six bone sections were heated in the furnace in covered crucibles and weighed at 15- to 20-minute intervals, with the first weighing occurring 15 minutes after the furnace was turned on. The masses were measured for approximately two hours, until it was assured that no further significant decreases in mass were occurring. After the final dry mass was measured, the bone sections were returned to the furnace, which was set to 500 degrees Celsius. After one hour and twenty minutes, the bone sections were checked to determine if they had reached calcination. Looking at the largest bone section (17-2), it was noticed that it was only reached the charred stage and not the calcined stage of burning, indicating that organic matter remained in the bone. As a result, the bone sections were left to continue to burn for another hour and ten minutes, at which time the furnace was turned off, leaving the bone sections inside. Bone section 17-2 was not completely calcined, yet it was decided to turn the furnace off as the other five bone sections had reached calcination after one hour and twenty minutes. The bone sections were left to cool slightly in the furnace for 17 hours, after which they were removed and placed in the desiccator. After an additional 5.5 hours, the ash masses were measured.

These two trial runs demonstrated that most of the water content evaporated within one hour and the organic content was burned after two additional hours at a higher temperature (500 degrees). As a result, subsequent rounds were burned with lids on the crucibles for one hour at 60 degrees Celsius after which dry masses were measured, followed by another two hours of burning at 500 degrees Celsius. After the additional two hours, the furnace was turned off and the bone sections were left to cool in the closed furnace for approximately 17 hours. Because the bone sections were still hot after this period of time, they were placed in a desiccator to cool off for approximately 5.5 hours. The lid was placed on the desiccator in order to prevent the absorption of atmospheric moisture by the dilated heated bones. The ash masses were measured after this period of time in order to determine the average organic composition of the bones. These procedures were also repeated on three rounds (six bone sections per round) of *Data Source A*. It should be noted that the masses of the crucibles and lids were measured before each round but no differences greater than 0.01 g were detected.

Once all data were collected, the percent water loss and organic matter loss were calculated for each bone section. A Student t-test with Welch correction for inequality of variances ($F_{11,15}=5.243$, $p<0.01$) was employed to test for significant differences in average wet weights between the human and animal sample. Differences in dry (water content) and ash (organic matter content) weight, after correction for initial weights were compared through two analysis of covariance (ANCOVA), with data source as the covariate, and wet-dry and dry-ash weight as the independent-dependent variables. These were intended to approximately quantify the differences in density between the human and pig samples (human bone showing lower densities), which might serve to explain potential differences in bone contraction and preservation when exposed to extreme temperatures.

Analysis of Kerf Width Dimensions

One of the key goals of this component was to determine whether highly diagnostic tool marks on bone, such as those allowing for the assessment of the class characteristics of an inflicting tool, can be expected to survive heat alteration at high temperatures or even calcination. Some tool marks, such as the ones described in the *Description of Coded Traits* section above, can help to identify class characteristics of the inflicting tool based on the presence/absence of a trait or based on general morphology. However, the evidentiary value of other traits derives from their metric properties.

Tool features such as teeth per inch, minimum blade width, and tooth size can only be inferred from metric traits such as the distance between tooth hops, the distance between pull out striae or minimum kerf width. As demonstrated in the previous section, during the burning process the bone tissue is subject to dramatic losses in water and organic matter content. Apart from bone weight, these changes can also result in changes in overall size (bone shrinkage), which may affect the dimensions of these metric traits and, therefore, their diagnostic utility.

On the other hand, if bone shrinkage may significantly affect relevant metric dimensions, these changes might affect either human or animal bone more severely, based on the differences in density and relative proportions of the organic and inorganic matrices observed in the previous section, thereby invalidating animal bones as an appropriate proxy for human bones in the study of these types of variables.

Finally, depending on how bone shrinkage affects metric dimensions, metric traits could lose all or some of their diagnostic value. For example, uniform shrinkage of the bone could bring both edges of a kerf close to one another. If this were the case, kerf width could still be indicative of minimum blade width (intuitively speaking, the minimum kerf width should not be smaller than the minimum width of the blade producing the kerf; Figure IV-15 and IV-16). On the other hand, a defect of this type also represents an area of low resistance to tension, so that the dense bone surfaces on both sides of the kerf could contract independently, pulling the kerf edges apart. The question posed here is if there is a great amount of shrinkage in the bone and therefore in the minimum kerf width could if affect the ability to determine the minimum blade width. In other words, can bone shrinkage create a situation in which a minimum kerf width measurement (and indirectly a minimum blade width calculation) be of by a great enough distance in which an inflicting tool would be falsely excluded from the pool of potential weapons used.

Thus, using kerf width as an example, the objective in this portion of the study was: 1) determining if significant changes in kerf width dimensions were evident after burning, and 2) determining whether there were significant differences in the degree of kerf deformation between the animal and human samples.

Research Design

All bone sections (seven bone sections) from *Data Source A* possessing a kerf defect created by either *Saw 101* or *Saw 104* were used (as explained above, *Saw 101* and *Saw 104* have extremely similar blade widths). *Data Source C* was represented by 25 bone sections also displaying 25 kerf defects.

As stated above, photographs were taken of the minimum kerf width of each bone section before and after furnace calcination (see description of the protocol in the previous section), using a *Leica MZ16 A* stereomicroscope with a 1/100th inch scale in the image. The scale was positioned perpendicular to the minimum kerf width of the false start (Figure IV-15).

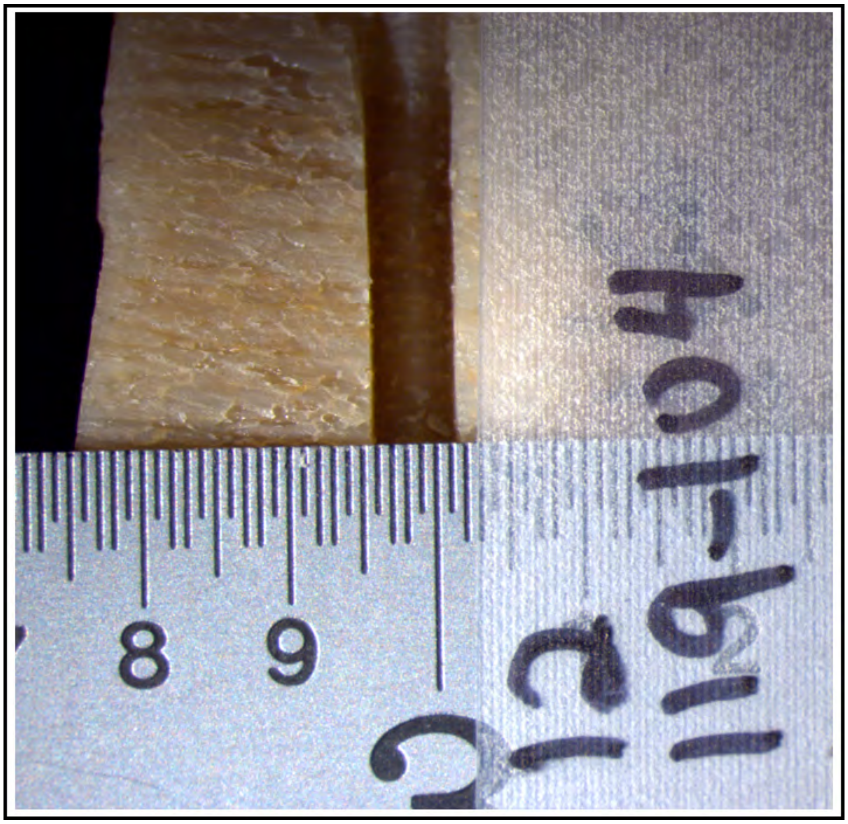
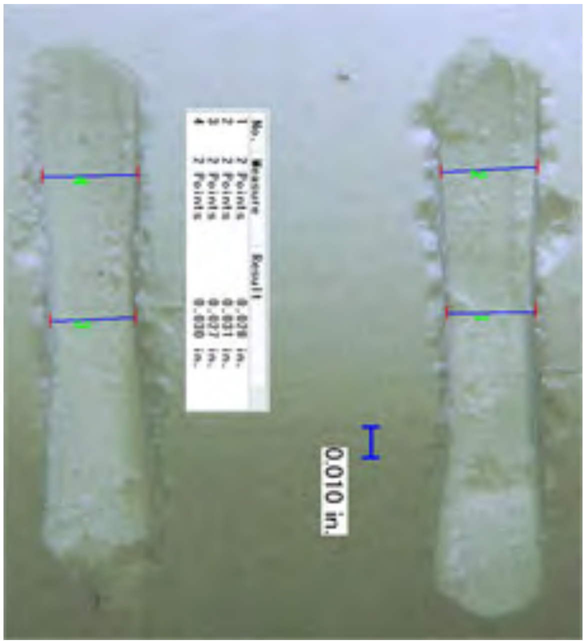


Figure IV-15. An example of an image taken with the stereomicroscope of the minimum kerf width including the bone section number. This bone section is from *Data Source A.*

All kerf widths (pre-burning and post-burning) were then measured from the photographs, with *ImagePro 5.1* software. The image file was opened in *ImagePro 5.1* and a scale was calibrated based on the 1/100 inch scale included in each photograph. After the scale was calibrated, the measurement, perpendicular to the kerf, was recorded (Figure IV-16).

Differences in pre- and post-burning kerf widths within each of the groups (*Data Sources A* and *C*) were then assessed from two different approaches. A t-test for repeated measurements was employed to test for significant within group differences in average kerf width between the pre- and post-burning images. A Wilcoxon test for paired observations was then used to assess directionality. In this application, the Wilcoxon test first calculates the difference between the pre- and post-burning dimensions and then tests whether the proportion of negative (kerf expansion) over positive (kerf shrinkage) values departs from randomness. A significant result in this test would therefore imply that the kerf width would tend to either contract or to expand in a consistent direction during cremation.



No.	Measure	Result
1	2 Points	0.028 in.
2	2 Points	0.031 in.
3	2 Points	0.027 in.
4	2 Points	0.030 in.

Figure IV-16. An example of a minimum kerf width measurement taken from a kerf created in calk. (Taken from previous NIJ grant report on sawmark analysis in bone.)

Finally, the animal and human bones were compared in term of the absolute values of the differences between each pair of observations, by means of a t-test for mean differences with Welch correction. This variable would express absolute deformation independently of whether this was positive or negative, even if deformation did not follow a consistent pattern (e.g. tending to contract more frequently than expanding), it would be possible that the bone of one of the two species tended to deform to a larger degree than the other.

Results

The main objective of this portion of the project was determining whether the same diagnostic traits used to detect, assess, and identify forensically significant perimortem trauma in non-burned bone, including the identification of class characteristics of the inflicting tool, are still effective after fire alteration. Ultimately, the question is whether the absence of certain class characteristics means that the tool typically producing those characteristics can be ruled out as the inflicting weapon or, on the contrary, exposure to fire is actually expected to significantly alter or even destroy the characteristics or traits. This component addresses this question for sharp trauma, through the analysis and documentation of saw marks in human bone and an animal model (*Sus scrofa* limbs), before and after burning in near real and laboratory conditions. Additionally, the study will evaluate the validity of the use of animal models for this kind of research, through the comparison of results obtained from animal and human limbs.

Both the *Data Source A* sample of human remains and *Data Source C* sample of animal bones received the exact same treatment, serving to compare the effects of fire on trauma class characteristics in human and animal remains. Additionally, the comparison of results from identical experiments in human and animal remains will serve to assess the validity for future research based on animal models. On the other hand, the comparison between bones from the same species (*Sus scrofa*), having received different treatments (controlled laboratory burning of fixed and defleshed bone in Data Source C, versus untreated, fleshed bone burned in real house fires in Data Source B), served to contrast the reliability of extrapolations from laboratory results to realistic scenarios, as well as the potential effect of elements such as bone fixation on the results.

Species Comparisons

Table IV-9 illustrates the total number of “presence” observations for the nine traits before and after burning for bone sections from *Data Source A*. Table IV-10 illustrates the total number of “presence” observations for the nine traits prior to and after burning for bone sections from *Data Source C*.

Table IV-9. Total number of "presence" observations for each trait for bone sections from *Data Source A.*

Trait	Pre-burn	Post-burn
Kerf Flare	5	11
Exit Chipping	42	38
B-A Spur	35	27
B-A Notch	24	22
Blade Drift	6	3
Tooth Hop	5	12
Pull Out Striae	2	1
Tooth Imprint/Floor Dip	4	8
# False Starts	57	58
Total # Traits Observed	***180***	***180***

Table IV-10. Total number of "presence" observations for each trait for bone sections from *Data Source C.*

Trait	Pre-burn	Post-burn
Kerf Flare	0	0
Exit Chipping	12	14
B-A Spur	11	11
B-A Notch	7	7
Blade Drift	6	7
Tooth Hop	6	10
Pull Out Striae	0	1
Tooth Imprint/Floor Dip	1	1
# False Starts	24	26
Total # Traits Observed	***67***	***77***

A comparison was done between the observed "presence" of specific traits before burning (pre-burn) and after burning (post-burn) for *Data Source A.* The frequency of each trait was then calculated in order to access the frequency in which individual traits were observed before and after burning (Table IV-11). There is an increase in total number of observed traits after the bone sections were burned, increasing from 67 observed traits to 77 observed traits. For *Data Source A* individual traits were never observed in higher frequencies before burning than after burning. In fact, for four traits (exit chipping, blade drift, tooth hop, and pull out striae) there was an increase in the number and frequency of observations in the bone sections after being burned. The conclusion is that not only are class characteristics and traits preserved but also in some cases they are actually easier to observe after exposure to burning in the human bone sample.

Table IV-11. Total number of "presence" observations for *Data Source A* before burning and after burning. Also listed is the frequency in which each trait is observed. Frequencies highlighted in yellow represent an increase in frequency of observed traits after burning.

Trait	Pre-burn	Frequency	Post-burn	Frequency
Kerf Flare	0	0.00%	0	0.00%
Exit Chipping	12	75.00%	14	87.50%
B-A Spur	11	68.75%	11	68.75%
B-A Notch	7	43.75%	7	43.75%
Blade Drift	6	85.71%	7	100.00%
Tooth Hop	6	37.50%	10	62.50%
Pull Out Striae	0	0.00%	1	6.25%
Tooth Imprint/Floor Dip	1	6.25%	1	6.25%
# False Starts	24	100.00%	26	100.00%
Total # of Traits Observed	*67*		*77*	

A comparison was then done between the observed "presence" of specific traits before burning (pre-burn) and after burning (post-burn) for *Data Source C.* The frequency of each trait was then calculated in order to access the frequency in which individual traits were observed before and after burning (Table IV-12). The total number of observed traits was the same before and after burning. There are three traits (kerf flare, tooth hop, and tooth imprint/floor dip) in which there was an increase in frequency of observed traits after burning. Unlike in Data Source A, more often there is a decrease in the frequency of observed traits after burning. However, the rate of destruction of traits is slight. The conclusion is that class characteristics and traits are preserved after exposure to fire. This comparison also provides evidence supporting the use of an animal model as an appropriate proxy for accessing preservation of class characteristics in saw trauma analysis.

Table IV-12. Total number of "presence" observations for *Data Source A* before burning and after burning. Also listed is the frequency in which each trait is observed. Frequencies highlighted in yellow represent an increase in frequency of observed traits after burning. Frequencies highlighted in purple represent a decrease in frequency of observed traits after burning. *Note: the decrease is slight in all cases.*

Trait	Pre-burn	Frequency	Post-burn	Frequency
Kerf Flare	5	16.67%	11	36.67%
Exit Chipping	42	70.00%	38	63.33%
B-A Spur	35	58.33%	27	45.00%
B-A Notch	24	40.00%	22	36.67%
Blade Drift	6	20.00%	3	10.00%
Tooth Hop	5	8.33%	12	20.00%
Pull Out Striae	2	3.33%	1	1.67%
Tooth Imprint/Floor Dip	4	6.67%	8	13.33%
# False Starts	57	100.00%	58	100.00%
Total Number of Traits Observed	*180*		*180*	

Table IV-13. Traits observed after burning that were not observed before burning.

Trait	Data Source A	Data Source C
Kerf Flare	0	18
Exit Chipping	2	5
B-A Spur	0	2
B-A Notch	0	3
Blade Drift	1	6
Tooth Hop	5	4
POS	1	0
Tooth Imprint/Floor Dip	1	4
# False Starts	2	4
Totals	12	46
Observations	12 out of 117	46 out of 450
Frequency	10.26%	10.22%

A comparison was made between the total number of observed traits after burning that were not observed before burning (Table IV-13). For Data Source A, 10.26% of all trait observations made were present after burning and not observed before burning. For Data Source C, 10.22% of all trait observations made were present after burning and not observed before burning. The gain in observable traits after burning is virtual identical (roughly 10%) for human and pig. This also provides evidence supporting that an animal model is a suitable proxy for accessing trait preservation and the analysis of sawmarks in humans.

A comparison was made between the total number of observed traits after before burning that were not observed after burning (Table IV-14). For *Data Source A*, 1.71% of all trait observations made were present before burning and not observed after burning. For *Data Source C*, 8.89% of all trait observations made were present before burning and not observed after burning, however, **these differences are not statistically significant** (χ^2=1.98, d.f.=8; p=0.98). This also provides evidence supporting that an animal model is a suitable proxy for accessing trait preservation and the analysis of sawmarks in humans, in spite of the higher density and surface area of the bone in the animal model. In the worse case scenario, if the observed differences in trait preservation had been statistically significant, observed trait losses in the animal model were actually larger than in human bone, making estimates obtained from the former conservative approximations to what can be expected in humans, therefore reducing type I error. Once again, this supports the idea that pig bones are an appropriate proxy for the study of saw marks in human bone.

Table IV-14. Traits observed before burning that were not observed after burning.

Trait	Data Source A	Data Source C
Kerf Flare	0	6
Exit Chipping	0	9
B-A Spur	0	2
B-A Notch	0	5
Blade Drift	0	12
Tooth Hop	1	3
POS	0	1
Tooth Imprint/Floor Dip	1	0
# False Starts	0	2
Totals	2	40
Observations	2 out of 117	40 out of 450
Frequency	1.71%	8.89%

Treatment Comparisons (Field vs. Laboratory Samples)

A comparison was made between *Data Sources B* and *C* in order to assess if the expected results from the controlled laboratory sample are comparable to the results seen in the field exercises under realistic conditions. Table IV-15 shows the observed number of traits for *Data Source B* compared to the expected number of observations, calculated from the results of *Data Source C*.

Table IV-15. Comparison of trait frequencies between *Data Sources B* and *C*. The expected values for the goodness-of-fit test are obtained by assuming that the frequencies observed in *Data Source B* would be identical to those obtained in the lab experiments (*Data Source C*) after burning. Note how in many cases the field sample actually exhibits a higher frequency of diagnostic traits than the laboratory sample. This indicates that the high degree of evidentiary trait preservation observed in the lab may actually be a very conservative estimate of the degree of preservation after burning expected in real fatal fire victims.

	Data Source B		
Trait	**Observed**	**Expected**	**# of Bone Sections**
Kerf Flare	6	3.67	10
Exit Chipping	9	19.00	30
B-A Spur	11	13.50	30
B-A Notch	11	11.00	30
Blade Drift	6	1.00	10
Tooth Hop	3	6.00	30
POS	4	0.50	30
Tooth Imprint/Floor Dip	2	4.00	30
Total	52.0	58.7	200

χ^2=161.9, p<0.001

In all samples collected all nine types of traits were still observed in the realistic *Data Source B*. The overall frequency of individual trait observations significantly differ between *Data Source B* and *C* (p<0.001). However the only type of trait that is significantly smaller in Data Source B is exit chipping, while most of the remaining traits (with particularly marked differences in the case of blade drift and pull out striae) are actually higher in the *Data Source B* sample (Table IV-15). Consequently, *Data Source C* proved to be not only a realistic representation of the expectations for diagnostic trait preservation in real/field conditions, but in fact a slight underestimation of potential evidence losses if the burned remains are not properly recovered and handled during scene processing.

Many of the differences between the two samples (*Data Source B* and *C*) can probably be explained by differences in the difficulty of cutting the defleshed bone (*Data Source* C) and fully articulated fleshed limbs (*Data Source B*). For example in the case of exit chipping, blade drift, and kerf flare, differences seen in the lab sample (*Data Source C*) versus the field sample (*Data Source B*) may be attributed to the relative ease of cutting a defleshed bone that has been fixed in a vice and a flesh fully articulated limb, as opposed to a more mobile fleshed and articulated limb.

Logistically speaking the *Data Source B* sample provided more difficulty in cutting than the *Data Source C* sample. Increased saw adjustments (including angle of cut and amount of force applied) would have been more common in the *Data Source B* sample due to an increased difficulty in cutting through the long bone limb of a freshed articulated pig limb. Traits such as blade drift and kerf flare (as defined in the *Methods* section above) are created by the movement of the saw blade while cutting through the bone. In the field sample we expect more difficulty in cutting through the limb and therefore more adjustments, we would then expect these types of traits to increase in frequency.

These results also remove a concern related to the potential bias introduced by laboratory bone pretreatment and chemical fixation. In case these elements could introduce some bias in trait preservation, the results indicate that it would be in any case by reducing trait preservation, as the fleshed bones burned under realistic conditions did in fact display higher frequencies for more traits.

Comparing Organic Compositions

The human and pig samples in data sources A and C did not show significant differences in initial wet weights (Welch-corrected t_{14}=0.0669, p=0.948) although, as mentioned above, the animal bones showed a much higher dispersion (Figure IV-17).

Wet (initial) weight was a perfect predictor of water loss in both samples, with perfect correlations (R=1, p<0.001). Animal and human bones did not show either differences in the slope of the relationship between wet and dry bone (Figure IV-17), this is to say, in the rate of increase of water loss per unit of wet weight ($F_{1,24}$=0.3977, p=0.534). However, they showed a significant, if small difference in the intercept ($F_{1,25}$ = 34.7826, p<0.001) with the human bones losing on average around 0.02 g more water content than animal bones, independent of initial weight (Figure IV-18). This is consistent with the higher density expected in animal bones, although the differences are almost negligible.

When dry versus ash weights were compared (indicative or organic matter content), no differences between samples were in the slope of the relationship ($F_{1,24}$=2.6448, p=0.117), this is to say, in the rate of organic content loss as dry weight increases. However, human bone lost much more organic matter on average (more than 0.6 g for any given initial dry weight, F1,25=12.103, p=0.002.) Dry weight was an almost perfect predictor of ash weight in *Data Source C* (animal), explaining more than 99% of the variance in organic matter loss (p<0.001), by just around 68% of variance explained in the human tissue (p<0.001.) These results are again indicative of the lower density of human bone, with a higher ratio of organic to inorganic matrix content.

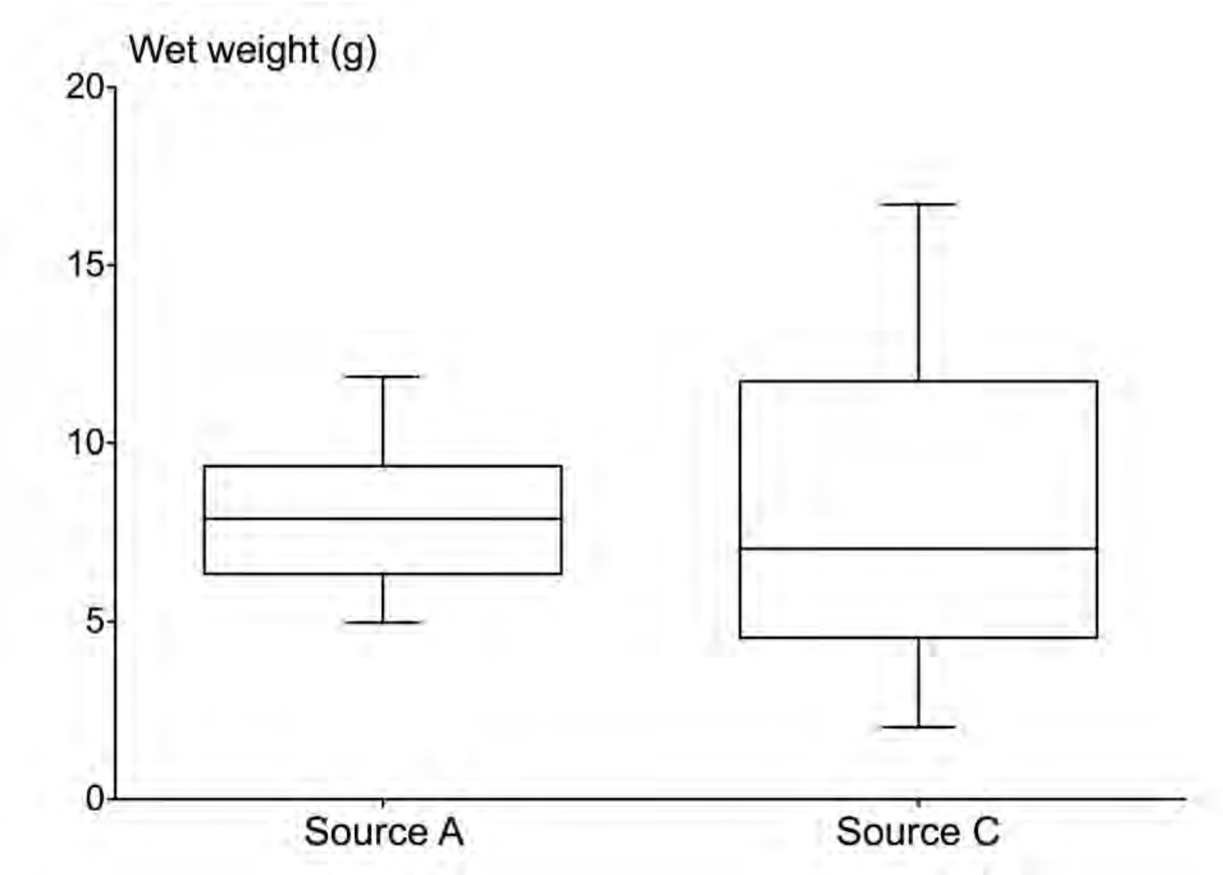
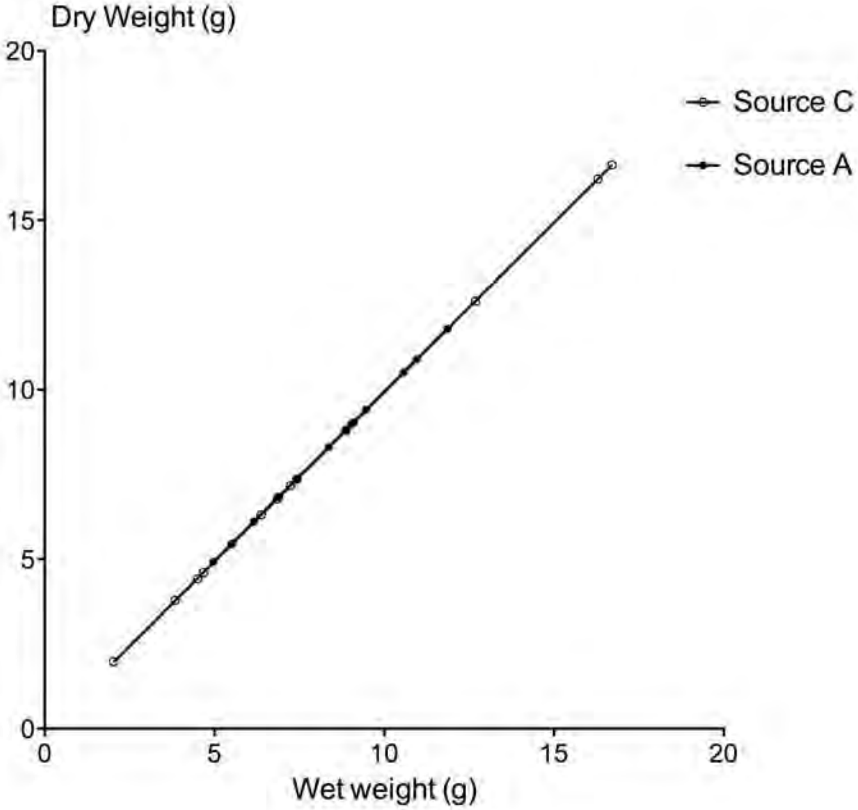


Figure IV-17. Initial (wet) weight distributions in the animal (*Source C*) and human (*Source A*) samples. No significant differences were found in average weight (Welch-corrected t_{14}=0.0669, p=0.948), although the animal sample displays a significantly larger variance ($F_{11,15}$=5.243, p<0.01.)



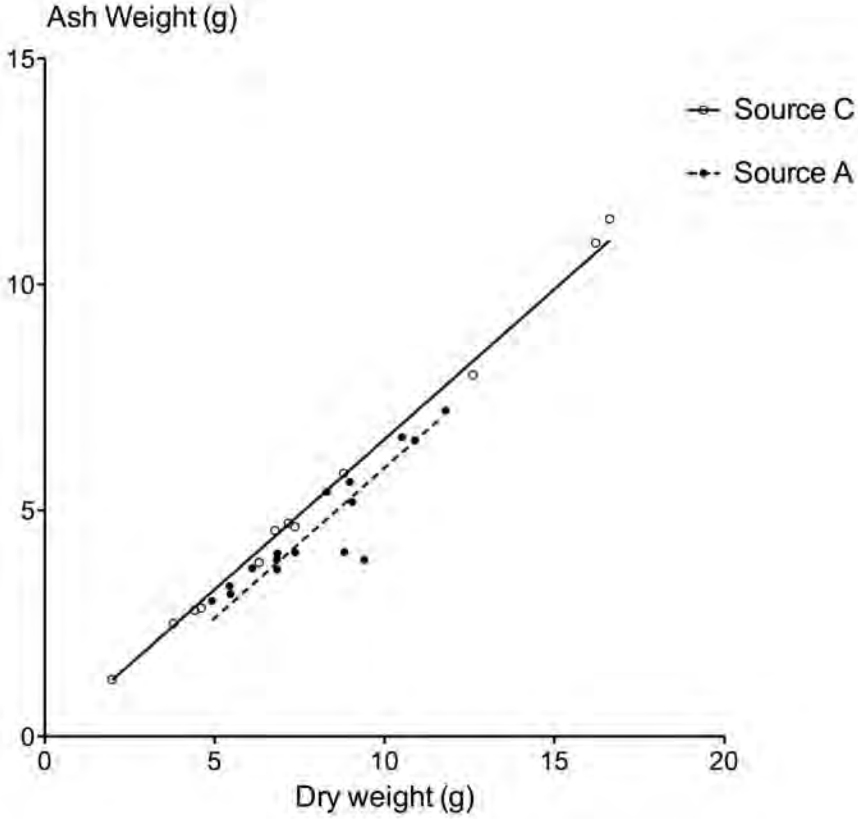


Figure IV-18. Above: Wet weight seems to explain all water loses at 60º with a perfect correlation between both parameters. As expected from its lower density, human bone (*Source A*) loses significantly more water than animal bone under this treatment, although the differences are almost negligible.
Below: Differences in organic matrix content loses at 500º are much more important than the initial water loses, with human bone losing on average more than 0.6 g of organic matter than a pig bone (*Source C*) of the same dry weight. This serves to quantify the differences in density between the animal and human samples employed in this study.

Minimum Kerf Width

No significant differences were found in average kerf widths before and after burning, either in pigs (t_{24}=0.5337; p=0.299) or in humans (t_6=0.2127; p=0.4193.) Neither pigs (p= 0.7468; Gaussian approximation) nor humans (p=0.6875; Gaussian approximation) showed any directionality, indicating that the kerfs did not tend to either contract or expand in a consistent manner.

Finally, no differences were found either between the degree of pre- to post-burn alteration of the human and animal samples (t_{11}=0.7258; p=0.2416, Welch corrected).

In sum, surprisingly, calcination does not seem to result in any definite pattern of changes in the dimensions of kerf defects, either in human or pig remains. As a matter of fact, the observed average absolute change in dimensions after burning is smaller than the respective standard deviations of kerf widths before burning (0.0043 for 0.0056 in humans, and 0.0055 for 0.0137 in suids), even with the small sample size of the human sample, with the assumption of the usually attached underestimation of the standard deviation. In other words, the differences in kerf width after and before burning are smaller than the variability observed in the original samples. Given that all the original cutmarks were inflicted with virtually identical blades, and thus the original differences between cutmarks can be positively attributed to measurement error or random noise, the apparent changes in pre- and post-burn dimensions can be attributed to the same sources.

These results indicate that (1) at least in the case of kerf width, extreme heat alteration does not seem to affect metric measurements, which therefore will conserve their diagnostic and evidentiary values, and (2) consequently pig bones are also a valid proxy to human remains when analyzing these metric traits.

Discussion

The analyses in this portion of the project confirm the idea that animal bones (in this case pigs) are an appropriate proxy for studying sawmark class characteristics in human bone, at least in controlled laboratory conditions such as those employed in this study. Even when differences between the human and animal samples in bone composition (in terms of water, organic and inorganic contents) were evident, these differences did not significantly alter either the preservation of diagnostic traits after burning, or their overall metric characteristics, such as kerf width.

More importantly, the data support the conclusion that class characteristics and traits are preserved in bone even after heat alteration. This fact provides impetus and support for proper field recovery and handling. Evidence of class characteristics is still present after cremation, which necessitates proper recovery in order to preserve the sawmarks in bone.

Actually, based on our observations from the field sample (*Data Source B*), the frequencies of diagnostic trait preservation after fire obtained from the lab sample (*Data Source C*) are probably very conservative estimates. Diagnostic traits are still visible even after exposure to extreme heat in both realistic and harsher laboratory conditions. Tissue shielding and other types of shielding observed in the realistic conditions likely explain why less heat alteration was observed overall in *Data Source B* than in both *Data Source A* and *C*. An increase in the variability of heat alteration and the range of overall alteration was observed in the *Data Source B* sample (Figure IV-2 above) as compared to *Data Source A* and *C*, which were evenly burned in controlled conditions.

Conversely, the diagnostic metric characteristics (highly indicative of potential overall shrinkage or dilation) analyzed in the study also showed to be surprisingly stable and resistant to heat alteration. All this again emphasizes how extreme caution should be taken in the recovery and preservation of remains in a fatal fire, as sharp trauma is still evident after a fire and the preservation of most of its evidentiary value and diagnostic characteristics is extremely likely, specially given factors such as tissue and debris shielding in real fires.

CHAPTER V

Conclusions

Discussion of Findings

Research Component 1

The results of the sections encompassed in *Component 1* (basically archival studies and mock scene exercises) have both negative and positive implications. The examination of archival records of past fire scenes revealed a high level of inconsistency and data losses beyond the most pessimistic initial expectations. Essentially, scene information appeared to be mostly recorded in a case-to-case anecdotal fashion, with the vast majority of case reports missing not only key elements for the anthropological analysis of human remains, but often also for the fire investigation.

Conversely, the mock scene exercises demonstrated that the classic fire scene recovery protocols are extremely prone to result in information and evidence losses. The upturn is that the new protocols developed in this research demonstrated that a fatal fire scene could be completely excavated, with comprehensive documentation, high evidence detection and recovery rates, as well as minimal evidence alteration in a matter of days, rather than weeks. Results indicate that a complex scene, like a two-story house that has burned to collapse, can be processed and documented in two to three days and a mobile home in one to two days.

The high rate of evidence recovery, as well as the identification of spatial and stratigraphic patterns attained during the mock scene exercises also demonstrated that these elements could still be detected, identified and analyzed even after aggressive fire suppression efforts.

Research Component 2

The results of *Component 2* demonstrate that regular, clear normal patterns of heat alteration of the human body can both be identified and successfully employed to detect suspicious cases. In particular, the agreement between the patterns observed in funerary cremations and those inferred from regular case documentation strongly indicate that efficient and systematic case documentation, analysis and comparison may represent the most promising research line to improve our understanding of heat related trauma to the human body.

Concurrently, the information provided by thermocouple readings from fire structures, illustrating the dynamic nature of temperature regimes in and around the body, coupled with the crematory observations on the influence of body position and posture on burn patterns further stresses the importance of careful scene documentation and processing.

Research Component 3

Research Component 3 provided clear answers to two main questions, relevant both for forensic practice and future research. First, the high rate of preservation even after calcination of forensically significant tool marks indicates that it is extremely erroneous to assume that fatal fire scenes can be processed more rapidly than conventional ones, or using substandard recovery protocols, as most evidence is destroyed. Actually, diagnostic traits indicative of the class characteristics of the tools used to inflict trauma on bone appear to be easier to detect and identify in burned bone. Due to the brittleness of burned bone, special care should be taken during scene recovery in order to minimize the potential damage to this type of evidence. On the other hand, the mimetic appearance of burned remains, which during a fire acquire a coloration and texture identical to the substrate, would advise the presence of forensic specialists trained to identify burned human bone at the scene, from the very early stages of identification.

The combination and internal consistency of the temperature ranges and conditions recorded in and around the bodies in the mock scene exercises, those at the crematoria and the laboratory and the preservation rates of both skeletal elements and bone surface marks observed in the later, strongly indicates that attributions of missing limbs or major elements to complete destruction by the fire must be very cautiously proposed, when not completely abandoned in the forensic practice.

Secondly, the results of the furnace experiments indicate that animal bones (at least in the case of domestic pigs) can serve as an efficient proxy to study sharp trauma on burned bone, in spite of the differences in density and composition between both types of bone.

Implications for Policy and Practice, as Well as Future Research

On the whole, the results obtained in the present project can be summarized in four major points relevant for forensic policy and practice. The study demonstrates that: 1) significant osteological evidence and its contextual relationships are still preserved in a fatal fire scene, and this evidence can and is frequently lost or damaged when the classic scene processing protocols are applied; 2) heat alteration of the human body follows clear, normal and regular patterns, which can be detected and inferred through different means, both experimentally and through the proper documentation of forensic cases, and can serve to identify potential criminal cases as departures from these patterns; 3) at the laboratory level, key diagnostic traits indicative of the type of trauma as well as of the tool used to inflict such trauma, can be preserved and analyzed in burned human remains, with little or no loss of their analytical value; and 4) animal bones can serve as a valid proxy for human remains for the purpose of sharp force trauma research.

The first three points place emphasis on the necessity of improving fatal fire scene processing, in order to minimize the loss, alteration or destruction of forensically relevant evidence. These points also indicate a need for the documentation of fire scene, fire response and body alteration in order to facilitate both ongoing forensic investigations and future research. Within this framework, this study provides:

1) Rigorous and detailed fire scene processing protocols, tested in the field demonstrating optimal evidence recovery rates. Their application in mock fires and real crime scenes have also demonstrated that they are realistically applicable to most fatal fire scenes, resulting in processing times that do not significantly exceed those of a common forensic scene, in spite of the much higher complexity of fire scenes. This is expected to benefit the analyses of all professionals involved, from anthropologists, to arson, and fire investigators. The enhanced contextual data and evidence integrity (precise body position, detection and recovery of *all* bone elements, relationship of other physical evidence to the body) will benefit the morgue/laboratory analysis of burned human remains, and the final determination of the events surrounding death.

   Furthermore, the standardized data collection forms provided in this report are aimed at enhancing and simplifying fire scene documentation and information sharing, allowing for rapid comprehensive documentation of all aspects relevant to the investigation not only of the human remains but also of the fire, without adding additional burdens to responders and investigators. The standardization of data coding and collection, as well as the integration of all scene data in a single dataset are expected to enhance team collaboration and coordination.

2) The normal heat alteration patterns observed in *Component 2* provide a baseline for the detection and analysis of atypical cases departing from this patterning, which may be indicative of criminal activities.

   Additionally, precise step-by-step explanations of the mapping and analysis process employed to produce the general patterns in this study are provided, allowing for their replication and refinement by other researchers and investigators. The clarity and explanatory power of the patterns has been found to depend largely on sample size, and our knowledge of heat alteration patterns would benefit enormously from new additions and samples.

3) The research protocols described in *Component 3*, paired with the demonstrated validity of animal models to approximate the response of human bones, open a wide window for the replication and further enhancement of laboratory research in this field. In particular, the forensic community would benefit from more detailed metric analyses, as well as the exploration of the effect of fire on the evidentiary value of other types of skeletal trauma.

In the same line, while the project demonstrates the utility as well as the research and inter-disciplinary information sharing opportunities of fire response training exercises, it also showed the difficulties for obtaining large sample sizes by a single team. Issues with the placement at the scene of obtrusive equipment like thermocouple wires, exercise scheduling, or funerary cremation donations evidenced the difficulties of obtaining large sample sizes under tight schedules. However, the number of these exercises, extremely common in the US, would allow for the compilation of large sample sizes and extremely useful information if approached from a clinical trial strategy. This is to say, combining the effort of a large number of teams who would collect and share the information following standardized protocols and data formatting.

We would like to close this report encouraging law enforcement officials, fire responders and investigators to contact each other and collaborate in these types of exercises in their jurisdictions. Simple additions, like introducing animal models to simulate human victims and processing the scene together, in multidisciplinary teams, discussing the needs and approaches of each group can result in extraordinary information gains and a very rewarding experience, apart from serving to improve exponentially our preparedness for the response to this type of scenario. Whenever the technology is available, additional data, like basic thermocouple readings, are enormously useful and needed. Of course, we also invite any fire or scene investigator, or fire responder, to contact us to ask for any additional advice, information or assistance.

CHAPTER VI

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CHAPTER VII

Dissemination of Research Findings

The investigators of this project have had the opportunity to disseminate information on proper fatal fire scene recovery protocols as well as soft tissue and skeletal trauma analysis of heat altered human remains to a vast network of professionals in fire investigation as well as other areas of forensic science. Workshops and lectures in the early phases of the project provided impetus for the creation and modification of the fatal fire scene processing protocols. One of the objectives of the investigators was to reach out to other professionals involved in the investigation of fatal fire scenes to gain feedback on current practices, current deficiencies, and to better understand the importance of specific protocols for the investigation of the cause and manner of the fire. During these workshops, lectures, and discussions the investigators of the project were able to garner a better understanding of the procedures and goals of fire scene investigators and fire fighters. Information gleaned regarding current practices was used to justify and shape the current proposed scene processing protocols based on forensic archaeology.

Over the last few years, one of the primary consultants (GOO) has delivered over 40 lectures and presentations pertaining to fatal fire scene recoveries utilizing forensic archaeology. Recently, the Canadian Police Research Centre published his Master's thesis on proper fatal fire scene recovery based on forensic archaeological methodologies. His thesis has also been published in the magazine for the Canadian Association of Arson Investigators (CAFI), which was distributed to all CAFI members and every fire department in Canada.

The proper handling and transportation of human remains to the autopsy or laboratory is another area of concern in this project. The ability of the investigators and forensic anthropologists to reconstruct a scene and interpret trauma is solely dependent upon proper recovery and documentation efforts. Through lectures and workshops the investigators of this project were able to disseminate imperative information regarding differentiating perimortem trauma from taphonomic influences caused by fire in human remains. The project has provided evidence that perimortem trauma can be distinguished from postmortem taphonomic influences of fire. Research has also provided a better understanding of burn pattern recognition. All information collected and analyzed during the project period will be published and distributed throughout the scientific and forensic community.

Table VII-1 below lists major dissemination milestones that have been completed for this project.

Table VII-1. Dissemination of project and project findings.

Date	Description	Author
March 2008	Workshop. Adams County Department of Emergency Services. Fatal Fire Recovery Techniques and the Analysis of Burned Human Remains. Workshop in conjunction with Tripwire. Gettysburg, PA.	DCD SAS
May 2008	Workshop. Office of the Chief Medical Examiner. Fatal Fire Recovery Techniques and the Analysis of Burned Human Remains. Workshop in conjunction with Tripwire. Norfolk, VA.	DCD SAS
May 2008	Workshop. Chester County Government Services Center. Fatal Fire Recovery Techniques and the Analysis of Burned Human Remains. Workshop in conjunction with Tripwire. Chester County, PA.	DCD SAS
May 2008	Workshop. Lyndora Volunteer Fire Company. Fatal Fire Recovery Techniques and the Analysis of Burned Human Remains. Workshop in conjunction with Tripwire. Lyndora, PA.	DCD SAS
June 2008	Workshop. Department of Public Safety. Fatal Fire Recovery Techniques and the Analysis of Burned Human Remains. Workshop in conjunction with Tripwire. Montoursville, PA.	DCD SAS
Sept 2008	Workshop. Northwest Pennsylvania Emergency Response Group. Fatal Fire Recovery Techniques and the Analysis of Burned Human Remains. Workshop in conjunction with Tripwire. Erie, PA.	DCD SAS
Nov 2008	Workshop. Alleghany County Emergency Operations Center. Fatal Fire Recovery Techniques and the Analysis of Burned Human Remains. Workshop in conjunction with Tripwire. Pittsburgh, PA.	DCD SAS
Feb 2009	Presentation at the Annual Bite Mark Breakfast entitled “Broken bones, bites, taphonomy, and tool marks: Getting more from traumatized bones.” Presented at the AAFS annual meeting. Denver, CO.	SAS
Feb 2009	Presentation entitled “The Recovery of Human Remains From a Fatal Fire Setting Using Archaeological Methodology”. Presented at the AAFS annual meeting. Denver, CO.	GOO
Feb 2009	Presentation at Fanshawe College for a law enforcement course. Presentation on the recovery of human remains in a fatal fire using archaeological methods. London, Ontario.	GOO
March 2009	Two hour lecture at the Ontario Police College for a Homicide Investigators Course. Presentation on archaeological methods at the fatal fire scene. Aylmer, Ontario.	GOO
March 2009	Lecture to undergraduates at the University of Ontario Institute of Technology on fatal fire investigations and recovery. Oshawa, Ontario.	GOO
March 2009	Lecture to undergraduate forensic course at the University of Toronto on fatal fire investigations and recovery. Toronto, Ontario.	GOO
April 2009	Workshop at California State University, Chico. Chico Forensics Conference, hosted by the Department of Anthropology. Presentation on traumatized bone. Chico, CA.	SAS

May 2009	Traveled to Bogotá, as an instructor for ICITAP, a US government agency that assists with forensic training for local professional. Presentations and workshops on traumatized bone. Bogotá, Columbia.	SAS
May 2009	Traveled to Medellin to examine potential human rights atrocity victims for Equatas. Medellin, Columbia.	SAS
May 2009	Lecture to undergraduates at the University of Ontario Institute of Technology on fatal fire investigations and recovery. Oshawa, Ontario.	GOO
May 2009	Lecture to undergraduate forensic course at the University of Toronto on fatal fire investigations and recovery. Toronto, Ontario.	GOO
May-June 2009	Series of five lectures to five platoons of Identification and Scenes of Crime officers at the Toronto Police Forensic Identification Bureau. Toronto, Ontario.	GOO
June 2009	Conducted two, one-week Recovery of Human Remains courses at the Ontario Police College. Presentations included fire scene recovery protocols. Aylmer, Ontario.	GOO
June 3, 2009	Presentation and workshop at the Ontario Police College for investigators. Presentation and workshop on traumatized bone. Aylmer, Ontario.	SAS
June 11, 2009	Lecture at the annual meeting of the Pennsylvania State Arson Investigators Organization regarding recovery and analysis of burned human remains. State College, PA.	SAS DCD
June 23, 2009	Lecture given to the AFIP and NTSB for their annual Forensic Anthropology short course. Dulles, VA.	SAS
June & July 2009	Two hour lecture at a Pre-Fire Fighter Program at Georgian College. Lecture on arson recovery and the recovery of human remains in fatal fires using archaeological methods. Barrie, Ontario.	GOO
June 2009	Lecture given during 5-day Short Course: Field Recovery Methods in Forensic Anthropology. Mercyhurst College, Erie, PA.	DCD
June 2009	Lecture given during 5-day Short Course: Post Bomb Blast. Mercyhurst College, Erie, PA.	DCD
2009	Lecturer, National Transportation Safety Board Mass Fatality Course, Ashburn, VA.	DCD
15 Feb 2010	Facilitator, National Forensic Academy and Law Enforcement Training Academy. Practical instructor and speaker on Bone Trauma for one day of a quarterly 10 week training course, Knoxville, TN.	SAS
22 Feb 2010	Co-Char, Workshop for the American Academy of Forensic Sciences, Taphonomy of Bone Destruction: Information Lost, Information Gained.	SAS
4-6 Mar 2010	Keynote Speaker, The Richard Frucht Memorial Lecture Series and Student Conference. Public lecture, faculty lecture, and half-day workshop. University of Alberta, Department of Anthropology, Edmonton, Alberta.	SAS
20 Mar 2010	Taught a one-week seminar on bone trauma analysis to the Guatemala Forensic Team and other professionals. Guatemala City, Guatemala.	SAS
18-24 Apr 2010	Organizer and lecturer, Pennsylvania State Coroner’s Basic Education Training Course. A 40-hour course for newly elected Pennsylvania state coroners and deputy coroners. Hershey, PA.	DCD

20 Apr 2010	Invited lecturer for the Annual Medicolegal Investigation of Death Conference sponsored by Dr. Werner U. Spitz. Dearborn, MI.	SAS
21-23 Apr 2010	Lecturer for the annual Pennsylvania State Coroner's Training Course. Hershey, PA.	SAS
22 Apr 2010	Lecturer, at the Kentucky Coroner's Association Annual Meeting. Louisville, KY.	DCD
26-30 Apr 2010	Taught a five-day seminar for the team members of the Equipo Argentino de Anthropologia Forense, sponsored by Luis Fondebrider. Buenos Aires, Argentina.	SAS
1-4 May 2010	Taught a four-day seminar for the Servicio Medico Legal and the University of Chile anthropology students, sponsored by Alejandra Jimenez Mora, Coordinator for the Human Rights Program, Ministry of Justice of Chile, Santiago.	SAS
1-5 June 2010	Organizer and lecturer, annual forensic archaeology summer short course at Mercyhurst College. A one-week course on recovery at the outdoor crime scene sponsored by the Department of Applied Forensic Sciences. Erie, PA.	DCD
6 Jun 2010	Lectured to the Armed Forces Institute of Pathology and National Transportation Safety Board for their annual Forensic Anthropology short course. Dulles, VA.	SAS
19 June 2010	Lecturer, Dialogues in Forensic Science: Looking to the Future of Forensic Anthropology at the University of Syracuse. Syracuse, NY and Blue Mountain Lodge in Old Forge, NY.	DCD
12 Jul 2010	Lecturer, Mercyhurst College Global Intelligence Forum (Best Analytic Practices): The Dungarvan Conference. Dungarvan, Ireland.	DCD
2010	Lecturer, Mass Disaster Protocols, The NIJ Conference 2010, Arlington, VA.	DCD
2010	Lecturer, Pennsylvania Association of Arson Investigators Continuing Education Course, Quakerstown, PA.	DCD
February 2010	Paper entitled "Using Spatial Analysis to Recognize Normal and Abnormal Patterns in Burned Bodies," to be presented at the annual meeting of the American Academy of Forensic Sciences in Chicago, IL.	CLF
February 2010	Paper entitled " New Forensic Archaeological Recovery Protocols for Fatal Fire Scenes," to be presented at the annual meeting of the American Academy of Forensic Sciences in Chicago, IL.	ARK

DCD: Dennis Dirkmaat; SAS: Steven Symes; GOO: Gregory Olson; ARK: Alexandra Klales; CLF: Christina Fojas

APPENDIX II-1. Data Collection Form Employed for the Archival Pilot Study

*Note: the form has been condensed from the original one, removing filling spaces and check boxes, for formatting purposes. The new data collection form and database include variable codes, that will be displayed as scrolling list menus, reducing the need for written notation.

Statistics Data Collection Form

(1) Structure:

Type of structure:

Square footage:

Roof style and material:

Date of construction:

Material used in structure construction:

Amount of destruction:

Number of windows/doors:

(2) Excavators:

Number of excavators involved in recovery:

Background education and training of excavators:

Start/Finish times for each excavator:

Number of hours on scene for each excavator:

(3) Fire Service:

Fire Service response time:

Distance from the Fire Service to fire scene:

Was the Fire Service a fulltime station or volunteer?

Classification of the fire:

(3) Fire Service (cont)

Were there charges laid in this fire:

If so, number of individuals charged and charges laid:

(4) **Human Remains And Context**

Number of deceased persons located within the structure:

Condition of deceased persons: (calcined etc.)

Location of deceased within the structure:

Inventory of deceased persons: (osteological inventory) (outstanding remains or all accounted for)

Was there a strata correlation made by excavators?

Where were the deceased persons located within the debris strata?

What was the approximate distance of the deceased persons from the nearest means of egress?

Were there associated artifacts located near or in association to the deceased persons, if so what artifacts were located? (I.e. Fire extinguishers, accelerants, sources of ignition etc.)

What form or forms of measurement were utilized? (Tape measure, total station etc.)

Cause of death for deceased persons:

Extent of thermal injuries and placement on deceased persons:

Carbon monoxide levels for deceased persons:

(5) **Other Agencies Involved:** (i.e. TSSA, ESA etc.)

(6) **Smoke Alarms:**

Present:

Number present:

Type and placement:

Were they fully operational, if not, why not?

(7) **Human behavior of fire victims if able to determine:**

APPENDIX II-2. Example of Mock Scene: Results and Procedures

COMPARATIVE STRUCTURE FIRE #3

OBJECTIVE: Determining what evidence/remains students with both education and experience in the fields of archaeology and Osteology can locate with the use of a proper grid-style search in a fire ravaged structure as compared to a search conducted by persons with a fire fighting background.

DATE: 23-25 November 2007

DESCRIPTION: Single-story wood frame farmhouse – 100 to 110 years old.
Pitched roof with asphalt shingles.

ARTIFACTS:
(1) 2 pig cadavers – 60 to 70 lbs.
(2) 20 pig limbs of various sizes (with stainless steel tags)
(3) 2 rifles
(4) 1 rifle bolt
(5) 3 shotgun shells (red)
(6) 6 handgun shells
(7) 12 2' x 2' carpet sections (with stainless steel tags)

SUMMARY: This wood frame farm house was “prepared” on 23 November 2007 with the above noted artifacts placed indiscriminately throughout the main floor and corresponding rooms. The artifacts were photographed in place while the structure was “wired” with thermocouples.

Personnel from the Centre of Forensic Sciences, Toronto, placed 12 2' x 2' pieces of carpet containing samples of alcohol. Each carpet sample was tagged with a stainless steel tag.

On 24 November 2007, the fire control officer with the fire department poured a quantity of gasoline inside the main structure and caused it to be set on fire by the external application of a common road flare. The initial reaction of fire to gasoline caused a predictable “push” inside the structure with the thermocouples registering an immediate 600° Celsius increase within the interior temperatures.

The structure grew from the incipient stage into a fully working structure fire within fifteen minutes. The building was allowed to totally burn to the ground before some measure of suppression was applied. The total time of the burn was slightly in excess of one hour.

On 25 November 2007, a crew of volunteer fire fighters commenced a pedestrian search of the structure remnants with a pre-search briefing, which involved a homicide scenario. All or any artifacts/remains were then flagged and the search was concluded.

Following this initial primary search by the fire crew, 13 fourth year archaeology students from an area university commenced setting up an archaeological style grid over the fire debris by the utilization of tape measures, chaining pins and colored string. The artifacts located initially by the fire crews were measured, mapped and removed. Once this was done, the students, who also have an osteological background, commenced the scene excavation, GRID by GRID and the debris run through a ¼ “ screen.

All artifacts/remains located by the students were also measured, mapped and removed from the areas where they were located.

Once the secondary search was completed, the artifacts/remains located by both search teams were compared and documented.

RESULTS:

FIRST CREW	SECOND CREW
7 pig limbs/tags	1 - rifle bolt
	1 - Shotgun shell
	2 - Rifle barrels
	12 - Pig limbs
	7 - Steel tags/carpet samples
	3 - Handgun casings
	2 - Pig cadavers
	1 - Shotgun shell

NOTE: the handgun casings and shotgun shell were found during the screening process, along with two pig limbs the remainder were found *in situ.* The carpet sections were totally destroyed in the fire leaving the stainless steel tags.

THERMOCOUPLE READINGS:

During the course of this structure fire, there were six thermocouples placed throughout the structure at various heights, four of which were associated to the pig cadavers both on top and underneath. The data logger unit, situated a short distance from the fire recorded the internal structure temperatures in ten second intervals. With the utilization of an accelerant, the temperature immediately climbed from 4° Celsius to 577° Celsius in 10 seconds before dropping to a predictable level to just below 200° Celsius in just a few moments.

The internal structure temperatures continued at this level for approximately eighteen minutes where there were visible upward spikes, although slight, they continued to rise while the fuel load within the structure reached ignition temperatures and became fully involved.

Interestingly enough, the thermocouples placed under the pig cadavers remained at a constant low temperature throughout the fire until approximately the forty minute mark, where the internal temperatures reached in excess of 1100° Celsius where the thermocouples became compromised with heat and fire impingement.

Appendix II-3: Example Progression of Mock Fatal Fire Scene Recovery

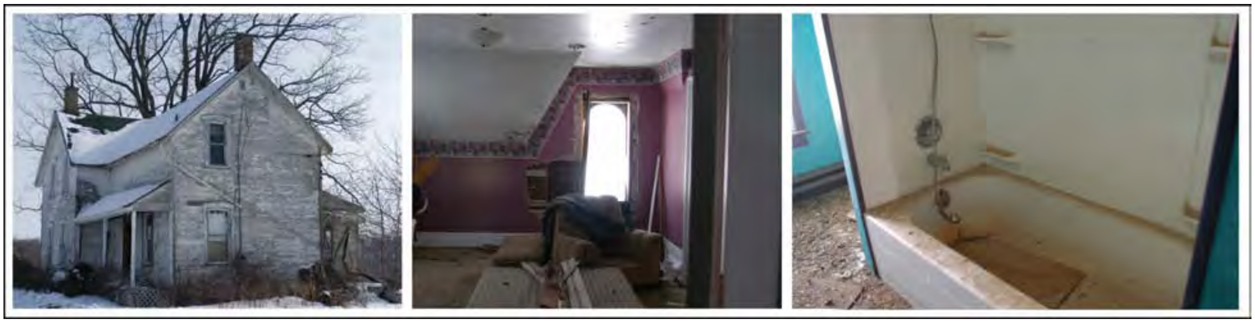


Figure 1. Pre-planning and documentation of structure inside and out.

Figure 2. Documentation of structure, remains, and physical evidence.

Figure 3. Day of the fire planning and preparation.

Figure 4. Fire progression. (A-C) Initial ignition of structure with a road flare. (D-E) Within minutes of ignition. Temperature readings being taken (E). (G-I) Fire progression. (J-L) In a little over two hours all walls of the structure had collapsed and the structure had burned to the ground.

Figure 5. Fire investigator walk through during initial search. Flag any remains and evidence identified.

Figure 6. Strategy planning and instruction of recovery team. Initial search of structure conducted, flagging any remains and evidence found.

Figure 7. Written, photographic, and GPS documentation of scene and structure continued throughout.

Figure 8. Initial excavation and removal of debris.

Figure 9. Excavation and removal of debris surrounding remains and physical evidence.

Figure 10. Pre-sorting of debris on tarps and archaeological screening process.

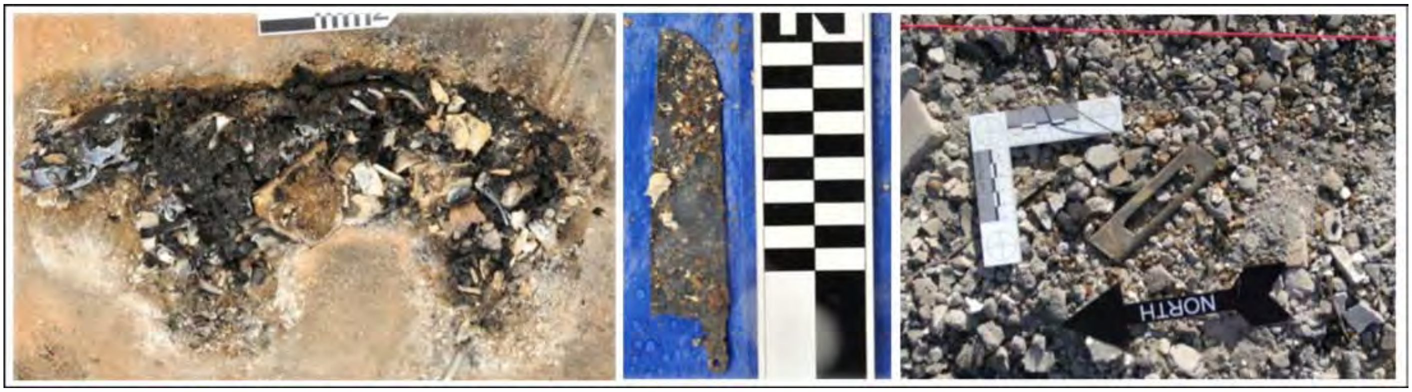
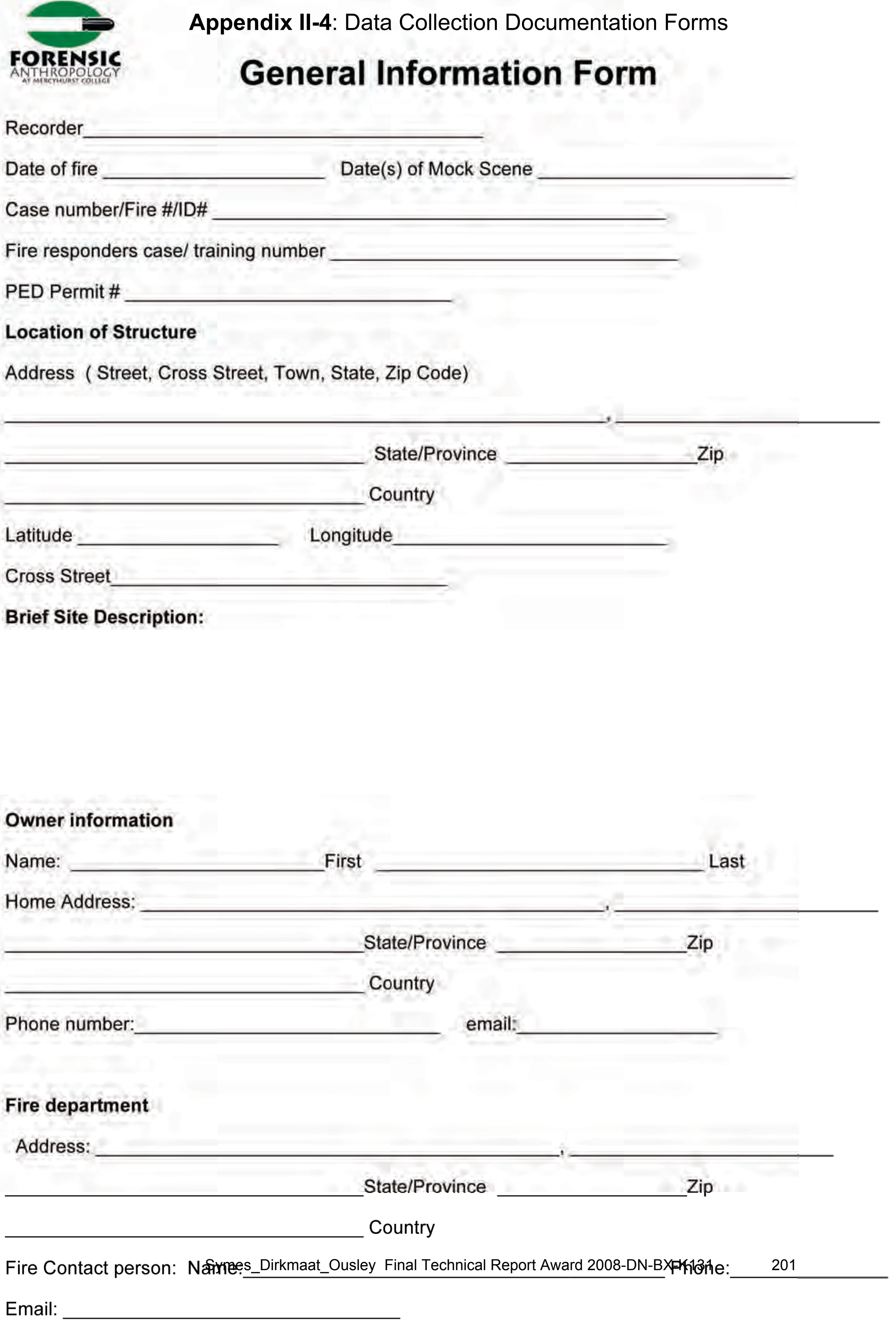


Figure 11. Photographic documentation of remains and physical evidence found *in situ.*

Figure 12. Hand-drawn map production of remains and other physical evidence *in situ.*

Figure 13. Evidence collection, final evaluation of site, and overall documentation of completed scene.

Appendix II-4: Data Collection Documentation Forms



General Information Form

Recorder ______________________________

Date of fire ________________ Date(s) of Mock Scene ____________________

Case number/Fire #/ID# ________________________________

Fire responders case/ training number ________________________

PED Permit # ________________________

Location of Structure

Address (Street, Cross Street, Town, State, Zip Code)

____, ____________________

__________________________ State/Province ______________ Zip

__________________________ Country

Latitude _______________ Longitude ____________________

Cross Street _________________________

Brief Site Description:

Owner information

Name: __________________ First ________________________ Last

Home Address: __________________________________, ____________________

__________________________ State/Province ______________ Zip

__________________________ Country

Phone number: ______________________ email: _______________

Fire department

Address: __________________________________, ____________________

__________________________ State/Province ______________ Zip

__________________________ Country

Fire Contact person: Name: ______________________________ Phone: ______________

Email: _________________________

Volunteer Fire Department ☐ Full time Fire department ☐

Other agencies/groups involved:

Name	Agency	Phone Number & Email Address
1.		
2.		

Photos/Video prior to burn

- ☐ Aerial photos/google maps
- ☐ Interior Photos
- ☐ Exterior Photos
- ☐ Interior Video
- ☐ Exterior Video

Scene mapped before burn

- ☐ Total station
- ☐ Sketch
- ☐ Blueprints
- ☐ GPS

Electricity tuned off ☐

Electric Company Name: Phone Number:

Gas off ☐

Gas Company Name: Phone Number

Number of people present: _______Fire _______ Mercyhurst ______ other School

______ volunteers _______ visitors

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Room Description Form

Case #
Date:
Recorder:
Page _____ of _____

Room:

- ☐ Attic
- ☐ Basement
- ☐ Bathroom 1
- ☐ Bathroom 2
- ☐ Bathroom 3
- ☐ Bedroom 1
- ☐ Bedroom 2
- ☐ Bedroom 3
- ☐ Bedroom 4
- ☐ Closet
- ☐ Dining Room
- ☐ Enclosed Porch/Sun room
- ☐ Family Room/Den
- ☐ Foyer
- ☐ Garage
- ☐ Great Room
- ☐ Kitchen
- ☐ Laundry
- ☐ Living Room
- ☐ Office
- ☐ Other:

Description of the room:

Square footage of room:

Number of Openings/Windows:

Number of Room Openings (no door):

Total number of doors:

Number interior doors:

Number exterior doors:

Fire alarm: Wired: Y N

Present: Y N

Interior Construction

- ☐ Gypsum board (Drywall)
- ☐ Lath and Plaster
- ☐ Masonry
- ☐ Concrete
- ☐ Exposed Wood
- ☐ Other

Type of insulation

- ☐ Cellulose
- ☐ Fiberglass
- ☐ Other:

Ceiling Construction

- ☐ Concrete
- ☐ Drop/False ceiling
- ☐ Gypsum board
- ☐ Lath and Plaster
- ☐ Other:

Floor Construction

- ☐ Combustible
- ☐ Noncombustible

Case #
Date:
Recorder:
Page _____ of _____

Wall Covering

- ☐ Cement/Cinder blocks
- ☐ Paint
- ☐ Paneled wood
- ☐ Plaster or stucco
- ☐ Tile
- ☐ Wall paper
- ☐ Other
- ☐ Not Present

Window Covering

- ☐ Vertical Blinds
- ☐ Horizontal Blinds
- ☐ Curtains Type:
- ☐ Other:
- ☐ Not present

Floor Covering

- ☐ Carpet
- ☐ Hardwood
- ☐ Ceramic Tile
- ☐ Concrete
- ☐ Stone/Brick
- ☐ Vinyl
- ☐ Linoleum
- ☐ Laminate
- ☐ Area Rug

Appliances in the Room

- ☐ Air Conditioner
- ☐ Bathtub
- ☐ Computer
- ☐ Dishwasher
- ☐ Dryer
- ☐ Fan
- ☐ Fireplace
- ☐ Freezer
- ☐ Furnace
- ☐ Heater
- ☐ Light- Ceiling
- ☐ Light- Lamp
- ☐ Light- Wall
- ☐ Microwave
- ☐ Radiator
- ☐ Refrigerator
- ☐ Shower
- ☐ Sink
- ☐ Stove/Oven
- ☐ Television
- ☐ Toilet
- ☐ VCR/DVD
- ☐ Washing Machine
- ☐ Water Heater

Furniture in the Room:

- ☐ Armoire
- ☐ Bed Frame
- ☐ Bookcase
- ☐ Box spring
- ☐ Buffet/Hutch
- ☐ Chair (__ #)
- ☐ Chair- Reclining Chair
- ☐ Chair- Upholstered
- ☐ Chair- Leather
- ☐ Chair- Metal
- ☐ Chair- Wooden
- ☐ Couch/Sofa
- ☐ Desk
- ☐ Dresser
- ☐ Entertainment Stand
- ☐ Filing Cabinet
- ☐ Mattress
- ☐ Mirror
- ☐ Night Stand
- ☐ Ottoman
- ☐ Sofa- Loveseat
- ☐ Table
- ☐ Table- Coffee Table
- ☐ Table- Side Table

☐ **Debris in the Room :**

Additional Notes/ Measurements:

Case #
Date:
Recorder:
Page _____ of _____

Fire Form

Weather Conditions
Brief weather description at the scene:

Weather/General condition

- ☐ Cloudy/overcast
- ☐ Sunny
- ☐ Partly cloudy
- ☐ Raining
- ☐ Snow
- ☐ Freezing rain/sleet
- ☐ Windy
- ☐ Calm
- ☐ Fog
- ☐ Lightning

Relative Humidity ____________ Temperature ____________F ____________C

Wind Direction _____________ Wind Speed ____________ Barometric Pressure ________

Precipitation: Amount ___________ Type: ________________

Ground covering (area around structure)

- ☐ None
- ☐ Snow
- ☐ Grass
  - ☐ Dry
  - ☐ Wet
- ☐ Concrete/Pavement
- ☐ Trees/ forest/woods
- ☐ Brush
- ☐ Pasture
- ☐ Leaf litter

Number of people present: ________Fire ________ Mercyhurst _______ Other School

_______ Volunteers ________ Visitors

Fire Start time _____________ **Fire Extinguish time**____________

Other notes:

Fire Origin

Area of fire origin:

Heat source:

Item first ignited:

Accelerants used ☐

Case #
Date:
Recorder:
Page _____ of _____

☐ Acetone
☐ Fuel
☐ Etyl alcohol
☐ Gasoline
☐ Kerosene
☐ Lacquer
☐ Paint thinner
☐ Other: __________

Thermocouple Readings

Number of thermocouples:______
Locations: **Channel Input #:**

1.
2.
3.
4.
5.
6.
7.
8.
9.
10.

Temperature Readings **Time of Reading:**

1.
2.
3.
4.
5.
6.
7.
8.
9.
10.

Amount of Destruction

Case #
Date:
Recorder:
Page _____ of _____

Fire spread

- ☐ Confined to object of origin
- ☐ Confined to room of origin
- ☐ Confined to floor of origin
- ☐ Confined to building of origin
- ☐ Beyond building of origin

Number of stories damaged: 1 2 3 4 5

- ☐ Minor damage (0-25%)
- ☐ Significant damage (25-50%)
- ☐ Heavy damage (50-75%)

- ☐ Extreme damaged (75-100%)
- ☐ Frame still standing
- ☐ Complete Destruction (no frame)

Fire Suppression

Water Used Y ☐ N ☐

Recorded time water was used**:**

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Case #
Date:
Recorder:
Page _____ of _____

Physical Evidence and Context

Physical Evidence Emplaced in Structure (not near pigs)

What	Location Placed	Where Recovered:

Evidence Recorded BEFORE burn

- ☐ Photographs
- ☐ Written documentation
- ☐ Video documentation
- ☐ Sketch
- ☐ Total Station
- ☐ GPS

Evidence Recorded AFTER burn

- ☐ Photographs
- ☐ Written documentation
- ☐ Video documentation
- ☐ Sketch
- ☐ Total Station
- ☐ GPS

Case #
Date:
Recorder:
Page _____ of _____

Excavation Form

Total number of excavators involved in the recovery: _________
Student: Volunteer:

Number of people present: _______Fire _______ Mercyhurst ______ Other School ______ Volunteers _______ Visitors

External Involvement Contact Sheet

Name	Agency/Institution	Address	Phone and Fax/Email

Case #
Date:
Recorder:
Page _____ of _____

Excavation Form

Name	Agency/Institution	Address	Phone and Fax/Email

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Case #
Date:
Recorder:
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Excavation Form

Team Member	Position	Team Member	Position

Case #
Date:
Recorder:
Page _____ of _____

Excavation Form

Team Member	Position	Team Member	Position

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Pig Remains and Context

Case #
Date:
Recorder:
Page _____ of _____

Pig Number:

Room/Area where pig located:

Mapping Measurements of Pig:

Approx distance of pig from nearest means of egress:

Description of Pig:

Clothed Y ☐ N ☐
Description Clothing:

Nose to rump-

Circumference:

Back to hoof:

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Pig Remains and Context

Case #
Date:
Recorder:
Page _____ of _____

Trauma to Pig ☐

Type of Trauma	Location

Associated artifacts

What :	Location Placed:	Where Recovered:

Case #
Date:
Recorder:
Page _____ of _____

Pig Remains and Context

Evidence/Remains Recorded before burn

- ☐ Photographs
- ☐ Written documentation
- ☐ Video documentation
- ☐ Sketch
- ☐ Total Station
- ☐ GPS

Pig Remains and Associated Evidence AFTER Fire

Location of Pig # ____ in Debris strata:

Mapping coordinates of Pig #_____:

Inventory of remains:

Evidence/Remains Recorded after burn

- ☐ Photographs
- ☐ Written documentation
- ☐ Video documentation
- ☐ Sketch
- ☐ Total Station
- ☐ GPS

Appendix II-5: Fire Fighter Letter and Questionnaire

MERCYHURST ARCHAEOLOGICAL INSTITUTE
MERCYHURST COLLEGE

Project supported by Award No. 2008-DN-BX-K131, awarded by the National Institute of Justice, Office of Justice Programs, U.S. Department of Justice

Program Title: Recovery and Interpretation of Burned Human Remains

The National Institute of Justice (NIJ) is the division of the U.S. Department of Justice dedicated to researching crime control and justice issues. The current grant funded by the NIJ and conducted by the Department of Applied Forensic Sciences (DAFS) at Mercyhurst College, Erie, PA, aims to research the recovery and interpretation of burned human remains.

Fire scenes that include human victims provide a number of investigative challenges for fire responders, investigators, forensic experts, and agents of law enforcement. In addition to determining the cause/origin of a fire, investigators must reconstruct *circumstances of death* of the victim, utilizing evidence related to cause and manner of death. In normal (non-burned) cases, the evidence is derived from the body location and positioning at the scene, and identification of perimortem trauma. Both of these assessments are significantly more difficult if the scene and the victim are subjected to fire, heat and alteration. Fatal fire scenes are often much more complex not only because the body and individual elements are dramatically modified by fire, but because the entire surrounding contextual environment is also modified in the same way, resulting in a homogeneous coloration and intermingling of materials. It is not surprising that fire is such a common method for attempting to conceal evidence of criminal activity inflicted on human victims.

The following project has three major research objectives. The first is to produce comprehensive guidelines and a simple, user friendly data collection database for the recovery of human remains from fatal fire scenes. Enhanced fatal fire scene recovery protocols and guidelines will be aimed at increasing the success rates of the location, recovery and preservation of human skeletal elements and tissue at the scene, while maximizing the compatibility of forensic anthropology protocols with those of standard fire investigation. The result will be timely scene processing and efficient onsite cooperation between a variety of investigators. Improved *in situ* recovery methods will also benefit subsequent laboratory analyses by providing better preservation of bone elements and relevant contextual information such as body location and orientation (essential for biological profile, taphonomic and trauma analyses), thus resulting in more accurate event reconstruction. The second research objective is to describe the basic, meaningful patterns of fire alteration to the human body, depending on temperature exposure of the corresponding anatomical area and their relative frequencies. This will produce a Daubert-compliant baseline for the recognition and interpretation of forensically significant perimortem trauma to the body or other forms of intentional body manipulation or modification prior to or during the fire episode. The final research objective is to assess and validate the applicability of conventional (non-burned) protocols for the analysis of sharp trauma to burned bone.

Your role in the project is to recover burnt remains and associated artifacts *in situ.* Comparing the recovery efforts by different personnel and taking into account the level of training and education they have undergone will allow us to evaluate the role of each investigator's experience in recovery efforts. Any and all information provided to us will remain anonymous and is needed solely for statistical and documentation purposes.

FORENSIC
ANTHROPOLOGY
AT MERCYHURST COLLEGE

Firefighter Excavator Form

Title:

First name
Last name

Agency:
Position:

Address: (city, state/province, zip)

Phone (ext)
Cell:
Fax:
Email:

Education background

- ☐ High School
- ☐ Some college
- ☐ College graduate
- ☐ Junior college graduate (Associates)

Degree/major: ____

Advanced degree: ☐ ____

Other / certificate programs ____

Fire Training
Type:

School:

Special certifications:

Number of previous fire cases worked:

Number of fatal fire scenes worked:

Any experience excavating or any archaeological experience? Yes No

Questions or Comments?

Thank You!!

APPENDIX III-1: Cremation Data Collection Forms

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Recorder:_________________________ Date:_________________________________

Crematory #______________________________ MC Burn Case Number _______________________

Age of individual:__________ Weight (lbs.): ______________

Positioned anteriorly/posteriorly? __________________ Feet or Head towards oven opening? _________________

Any pathology/ trauma:____
____

Time of ignition:_____________ Temperature at ignition: _____________

Time when stopped documentation:___________ Temperature at finish:__________

Patterns on skin: (describe ex. bubbling on the arms) ____

1st bone(s) exposed:____

1st places to burn off:____

1st bones calcined:____

Right:

- ☐ Pugilistic posture of hand Temperature:___________ When:_____________________________________
- ☐ Pugilistic posture of upper limb Temperature:__________ When:__________________________________
- ☐ Thumb burned off Temperature:___________ When:____
- ☐ Pugilistic posture of lower limb Temperature:___________ When:________________________________
- ☐ Hand disarticulates Temperature:___________ When:____
- ☐ Foot disarticulates Temperature:__________________When:_____________________________________
- ☐ Patella disarticulated to ________ side Temperature:_______When:_____________________________
- ☐ Radius/ulna distal third fractures Temperature:___________ When:______________________________
- ☐ Distal tibia and fibula fracture off Temperature:___________ When:______________________________
- ☐ Distal femur fractured from shaft Temperature:___________ When:_______________________________
- ☐ Femoral head or proximal end fractured from shaft Temperature:___________ When:_____________

Left:

- ☐ Pugilistic posture of hand Temperature:___________ When:_____________________________________
- ☐ Pugilistic posture of upper limb Temperature:__________ When:__________________________________
- ☐ Thumb burned off Temperature:___________ When:____
- ☐ Pugilistic posture of lower limb Temperature:_____________When:_______________________________
- ☐ Hand disarticulates Temperature:___________ When:____
- ☐ Foot disarticulates Temperature:__________________When:_____________________________________
- ☐ Patella disarticulated to ________ side Temperature:_______When:_____________________________
- ☐ Radius/ulna distal third fractures Temperature:___________ When:______________________________
- ☐ Distal tibia and fibula fracture off Temperature:_____________ When:____________________________
- ☐ Distal femur fractured from shaft Temperature:___________ When:_______________________________
- ☐ __ Femoral head or proximal end fractured from shaft Temperature:___________ When:_____________

Midline:

- ☐ Window in abdomen Temperature:___________ When:____
- ☐ Sternal end of ribs fraying Temperature:___________ When:_____________________________________
- ☐ Separation of head from neck Temperature:___________ When:__________________________________

See Reverse side for Additional Notes

- ☐ Curved transverse fractures appeared on ________________________________ Temperature:___________
  When:____

Last place(s) to burn: ____

Last place(s) to calcine: ____

Pattern of os coxae: ____

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Pattern of feet: ____

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Additional notes:

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Crematory Case _______ Recorder___________ Date_______________________

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APPENDIX IV-1. Cuts Made to Pig Limbs for Mock Fatal Fire in Franklin, PA

Data Source B: Pig Limbs burned at the mock fatal fire scene in Franklin, PA

Pig Number	*Side*	*Limb*	*Location*
1	R	Forelimb	1 false start through proximal humerus 1 full cut distal to the first false start 1 false start distal to the second cut
	R	Hindlimb	1 complete cut through proximal femur 1 false start distal to first cut 1 complete cut distal to second cut
	L	Forelimb	2 complete cuts to humerus 1 cut to radius and ulna
	L	Hindlimb	1 complete cut through femur
2	R	Forelimb	1 complete cut through radius 1 complete cut to proximal radius and ulna several false starts to distal forelimb in the carpal region
	R	Hindlimb	1 complete cut through femur 1 complete cut through proximal tibia and fibula
	L	Forelimb	1 complete cut through humerus
	L	Hindlimb	1 complete cut through femur

APPENDIX IV-2. Cuts Made to Pig Limbs for Mock Fatal Fire in McDonald, PA

Data Source B: Pig Limbs burned at the mock fatal fire scene in McDonald, PA

Pig Number	*Side*	*Limb*	*Location*
1 (smaller)	R	Forelimb	1 complete cut proximally 1 false start 1 complete cut distally
	R	Hindlimb	2 complete cuts
	L	Forelimb	2 complete cuts proximally several false starts distally
	L	Hindlimb	2 complete cuts proximally 1 false start 1 complete cut distally
2 (larger)	R	Forelimb	2 complete cuts
	R	Hindlimb	2 complete cuts
	L	Forelimb	1 complete cut proximally 1 false start 2 complete cuts distally
	L	Hindlimb	3 complete cuts

APPENDIX IV-3. Cuts Made to Pig Limbs in Mock Fatal Fire in Waynesboro, PA

Data Source B: Saw cut mark description of description of pig limbs used in Waynesboro, PA mock fire. Cuts are listed from most proximal to most distal.

Pig Number	*Side*	*Limb*	*Location*
1	R	Forelimb	1 complete cut to humerus 1 deep false start to humerus 1 shallow false start to humerus 1 complete cut to radius and ulna 1 deep false start to radius and ulna 1 complete cut to radius and ulna
	R	Hindlimb	2 complete cuts to femur (very proximally) 1 false start to metaphysis 1 complete cut to femur 1 complete cut to trabecular bone of distal femur 1 complete cut to fibula and false start to tibia 1 complete cut to fibula and false start to tibia
	L	Forelimb	2 complete cuts to humerus 1 oblique false start to humerus 2 complete cuts to radius and ulna
	L	Hindlimb	3 complete cuts to femur 2 false starts to femur 1 complete cut to metaphysis of femur 1 complete cut to fibula with false start
2	R	Forelimb	1 oblique complete cut to humerus 1 complete cut to humerus 1 false start to humerus 1 false start to radius and ulna 1 complete cut to radius and ulna in metaphyseal area
	R	Hindlimb	2 complete cuts to femur 1 false start to distal femur 1 complete cut to tibia and fibula 1 deep false start to tibia 1 shallow false start to tibia
	L	Forelimb	1 false start to humerus 3 complete cuts to humerus 2 complete cuts to radius and ulna
	L	Hindlimb	1 false start to femur 1 complete cut to femur 1 complete cut through metaphyseal area of femur
3	R	Forelimb	1 false start on proximal humerus 3 complete cuts on humerus 1 shallow false start on humerus 1 complete cut on proximal radius and ulna 1 false start on distal radius and ulna

	R	Hindlimb	1 complete cut on proximal femur 1 false start on femur 1 complete cut 1 false start 1 complete cut 2 complete cuts on tibia and fibula
	L	Forelimb	2 complete cuts on proximal humerus 1 false start on distal humerus 2 complete cuts on radius and ulna
	L	Hindlimb	2 complete cuts on femur 1 false start 1 complete cut 2 complete cut on tibia and fibula 1 complete cut on fibula 3 false starts (1 deep) on tibia
4	R	Forelimb	2 complete cuts on humerus 1 false start on humerus 2 complete cuts on radius and ulna
	R	Hindlimb	1 complete cut on femur 1 wide, shallow false start on femur 1 complete cut on femur 1 complete cut on fibula with false start on lateral tibia 1 complete cut on tibia and fibula
	L	Forelimb	1 complete cut on humerus 2 false starts on humerus 1 complete cut on humerus 1 false start on radius and ulna 1 complete cut on radius and ulna 2 false starts on radius and ulna
	L	Hindlimb	1 complete cut on proximal femur 1 shallow false start on femur 2 complete cuts on femur 1 complete cut on fibula with false start on lateral tibia 1 complete cut on tibia and fibula

APPENDIX IV-4. Bone Sections Analyzed from *Data Source B*

Mock Fatal Fire Location	Bone Section	Cut Surface (A or B)
McDonald, PA	2-008A	A
McDonald, PA	2-021A	A
Waynesboro, PA	3-005A	A
Waynesboro, PA	3-085A	A
Waynesboro, PA	3-049B	B
Waynesboro, PA	3-079A	A
Waynesboro, PA	3-033A	A
Waynesboro, PA	3-045A	A
Waynesboro, PA	3-038A	A
Waynesboro, PA	3-092A	A
McDonald, PA	2-006B	B
McDonald, PA	2-010A	A
Waynesboro, PA	3-028A	A
Waynesboro, PA	3-071A	A
Waynesboro, PA	3-047B	B
Waynesboro, PA	3-045B	B
Franklin, PA	1-004A	A
Waynesboro, PA	3-019A	A
Waynesboro, PA	3-010A	A
Waynesboro, PA	3-090A	A
Waynesboro, PA	3-055B	B
McDonald, PA	2-026A	A
Waynesboro, PA	3-063A	A
Waynesboro, PA	3-037A	A
Waynesboro, PA	3-081A	A
Waynesboro, PA	3-057A	A
McDonald, PA	2-024B	B
McDonald, PA	2-027A	A
Franklin, PA	1-005A	A
Waynesboro, PA	3-030B	B

APPENDIX IV-5. Bones and Bone Sections Cut for Data Source C

Bone #	*Side*	*Bone*	*# False Starts*	*# Complete Cuts*	*Total # Cuts*
1	R	Femur	7	4	11
2	L	Femur	5	4	9
3	L	Humerus	7	3	10
4	L	Humerus	5	4	9
5	L	Ulna	2	5	7
6	R	Femur	8	4	12
7	R	Tibia	5	4	9
8	R	Femur	6	4	10
9	L	Humerus	3	3	6
10	L	Radius	3	3	6
11	L	Humerus	4	3	7
12	L	Tibia	7	3	10
13	R	Humerus	5	3	8
14	L	Radius	6	3	9
15	L	Femur	6	3	9
16	R	Femur	7	4	11
17	L	Femur	8	4	12
18	R	Humerus	5	3	8
19	L	Femur	8	4	12
20	L	Tibia	8	5	13
21	L	Radius	7	4	11
22	R	Humerus	7	4	11

23	R	Tibia	9	5	14
24	R	Ulna	10	5	15
25	R	Ulna	9	4	13
26	L	Ulna	6	4	10
27	L	Radius	8	4	12
28	L	Tibia	11	7	18
29	R	Femur	9	4	13
30	L	Humerus	5	3	8
31	R	Femur	10	4	14
32	R	Tibia	10	5	15
33	L	Tibia	6	4	10
34	L	Ulna	5	3	8
35	L	Humerus	4	2	6
36	L	Tibia	6	3	9
37	L	Femur	7	4	11
38	R	Ulna	4	3	7
39	R	Tibia	9	4	13
40	R	Radius	6	3	9
41	R	Radius	4	1	5
42	R	Ulna	4	3	7
43	R	Tibia	5	4	9
44	R	Radius	3	2	5
45	L	Femur	8	5	13
46	L	Ulna	11	3	14
47	R	Radius	6	4	10

48	R	Ulna	7	5	12
49	L	Ulna	7	5	12
50	R	Ulna	10	4	14
51	R	Radius	7	4	11
52	L	Radius	7	4	11
53	R	Humerus	4	1	5
54	L	Radius	6	4	10
55	R	Radius	7	5	12
56	L	Tibia	9	5	14
57	R	Humerus	5	3	8
58	R	Humerus	7	3	10
59	L	Ulna	7	3	10
TOTALS			387	220	607